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ORGANIC AMELIORANTS' EFFECT ON COTTON (*GOSSYPIUM HIRSUTUM* L.) FIBER QUALITY AND PHYSIOLOGICAL ATTRIBUTES

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SUMMARY

The application of organic ameliorants can significantly enhance fiber technological properties and seed cotton yield of upland cotton (*Gossypiumhirsutum*L.) plants by considerably improving the growth and development processes and the formation of plant generative parts. This study, conducted on irrigated calcisols (sierozems) of the Turkestan Region, Kazakhstan, aimed to investigate the effect of organic ameliorants on the cotton fiber and its physiological traits and soil health. According to the study, the most effective results occurred by applying an organic ameliorant (3.5 t/ha) with a soil improver (350 kg/ha) during plowing, followed by a spring application of 0.5 t/ha and 50 kg/ha, respectively. This treatment resulted in an average boll weight of 6.4 g, with a 9.4% increase over the control. For the cotton cultivar M-5027, fiber length reached 34.1 mm, and fiber yield was 40.6%, representing improvements of 2.6% and 7.6%, respectively. Furthermore, the dry root mass gained enhancement up to 24.5 g (35.1% above the control), with a total seed cotton yield of 3.13 t/ha. The root system showed that 73.4% and 17.4% of roots emerged in the 0–30 cm and 30–50 cm soil layers, respectively. The application of organic ameliorants fosters intensive root development and superior fiber quality traits, mitigating the impact of diverse environmental and agrotechnical conditions.

Keywords: Upland cotton (*G. hirsutum*L.), cultivars, organic ameliorants, soil bulk mass, fiber length, fiber yield, seed cotton yield, root mass

Key findings: The combinedapplication of organic ameliorant (3.5 t/ha) and soil improver significantly enhanced cotton (*G. hirsutum*L.) productivity. In applyingorganic ameliorants, the cultivar M-5027 was evidentwith an enhanced fiber length (34.1 mm) and fiber yield (40.6%), while its dry root mass increased by 35.1%.

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INTRODUCTION

The Turkestan Region possesses ideal climatic conditions for cotton (*Gossypiumhirsutum*L.) cultivation, including abundant sunlight and extensive irrigation resources. However, currently, cotton production faces critical challenges. Increasing soil salinity and degradation of irrigated arable lands have negatively affected the seed cotton yield and fiber quality traits. Historically, heavy dependency on using mineral fertilizers and chemical pesticides has led to environmental contamination and severe soil compaction, and the optimal soil density rose from 1.15–1.30 g/cm³ to 1.50–1.60 g/cm³ (Makhmadjanov *et al*., 2025). Consequently, the urgent need for intensive and resource-saving technologies mustrestore soil fertility and enhance the competitiveness of domestic cotton cultivars.

In the context of cotton monoculture, the lack of organic ameliorants and prolonged shallow tillage has caused secondary salinization, especially where groundwater mineralization occurs at the depth of 1.5–2.0 meters. In addressing these challenging field issues, breeders at the Kazakhstan Agricultural Experimental Station developed the cotton cultivar Maqtaaral-5027. This cultivar comprised characteristics of early maturity (117–125 days), higher seed cotton yield potential (40.0–45.0 t/ha), and significant resistance to salinity and pests (Makhmadjanov *et al*., 2023). Recent studies revealed the fiber quality parameters of raw cotton, particularly in the cultivar Maqtaaral-5027, were highly dependent on sowing technology and the integrated use of fertilizers (Makhmadjanov *et al*., 2024, 2025).

Advanced research emphasizes that organic fertilizers, particularly those based on fulvic acids and amino acids, can significantly improve soil structure and crop growth and development (Jin *et al*., 2022; Jiang *et al*., 2023). Fulvic acid, known for its low molecular weight and high physiological activity, optimizes soil porosity and water permeability in saline-alkaline soil conditions (Li *et al*., 2020). It also increases the stability of soil aggregates and promotes nutrient adsorption, which eventually effectively reduces leaching losses (Liu *et al*., 2025). Previous studies have demonstrated that such soil amendments can enhance the raw cotton yields by 1.01%–20.49% while simultaneously optimizing fiber quality in the cotton crop (Shi *et al*., 2024).

The National Project for the Development of the Agro-Industrial Complex of Kazakhstan (2021–2025) also highlighted the necessity of implementing innovative soil-improvement strategies to restore underdeveloped lands. Despite existing knowledge on individual compounds, a research gap prevails regarding the synergistic effect of complex organic ameliorants on the technological properties of specific domestic cotton cultivars like Maqtaaral-5027 (Makhmadjanov *et al*., 2024, 2025).

