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Technological Aspects of the Influence of Mineral and Organic Fertilizers on the Size of Water- Resistant Aggregates of Irrigated Meadow-Forest Soils under Vegetable Agrocenoses

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Abstract. *This article focuses on the technological optimization of the structure of alluvial-meadow-forest soils in the north-eastern region of Azerbaijan. Under the conditions of the transition to intelligent agriculture (Smart Farming), the water resistance of soil aggregates is considered a key indicator of agroecosystem stability. Experimental results demonstrated that the application of biotechnological vermicompost at a rate of 7 t ha^{-1} provided the highest content of water-resistant aggregates (>0.25 mm), reaching 71.6%, which significantly exceeded the values obtained under conventional mineral fertilizer systems. Comparative analysis confirmed the technological superiority of organic fertilization in promoting stable soil aggregation and reducing the risk of irrigation-induced soil erosion.*

Keywords: *water-resistant aggregates, vermicompost, agricultural technologies, alluvial-meadow-forest soil, vegetable crops, Smart Farming, sustainable development*

Introduction

Soil structure is one of the most important morphological characteristics determining soil physical quality and agricultural productivity (Lal, 2020). It not only provides a favorable habitat for soil microorganisms but also regulates soil water, air, and nutrient regimes (Kachinsky, 1965). Under conditions of intensive modern agriculture, where anthropogenic pressure on soils continues to increase, evaluating the size distribution and stability of water-resistant aggregates has become an essential component of sustainable soil management. The scientific basis of soil structure formation depends on several major factors, including soil texture, humus content, and vegetation cover. Only an agronomically valuable soil structure can provide plants with adequate water, nutrients, and aeration during critical growth stages. Numerous studies conducted in Azerbaijan have emphasized the importance of preserving the structural stability of agricultural soils (Mamedov, 1961). This issue becomes particularly important when comparing different agroecosystems. Studies carried out in the Mughan region demonstrated that, under cotton–alfalfa crop rotations, the proportion of water-resistant soil aggregates under cotton ranged from 28.4% to 30.5%, whereas under perennial alfalfa stands it increased to 39.7–63.4%. These findings indicate that scientifically based crop rotation systems and balanced nutrient management are effective tools for improving soil structure and enhancing soil stability.

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The aim of the present study was to develop an optimal fertilization strategy for stabilizing the structure of alluvial-meadow-forest soils cultivated with vegetable crops (tomato) through the application of different fertilizer systems (Kachinsky, 1965).

Methods

Study Area and Climatic Conditions

The study was conducted in the north-eastern region of Azerbaijan, within the Shabran District, at the *Svobodnaya Novaya* farm (Hadzhiev & Rahimov, 1977). The study area is characterized by a gently sloping plain dissected by numerous slopes and deep canyon-like valleys, reflecting the active influence of erosion processes. The climate of the region is classified as a moderately warm semi-desert with a pronounced dry summer. The mean annual air temperature ranges from 12 to 13°C, while the average annual soil temperature varies between 12 and 15°C. Annual precipitation ranges from 300 to 600 mm, with the majority occurring during the autumn season. High evaporation rates (600–800 mm $year^{-1}$), together with a radiation balance of 40–50 kcal cm^{-2}, create specific environmental conditions that require careful regulation of the soil water regime (Mammadov & Kuliev, 2002).

Detailed agroclimatic characteristics of the study area are presented in Table 1.

Table 1

Agroclimatic and soil characteristics of the area of studies

Parameter	Value / Description
Soil type	Irrigated alluvial-meadow-forest
Relief	Inclined plain with canyons and river valleys
Average annual temp. air	12-13°C
Annual precipitation	300-600 mm (maximum in autumn)
Evaporation	600-800 mm
Radiation balance	40-50 kcal/cm²
Plant cover	Mountain-meadow, forest and semi-desert

