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Application of Innovative Organic–Mineral Technologies in Cotton Agroecosystems: Agrochemical Optimization and Management of Fiber Quality Using Hvi Digital Analytics

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Abstract. *The exceptional role of organic substances in improving soil fertility constitutes one of the main research directions of modern agrochemical science. In this regard, the application of organic–mineral complexes that positively affect the productivity and quality of agricultural crops, the determination of optimal fertilizer rates, and the development of new technologies represent an urgent issue of scientific and practical significance. The intensity of biological processes occurring in the soil directly determines fertility indicators. The activity of microorganisms requires sufficient soil moisture, the presence of organic matter, and a favorable soil reaction. Within the framework of the present study, a technology for the preparation of organic–mineral complexes based on local raw material resources was developed, and these complexes were tested under cotton cultivation conditions.*

Keywords: *meadow-gray soil, cotton, technology, fertility, nitrogen, phosphorus, potassium, physicochemical properties, fertilizer, organic–mineral complex*

Introduction

Beginning in the second half of the twentieth century, chemicalization became the main direction in the development of world agriculture. Although this approach resulted in a significant increase in agricultural productivity (Akhundova, 2022, pp. 55–62), in the long term it also created a number of serious problems affecting the soil ecological environment. Among these problems, the deterioration of the physical and chemical properties of soils, the depletion of humus reserves, and environmental pollution should be particularly noted. The exceptional role of organic substances in improving soil fertility has been emphasized in numerous studies (Abbasov et al., 2021).

At present, the application of organic fertilizers in agricultural production has become a priority issue (Mammadov et al., 2024). Furthermore, the use of organic–mineral complexes has been shown to improve both crop productivity and product quality. At the same time, determining optimal fertilizer application rates and developing innovative fertilization technologies remain important scientific and practical challenges (Alosmanov et al., 2022). In addition to increasing the availability of essential nutrients in the soil, these organic wastes also have a positive effect on the productivity of agricultural crops (Akhundova & Salimova, 2019, pp. 214–218).

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P.B. Zamanov (2015, pp. 42–47) reported that there are up to 40 types of waste suitable for use as organic fertilizers, with total reserves exceeding 22 million tons. In recent years, following the transition to a market economy, the prices of mineral fertilizers have increased significantly, while the shortage of organic fertilizers in the republic has become even more acute. Therefore, evaluating local waste and raw material resources for use as organic fertilizers is of great importance from both economic and environmental perspectives. The application of organic fertilizers makes it possible to considerably reduce the application rates of mineral fertilizers, providing both ecological and economic benefits. The use in agriculture of widely distributed non-metallic mineral resources in Azerbaijan, such as volcanic mud, oil shale, and other natural materials, has become an important scientific priority as an alternative source of fertilizers (Mammadov et al., 2024). Previous studies demonstrated that organo-mineral complexes prepared from oil shale, plant residues, and industrial wastes had a more favorable effect on cotton growth and productivity than conventional fertilizers (Mammadov & Khalilov, 2003).

Chemical analyses of organic fertilizer resources in Azerbaijan showed that they contain approximately 170 thousand tons of pure nitrogen, 77 thousand tons of pure phosphorus, 221 thousand tons of potassium, 6 million tons of organic matter, and 5 million tons of ash. According to the State Statistical Committee of the Republic of Azerbaijan (2021), 129.9 thousand tons of mineral fertilizers were imported into the country, including 95.7 thousand tons of nitrogen fertilizers and 2.7 thousand tons of potassium fertilizers. During the same year, 88.0 thousand tons of mineral fertilizers (calculated as 100% active substance) were applied to agricultural crops. Cotton was cultivated on 100,590 ha, with an average yield of 28.6 centners ha^{-1}. In recent years, cotton cultivation under monoculture conditions, the absence of crop rotation, the unbalanced application of mineral fertilizers, and the extremely low use of organic fertilizers have led to the deterioration of the water-physical and biological properties of soils, as well as a decline in their natural fertility. Therefore, improving the physical, mechanical, and agrochemical properties of these soils, together with maintaining a balanced humus content, is essential for obtaining the planned high cotton yields.