Therefore, this study aimed to evaluate the effect of a new generation fertilizer comprising organic and biological ameliorants on the root system development, fiber quality (length and yield), and overall productivity of the cotton cultivar Maqtaaral-5027. By integrating science and production, this research seeks to provide a sustainable technological framework for preventing soil degradation and enhancing fiber production and quality of medium-fiber cotton in the global market.

MATERIALS AND METHODS

Experimental procedure

Field experiments and laboratory analyses proceeded following standardized international and regional methodologies for cotton (*G. hirsutum* L.) research. The study integrated the classical principles of the "Methodology for Field Experiments with Cotton under Irrigation Conditions" (Tashkent, 1981) with modern international standards to ensure data accuracy and global comparability. Phenological observations on the growth stages and development of cotton plants were carried out according to the methodology outlined by Simongulyan et al. (1980).

The soil's physical properties, specifically bulk density, underwent determination according to ISO 11272:2017

(Soil quality—Determination of dry bulk density). The research utilized high-volume instrument (HVI) systems, which are the global standard for cotton fiber quality testing for assessing fiber technological traits, i.e., length, strength, and micronaire.

The research used a randomized complete block design with four replications. Each experimental plot had a total area of 120 m² (4.8 m × 25 m), ensuring a robust statistical framework for the comparative analysis.

Soil conditions

The soil in the experimental area was light gray and medium loamy in mechanical composition. Light gray soils are characteristically of a low humus content, ranging from 0.780% to 0.850% in the upper soil layer. The content of mobile forms of nitrates (NO_3) in the arable layer is very low, ranging from 5.0 to 10.0 mg/kg. The content of mobile forms of phosphorus (P_2O_5) in these soils is also low, ranging from 15.0 to 25.0 mg/kg of soil. When evaluating medium-saline soils for reclamation purposes, their characteristics concerning chemical composition (salt content) and the degree of salinity are particularly important.The soil in the experimental area has a medium-saline classification, with a total residual salt content of 0.3%–1.0% and a chloride ion content of 0.04%–0.1%.

The research, organized using a randomized experimental design, comprised four primary treatments to evaluate the efficacy of organic amendments:

Treatment 1 (Control): Traditional cotton cultivation technology without the application of organic fertilizers or ameliorants;

Treatment 2 (Agromelioration): Combined application of an organic ameliorant at 2.5 t/ha (autumn) and 1.5 t/ha (spring), supplemented with a soil conditioner at 250 and 150 kg/ha, respectively;

Treatment 3 (Agromelioration): Combined application of an organic ameliorant at 3.0 t/ha (autumn) and 1.0 t/ha (spring), with a soil conditioner at 300 and 100 kg/ha, respectively; and

Treatment 4 (Agromelioration): Optimized application of an organic ameliorant at 3.5 t/ha (autumn) and 0.5 t/ha (spring), with a soil conditioner at 350 and 50 kg/ha, respectively.

The organic ameliorant used in this study is a complex organic-biological fertilizer based on high-purity fulvic acids. These compounds are natural organic substances formed during the decomposition of plant and animal residues by soil microorganisms. The treatment also incorporates essential soil conditioners that enhance humification and microbial activity. All the experimental plots received the management with uniform irrigation and agrotechnical conditions to ensure the accuracy of the comparative analysis.

Statistical analysis

The obtained data received evaluation through the analysis of variance (ANOVA) to determine the significance of differences among treatments. The least significant difference ($LSD_{0.05}$) test aided in the comparison and separation of means. All calculations performed used the software package Statgraphics Centurion or Microsoft Excel, following the procedures described in the "Methodology of Field Experiment" (Dospekhov, 1985) and standard biometrical approaches (Snedecor and Cochran, 1989).

RESULTS AND DISCUSSION

Organic ameliorants' effect on fiber quality

The description of the Maktaaral-5027 (M-5027) variety consists of its origin coming from the Agricultural Experimental Station of Cotton and Melon Growing, with its hybridization using the DIAS system. Breeding continued using the synthetic selection method ([Maktaral 4007 x S-1604] x M-4011), followed by the multiple selection of offspring. It belongedto the group of early-ripening varieties, and the period from germination to the opening of the first cotton pod is 117 to 119 days. The fiber length is 34.1

mm, and the fiber yield is 38.7%. The variety has a conical bush shape, doesnot spread, and is 120–125 cm tall, with the first type of branching. The seeds are medium-sized, egg-shaped, and light gray. The weight of 1,000 seeds is 98–100 g. The fiber is white, with a micronaire at 4–5. It is demanding in terms of nutrition buttolerates late watering well. It develops well when sown in a 90 cm ×1–2 cm ×10 cm pattern and adapts wellto machine harvesting.