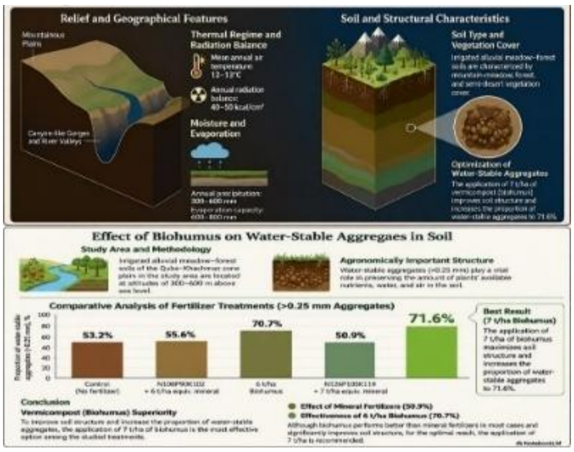

Figure 1

Agroclimatic and soil characteristics of the study area

Object of the Study and Soil Conditions

The object of the study was irrigated alluvial-meadow-forest soils formed on the floodplain terraces of mountain rivers. These soils developed under conditions of continuously disturbed pedogenesis, resulting in considerable variations in their genetic profiles.

Experimental Design

Field experiments were conducted under tomato cultivation following the methodology adopted in the Republic of Azerbaijan (Morphogenetic Profile of Soils of Azerbaijan, 2004). The experimental design consisted of nine treatments, including a control, mineral fertilizer treatments, and different application rates of biotechnological vermicompost. Soil structural composition was evaluated using the wet-sieving method developed by Kachinsky (1965). To ensure the reliability and statistical validity of the experimental results, all treatments were arranged in a randomized block design with three replications. Soil samples were collected from the 0–20 cm layer at the main stages of tomato growth and analyzed under laboratory conditions. The distribution of water-resistant aggregates was determined by the wet-sieving method, and the obtained data were statistically analyzed using analysis of variance (ANOVA). Treatment means were compared at a significance level of $p \leq 0.05$ to determine statistically significant differences among fertilizer treatments. This methodological approach enabled a comprehensive evaluation of the effects of mineral fertilizers and vermicompost on soil structural stability under irrigated vegetable agroecosystems.

Results

The obtained results demonstrated that the optimal technological approach for stabilizing the structure of alluvial-meadow-forest soils under vegetable agroecosystems is the application of vermicompost at a rate of 7 t ha^{-1}. This application rate produced the highest proportion of water-resistant aggregates (71.6%), thereby reducing the risk of irrigation-induced soil erosion and improving the soil water–air regime (Mirzoeva & Geraizade, 2017). In contrast, high application rates of mineral fertilizers without supplementary organic amendments resulted in the deterioration of the physical properties of irrigated soils. The effects of different fertilizer application rates on the proportion of water-resistant soil aggregates are presented in Table 2.

Table 2

Influence of fertilizer systems on the size of water-resistant soil aggregates

Experience option	Contribution rate	>7 mm	1-3 mm	Total >0.25 mm (%)	<0.25 mm (%)
Control (without fertilizer)	-	6.1	15.2	53.2	46.8
N108P90K102 + biohumus equivalent (6 t/ha)	Mixed	1.7	16.9	55.6	44.4
Biohumus (6 t/ha)	Org. (Bio)	5.4	17.3	70.7	29.3
Biohumus (7 t/ha)	Optimal	7.3	20.1	71.6	28.4
N126P105K119 + biohumus equivalent (7 t/ha)	Min.	-	16.8	50.9	49.1
N36P30K34 + biohumus (5.0 t/ha)	Integrated	4.1	22.5	66.2	33.8

Influence of fertilizer systems on the size of water-resistant soil aggregates

In the control variant, the amount of water-resistant aggregates was 53.2%. The maximum result was recorded when applying 7 t/ha of vermicompost — 71.6% , where the most valuable fraction 1–3 mm was 20.1%. The mineral system (N126P105K119) led to a decrease in water resistance to 50.9%.