Methods

The study was conducted under cotton cultivation on irrigated meadow-gray soils located in the Bilasuvar and Saatly districts of the Mughan-Salyan region of Azerbaijan. Agrochemical analyses of the collected soil samples were performed using generally accepted analytical methods. To determine the agrochemical characteristics of the experimental field, soil samples were collected from the 0–20, 20–40, 40–60, 60–80, and 80–100 cm soil layers using the envelope sampling method. Soil pH (measured in a water suspension) was determined using a potentiometer. Total humus content was determined according to the Tyurin method, total nitrogen by the Kjeldahl method, total phosphorus according to the Ginzburg method, and total potassium according to the Smith method. The following analyses were also performed: exchangeable ammonium nitrogen ($N{-}NH_4$) according to Konev, nitrate nitrogen ($N{-}NO_3$) according to the Grandval–Lajoux method, available phosphorus (soluble in 1% ammonium carbonate) according to Machigin, and exchangeable potassium according to the Protasov method modified by Huseynov. The technology for preparing the organo-mineral complex was developed and evaluated in a field experiment established within the Azadkend municipality of the Saatly district. The experiment included four treatments with four replications. The area of each experimental plot was 100 m^2. Field experiments were conducted in accordance with generally accepted agronomic practices (Dospekhov, 1985). Ammonium nitrate (33.4%) was applied as the nitrogen fertilizer, ammophos (51%) as the phosphorus fertilizer, and potassium sulfate (52%) as the potassium fertilizer. The organo-mineral complex was applied in combination with these fertilizers. In the agrochemical analyses of soil samples, total nitrogen was determined by the I.V. Tyurin method, exchangeable ammonium ($N{-}NH_4$) Exchangeable ammonium nitrogen ($N{-}NH_4$) was determined by the D.P. Konev method, nitrate nitrogen ($N{-}NO_3$) by the Grandval–Lajoux method, total phosphorus by the A.M. Meshcheryakov method, available phosphorus by the M.P. Machigin method, total potassium by the P.K. Smith method, and exchangeable potassium by the P.V. Protosov method. Phenological observations, including main stem height, number of bolls per plant, and raw cotton mass per boll, were carried out on 20 marked plants from each treatment according to the methodology described by Dospekhov (1973). Biometric measurements were performed during the squaring (flower-bud formation), flowering, and boll formation stages. The BO-440 Aghgizil cotton variety was used in the field experiments (Aslanov & Valiyeva, 2014). Cotton fiber quality parameters were determined in accordance with international standards using the Statex-type High Volume Instrument (HVI), a high-precision and high-speed fiber testing system. According to the international classification, the following 12 quality indicators were evaluated: Mean Length (ML), Upper Half Mean Length (UHML), Uniformity Index (UI), Short Fiber Index (SFI), Fiber Strength (Str), Elongation at Break (Elg), Micronaire (Mic), Fiber Fineness (Fin), Reflectance (Rd), Yellowness (+b), Leaf Grade, and Color Grade (CG).

Results

The principal physical and chemical properties of the irrigated meadow-gray soils in the experimental field located in the Bilasuvar district were analyzed in accordance with previously published methodologies (Mammadov, 2007; Salayev, 1991). The obtained results are presented in Tables 1 and 2.

Table 1

Agrochemical indicators of irrigated meadow-gray soils of the Mughan–Salyan region

Depth (cm)	Total N (%)	Hydrolyzable N (mg/kg)	N-NH_4 (mg/kg)	N-NO_3 (mg/kg)	Total P (%)	Water-soluble P (mg/kg)	Available P (mg/kg)	Total K (%)	Water-soluble K (mg/kg)	Exchangeable K (mg/kg)	pH	Humus (%)
0–20	0.14	85	7.20	11.50	0.15	7.20	18.5	2.85	38.5	285.40	7.60	2.35
20–40	0.11	68	5.80	9.20	0.13	5.40	14.2	2.52	31.2	238.60	7.65	1.82
40–60	0.09	52	4.50	7.10	0.11	3.80	10.5	2.24	24.8	192.30	7.72	1.42
60–80	0.07	38	3.40	5.40	0.09	2.50	7.30	1.98	18.5	152.80	7.78	1.08
80–100	0.05	28	2.60	4.10	0.07	1.60	4.80	1.75	13.2	118.50	7.85	0.82