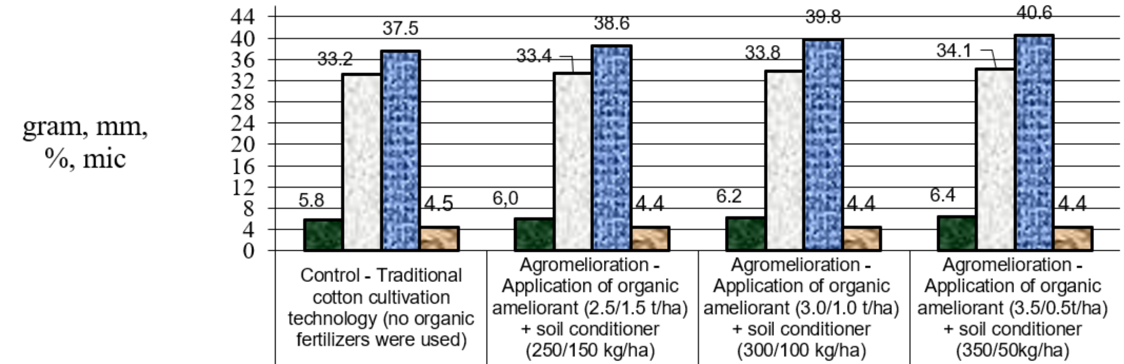
The application of organic ameliorants is critical for enhancing fiber yield, technological properties, and the overall productivity of cotton (*G. hirsutum* L.). These soil amendments stimulate key physiological processes and optimize the formation of reproductive organs, thereby maximizing the crop's genetic potential. In this study, evidence showed a significant improvement in fiber quality and boll weight in treatment 4. These observations align with past findings that organic soil conditioners optimize the metabolic transition from vegetative to generative stages (Shi *et al*., 2024). Furthermore, Jiang *et al*. (2023) emphasized that the strategic use of fulvic acids fosters a more robust metabolic environment for the development of high-quality fiber in cotton crops.

Technological properties of cotton fiber attained primary characterization from the fiber yield and length. In the studied cotton cultivar Maqtaaral-5027, the highest average boll weight resulted in Treatment 4 (3.5 t/ha organic ameliorant and 350 kg/ha soil improver during plowing, followed by 0.5 t/ha and 50 kg/ha in the spring). The average boll weight reached 6.4 g, representing a 9.4% increase over the control. These results align with Makhmadjanov *et al*. (2023), who reported the genetic potential of the cultivar M-5027 for larger boll size was best realized with the conditions of enhanced organic nutrition. Similarly, Jin *et al*.'s (2022) findings revealed that integrated soil improvement strategies significantly prevent boll shedding and increase the individual fruit weight in cotton.

Fiber length and yield are polygenic traits with the highest heritability (0.4 to 0.7) in cotton (*G. hirsutum* L.). In this study, the use of organic ameliorants on the cultivar M-5027 resulted in a fiber length of 34.1 mm and a fiber yield of 40.6%, which were 2.6% and 7.6% higher, respectively, than the control. The observed improvement in fiber yield confirmed the hypothesis of Negmatov (2008), who reported that optimizing the soil-water-nutrient nexus is critical for achieving the fiber yield exceeding 40%. Moreover, Liu *et al*. (2025) recently also confirmed that amino-acid-based fertilizers improved the deposition of secondary cell wall cellulose, which directly enhanced fiber quality traits such as fiber strength and length.

The synergistic effect of fulvic acids and soil conditioners on fiber quality can be due to several biochemical mechanisms. Fulvic acids, given their low molecular weight and high biological activity, act as natural chelating agents that enhance the bioavailability of essential micronutrients and nitrogen. This optimization of the "soil-root" interface triggers more intensive translocation of photo-assimilates to the bolls during fiber elongation and secondary cell wall thickening stages. Consequently, the improved deposition of cellulose, mediated by the organic treatment, results in superior fiber length and optimal micronaire values, ensuring the realization of the genetic potential of the Maqtaaral-5027 cultivar.