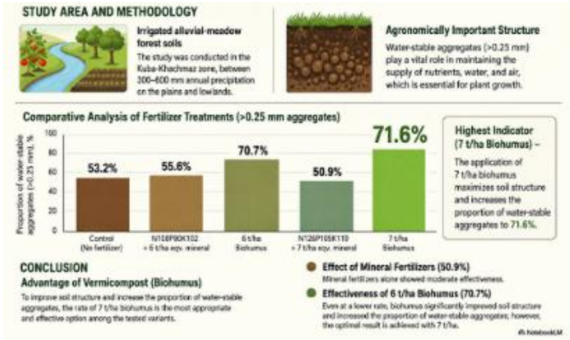

Figure 2

Impact of biohumus on water-stable aggregates in soil

Discussion

The results obtained in this study provide important insights into the aggregation processes occurring in irrigated alluvial-meadow-forest soils under different fertilization systems. The structural condition of the soil is closely related to the biochemical effects of the applied fertilizers (Chen et al., 2023; Edwards, 2019). The technological superiority of vermicompost can be explained by its ability to function as a natural biological binding agent. Unlike mineral fertilizers, vermicompost enriches the soil with humic substances and organic compounds that promote the formation of stable organo-mineral complexes. This process is particularly important in the Shabran region, where sloping terrain increases the susceptibility of soils to water erosion. Consequently, the improved stability of water-resistant aggregates contributes directly to reducing the risk of irrigation-induced soil degradation. A comparison with previous studies conducted in the Mughan region highlights the specific characteristics of alluvial-meadow-forest soils. While the maximum proportion of water-resistant aggregates under alfalfa reached 63.4% in earlier studies, the application of vermicompost in the present investigation increased this value to 71.6% under intensive tomato cultivation. These findings indicate that biologically based soil amendments may provide greater improvements in soil structural stability than traditional crop rotation systems alone.

The adverse effect of high application rates of mineral fertilizers, reflected by the lower proportion of water-resistant aggregates (50.9%), confirms that excessive chemical fertilization may accelerate the dispersion of soil colloids and contribute to structural degradation (Hasanov, 2013). Within modern Smart Farming systems, such information can be used to optimize fertilizer application rates and minimize the physical degradation of irrigated soils. Furthermore, the proportion of agronomically valuable aggregates (1–3 mm), which reached 20.1% under the optimal vermicompost treatment, provides a favorable balance of capillary porosity under the arid climatic conditions of the Shabran region (Mammadov, 2022; Smith et al., 2021).

The improvement in aggregate stability observed following vermicompost application is also important from the perspective of sustainable land management and climate-resilient agriculture. Water-resistant aggregates increase soil infiltration capacity, reduce surface runoff, improve resistance to soil compaction, and enhance the efficient use of irrigation water. In regions with limited water resources and increasing climatic variability, such as the north-eastern region of Azerbaijan, the application of organic soil amendments represents an effective strategy for maintaining long-term soil fertility and agroecosystem stability. Therefore, integrating vermicompost into fertilization programs should be considered not only as a means of improving soil structural quality but also as an essential component of environmentally sustainable agricultural technologies.

Conclusion

The results of the present study demonstrate that both organic and mineral fertilizers significantly influence the structural stability of irrigated alluvial-meadow-forest soils under vegetable agroecosystems. Among the tested fertilization treatments, the application of vermicompost at a rate of 7 t ha^{-1} proved to be the most effective, increasing the proportion of water-resistant aggregates (>0.25 mm) to 71.6%, which substantially exceeded the values recorded for both the control treatment and mineral fertilizer treatments. The findings confirm that vermicompost promotes the formation of stable soil aggregates through the accumulation of organic binding agents and humic substances. As a result, soil physical properties are improved, the risk of irrigation-induced erosion is reduced, and the soil water–air regime is optimized. In contrast, intensive mineral fertilization without adequate organic matter inputs resulted in lower aggregate stability and a tendency toward soil structural degradation. From a technological perspective, integrating vermicompost into fertilization programs represents an effective strategy for sustainable soil management in irrigated vegetable production. The obtained results support the implementation of biologically based fertilization technologies within modern Smart Farming systems to improve soil quality, enhance irrigation efficiency, and promote the long-term sustainability of agricultural ecosystems in the north-eastern region of Azerbaijan. Further long-term studies under different crop rotation systems and climatic conditions are recommended to evaluate the persistence of these positive effects and to optimize integrated fertilizer management strategies.

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