Table 2

Selected physicochemical properties of meadow-gray soils

Depth (cm)	Dry Residue (%)	$CaCO_3$ (%)	Total Exchangeable Bases (meq/100 g)	Exchangeable Ca (meq/100 g)	Exchangeable Mg (meq/100 g)	Exchangeable Na (meq/100 g)	<0.001 mm (%)	<0.01 mm (%)
0–20	0.45	7.7	24.3	14.5	8.3	1.5	35.88	83.12
20–40	0.52	9.8	24.7	15.1	7.0	2.6	37.36	84.56
40–60	0.68	11.2	22.8	13.2	7.2	2.4	36.90	85.00
60–80	0.85	13.6	20.1	10.9	7.4	1.8	32.64	80.72
80–100	0.92	12.1	18.7	11.0	6.2	1.5	28.32	72.18

Table 3
Technological properties of votton fiber

No.	Treatment	Mean Length (mm)	Upper Half Mean Length (mm)	Uniformity Index (%)	Fiber Strength (g/tex)	Elongation (%)	Micronaire	Fineness (m/tex)	Reflectance (Rd, %)	Yellowness (+b)	Color Grade (CG)	Leaf Factor (%)	Short Fiber Index (%)
1	Control	26.7	27.4	97.3	27.4	6.8	5.0	168	63.6	18.5	21-1	–	<3
2	N120P120K120 Background	25.5	27.9	95.0	26.4	7.0	5.0	176	63.0	16.9	21-1	–	<3
3	Organic–Mineral Complex	25.3	26.7	94.8	27.1	7.0	4.9	159	62.7	16.8	21-1	–	<3
4	Silt + Sand	25.3	27.6	91.1	25.8	6.7	5.1	187	64.5	17.3	21-1	–	<3

As shown in Table 1, the total nitrogen content in the upper soil layer (0–20 cm) of the study area was 0.13%, decreasing progressively with depth to 0.03% in the 80–100 cm layer. This trend can be explained by the accumulation of organic matter primarily in the upper soil horizons. The content of hydrolysable nitrogen followed the same pattern, decreasing from 82 mg kg^{-1} in the 0–20 cm layer to 26 mg kg^{-1} in the 80–100 cm layer (Mammadov, 2007). Among the mineral nitrogen forms, exchangeable ammonium ($N–NH_4$) and nitrate nitrogen ($N–NO_3$) in the upper layer amounted to 6.06 and 13.74 mg kg^{-1}, respectively. With increasing soil depth, both indicators decreased proportionally, reaching their lowest values (1.50 and 4.66 mg kg^{-1}, respectively) in the 80–100 cm layer. This decrease is associated with reduced microbiological activity and, consequently, a lower rate of organic matter mineralization in the deeper soil horizons.

Analysis of the phosphorus regime revealed that the total phosphorus content in the 0–20 cm layer was 0.15%, while the water-soluble and available phosphorus contents were 6.70 and 16.8 mg kg^{-1}, respectively. These values gradually decreased with soil depth. Regarding potassium, the total potassium content in the upper layer was 3.17%, whereas the water-soluble and exchangeable forms reached 45.2 and 342.22 mg kg^{-1}, respectively. A similar decreasing trend with depth was observed for potassium (Mammadov, 2007). The soil reaction (pH) became increasingly alkaline with depth, whereas humus content gradually decreased from the surface horizons to the deeper layers (Mammadov, 2007; Salayev, 1991). The data presented in Table 2 characterize the physicochemical properties of the soil. Dry residue increased with depth, calcium carbonate ($CaCO_3$) reached its maximum concentration in the middle horizon, exchangeable calcium predominated among exchangeable cations, and the soil exhibited a heavy clay texture (Mammadov, 2007; Salayev, 1991). Overall, the results presented in Tables 1 and 2 indicate that the studied soils possess relatively low fertility potential due to weak nitrogen and phosphorus regimes, while their heavy clay texture adversely affects soil structure (Mammadov, 2007; Salayev, 1991).