Micronaire value, a critical indicator of fiber fineness and maturity, had a measurement of 4.4 units in the variants treated with organic ameliorants. The said micronaire value falls within the premium range for air permeability and spinning quality. The presented results also got support from past findings of Zhumaniyazov *et al*. (2009), who stated that the micronaire value, as a function of both fiber fineness and cell wall maturity, determines the resistance to airflow. They said a value of 4.4 represents an optimal balance for textile processing. Additionally, Garcia *et al*. (2011) reported that organic amendments stabilized the micronaire index even under fluctuating environmental conditions, ensuring consistent textile quality. The findings on technological quality traits of upland cotton fiber using organic ameliorants appear in Figure 1.



	Control - Traditional cotton cultivation technology (no organic fertilizers were used)	Agromelioration - Application of organic ameliorant (2.5/1.5 t/ha) + soil conditioner (250/150 kg/ha)	Agromelioration - Application of organic ameliorant (3.0/1.0 t/ha) + soil conditioner (300/100 kg/ha)	Agromelioration - Application of organic ameliorant (3.5/0.5t/ha) + soil conditioner (350/50kg/ha)
Average weight of one box. G	5.8	6	6.2	6.4
Fiber length, mm	33.2	33.4	33.8	34.1
Fiber output, %	37.5	38.6	39.8	40.6
Micronair, mic	4.5	4.4	4.4	4.4

Figure 1. Effect of organic ameliorants application on fiber quality traits of cotton.

Organic ameliorants' effect on the root system

The development of the cotton root system acquires direct influence from agrotechnical practices, as the soil environment mediates the plant's physiological response to the application of external inputs. Under the organic treatment, a comprehensive understanding of root architecture is essential for optimizing cotton maturity and fiber yield. This is consistent with the findings of Arora *et al*. (2017), who reported that improving the soil physical environment through organic amendments is crucial for alleviating salt stress and promoting vigorous root branching. Furthermore, Yang and Niu's (2016) findings enunciated that organic-biological fertilizers trigger the release of growth-promoting hormones, eventually enhancing the primary and secondary root elongation.

The results revealed in the control variant, where no application of organic ameliorants transpired, root penetration into deeper soil horizons was insufficient, leading to a significant reduction in growth and development and ultimately, the fiber yield (Table 1, Figure 2). In this variant, the dry root weight was only 15.9 g in the 0–70 cm horizon, resulting in a seed cotton yield of 2.70 t/ha. In contrast, Treatment 4 (3.5 t/ha organic ameliorant and 350 kg/ha soil improver during plowing, with supplemental spring application) showed the most robust growth and development. For the said organic ameliorant variant, the dry root weight reached 24.5 g, with a 35.1% increase over the control, supporting the higher seed cotton yield of 3.19 t/ha (Figure 3).

In the optimized variant, root distribution displayed aconcentrationof73.4% and 17.4% in the 0–30 cm and 30–50 cm layers, respectively. The increased presence of first-order lateral roots in the moist topsoil (6–8 cm depth) appeared to be closely associated with higher boll retention. These observations align with the research of Blaise *et al*. (2005), who also reported the higher density of lateral roots in the upper soil profile is a key determinant of nutrient uptake efficiency and reproductive success in cotton. Moreover, Makhmadjanov *et al*. (2025) recently highlighted that reducing soil density via organic reclamation allows for a more expansive root network, directly correlating with improved fiber productivity.

Organic ameliorants' effect on soil properties

The presented research demonstrated that soil physical properties undergo significant positive transformations upon applying organic ameliorants. In the control variant (Treatment

Table 1. Development of the cotton root system depending on the use of organic ameliorants.

No.	Variants	Average weight of plant roots in the 0–70 cm layer (g)	Location of theroot system by layer (%)		Seed cotton yield (t/ha)
		0–70 см,	0–30	30–50	
1	Control. Traditional cotton cultivation technology (no organic fertilizers were used)	15.9	61.6	14.5	2.70
2	Agromelioration - Application of organic ameliorant 2.5/1.5 t/ha. Application of soil conditioner (250/150 kg/ha)	17.5	69.0	16.2	3.02
3	Agromelioration - Application of organic ameliorant 3.0/1.0 t/ha. Application of soil conditioner (300/100 kg/ha)	22.4	72.0	16.9	3.14
4	Agromelioration - Application of organic ameliorant 3.5/0.5t/ha. Application of soil conditioner (350/50kg/ha)	24.5	73.4	17.4	3.19

$LSD_{0.05}$: Root weight = 1.14; Root location (0–30 cm) = 2.10; Yield = 0.09

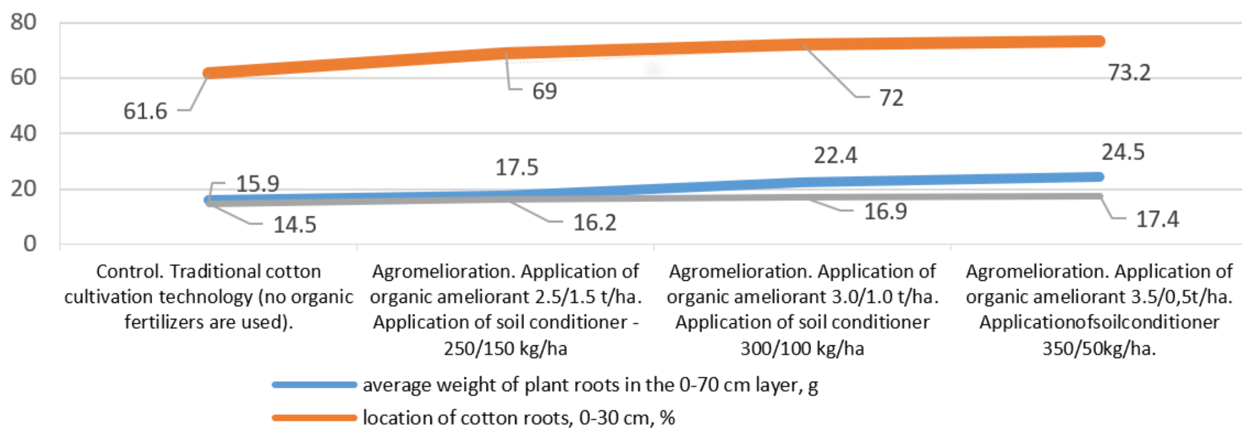


Figure 2. Effect of organic ameliorants application on the weight and location of cotton roots in soil layers.

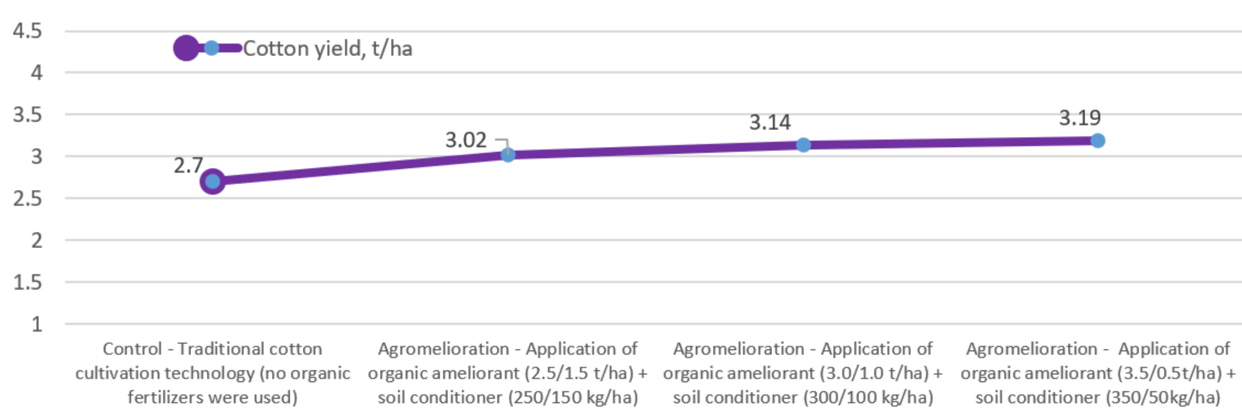


Figure 3. Dynamics of cotton yield growth, t/ha.

Table 2. Soil density variations depending upon the application of organic ameliorants (g/cm³).