Sowing in the experimental field was carried out during the third ten-day period of April, and seedling emergence was observed during the first ten-day period of May. Phenological observations were conducted on June 30, July 27, and August 30, 2021. During the squaring, flowering, and full maturity stages, plants treated with the organo-mineral complex exhibited greater plant height, a higher number of branches, and more bolls per plant than those in the control and mineral fertilizer treatments (Abbasov & Ibadzade, 2021; Mammadov et al., 2023). The effects of fertilizer application on cotton yield and fiber quality were investigated under irrigated meadow-gray soil conditions in the Saatly district. The production of cotton fiber with high technological quality is of considerable economic importance for the textile industry. According to the analytical results, the Upper Half Mean

Length (UHML), Uniformity Index (UI), and Fiber Strength (Str) corresponded to medium-staple cotton with a high degree of fiber uniformity. Compared with the other treatments, the organo-mineral complex treatment produced superior improvements in cotton fiber quality characteristics (Abbasov & Ibadzade, 2021; Akhundova, 2022).

Discussion

Irrigated meadow-gray soils are among the agriculturally important soil types formed under arid and semi-arid climatic conditions, mainly on alluvial and proluvial deposits (Mammadov, 2007; Salayev, 1991). Although these soils develop under naturally limited moisture conditions, their morphogenetic, physical, and chemical properties change considerably under irrigation.

From a physical perspective, these soils are predominantly loamy to heavy clay loamy, and irrigation affects bulk density, porosity, water-physical characteristics, aggregate stability, and salinization processes (Mammadov, 2007; Salayev, 1991). Chemically, irrigated meadow-gray soils are characterized by carbonate accumulation, relatively low humus content, an alkaline reaction, and varying degrees of salinity. These characteristics are strongly influenced by irrigation water quality and agricultural management practices (Mammadov, 2007). Consequently, the physical and chemical properties of irrigated meadow-gray soils are closely associated with soil-forming factors, irrigation regimes, and anthropogenic activities. Understanding these characteristics provides an important scientific basis for sustainable soil management (Mammadov, 2007; Salayev, 1991).

For normal cotton growth and development, balanced applications of nitrogen, phosphorus, potassium, and essential macro- and micronutrients are required (Akhundova & Salimova, 2019; Aslanov & Valiyeva, 2014). Organic fertilizer resources available in Azerbaijan constitute an important reserve for sustainable agriculture and environmentally sound waste utilization (Zamanov, 2015). Meadow-gray soils belong to the heavy clay soil group and are characterized by relatively low fertility because of their limited organic matter and nutrient contents. The application of organo-mineral complexes improves soil structure, porosity, microbial activity, moisture retention, aeration, nutrient availability, and ultimately enhances cotton growth and fiber quality (Abbasov & Ibadzade, 2021; Alosmanov et al., 2022; Mammadov et al., 2024).

Conclusion

1. The study demonstrated that although irrigated meadow-gray and gray-meadow soils of the Yevlakh and Imishli districts contain relatively high total amounts of the principal nutrients, the concentrations of plant-available nutrients remain insufficient. Therefore, balanced fertilizer application is essential for achieving high and high-quality crop yields.
2. The results showed that the contents of nitrogen, phosphorus, and potassium were moderate in the upper soil layer (0–20 cm), low in the plow layer, and very low in the 40–80 cm soil layers.
3. The production and application of organo-mineral complexes prepared from household waste and locally available raw materials are economically efficient and environmentally sustainable. Their use not only reduces environmental pollution but also minimizes the costs associated with waste transportation and disposal.
4. Field experiment results demonstrated that the organo-mineral complex treatment outperformed the other treatments with respect to cotton plant growth, development dynamics, and fiber quality characteristics. Therefore, the combined application of organo-mineral complexes and mineral fertilizers can be recommended as an effective agronomic practice for achieving high and stable crop yields.

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