Soil layer (cm)	Variants							
	Control - Traditional cotton cultivation technology (no organic fertilizers were used)		Agromelioration - Application of organic ameliorant (2.5/1.5 t/ha) + soil conditioner (250/150 kg/ha)		Agromelioration - Application of organic ameliorant (3.0/1.0 t/ha) + soil conditioner (300/100 kg/ha)		Agromelioration - Application of organic ameliorant (3.5/0.5t/ha) + soil conditioner (350/50kg/ha)	
	Growing seasonbeginning	Growing season end	Growing seasonbeginning	Growing season end	Growing seasonbeginning	Growing season end	Growing season beginning	Growing season end
0–10	1.37	1.38	1.34	1.35	1.34	1.35	1.31	1.32
10–20	1.42	1.42	1.38	1.38	1.35	1.35	1.32	1.33
20–30	1.51	1.53	1.41	1.43	1.37	1.38	1.33	1.34
0–30	1.43	1.45	1.37	1.39	1.35	1.36	1.32	1.33

$LSD_{0.05}$: Soil bulk density (beginning) = 0.021; Soil bulk density (end) = 0.023

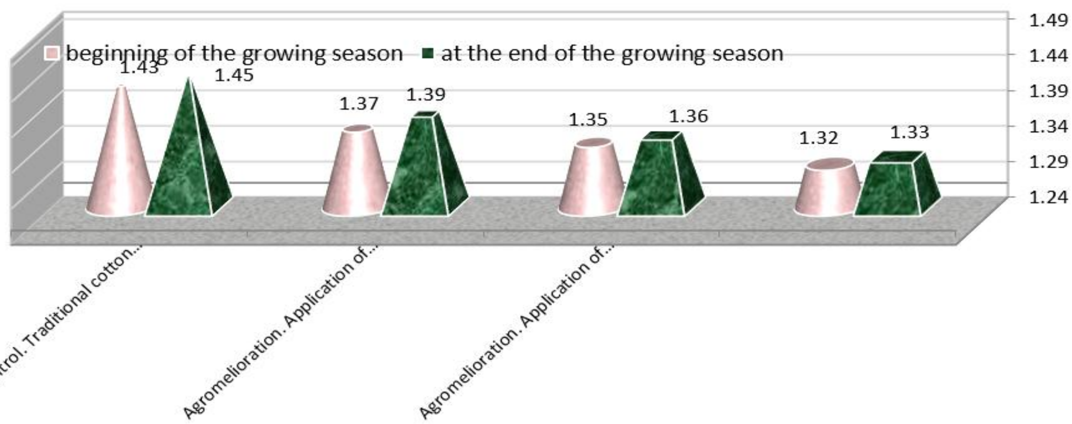


Figure 4. Soil density variations in the 0–30 cm deep soil layer by using organic ameliorants.

1), where no usage of organic amendments occurred, a consistent increase was evident in the soil bulk density throughout the growing season. However, at the beginning of the crop season, density indicators for the 0–10, 10–20, and 20–30 cm layers were 1.37, 1.42, and 1.51 g/cm³, respectively; and by autumn, these values had further increased to 1.38, 1.45, and 1.53 g/cm³ (Table 2). In control plots, this type of trend showed an alignment with the findings of Rao *et al*. (2017), who reported arising bulk density due to a low organic matter content and the resulting loss of total porosity in degraded soils. Similarly, Liu *et al*. (2025) emphasized that without organic intervention, irrigation and heavy tillage inevitably lead to soil compaction and structural decline.

The application of Treatment 4 (3.5 t/ha of organic ameliorant and 350 kg/ha of soil improver) established an optimal soil bulk density throughout the crop cycle. Following application during autumn plowing, the bulk density exhibited a significant reduction to 1.31, 1.32, and 1.33 g/cm³ in the 0–10, 10–20, and 20–30 cm layers, respectively. Notably, these indicators remained stable until the end of the growing season (1.32–1.34 g/cm³), demonstrating a significant seasonal stability in the treated plots compared with the control (Figure 4). This structural maintenance is likely due to the enhanced soil porosity and aggregation mediated by fulvic acids.

The optimized organic treatment (Treatment 4) at the onset of the growing season led to a proactive reduction in soil density. The application of Treatment 4 (3.5 t/ha organic ameliorant) notably improved soil structural stability. In the 0–30 cm layer, the bulk density had a decline to 1.32 g/cm³, which was 8.0% lower than the control ($P < 0.05$). This reduction in compaction facilitated better root penetration and nutrient uptake.

This improvement received considerable support from past findings of Jin *et al*. (2022), who reported that high-tech organic amendments enhanced structural stability indices and soil porosity, thereby preventing seasonal compaction. Furthermore, Jiang *et al*. (2023) also confirmed the incorporation of organic matter and carbohydrates effectively maintains soil structure stability, which is crucial for sustainable cotton cultivation in saline-irrigated arable zones.

The optimal level of soil bulk density (Treatment 4) entailed determination in the variant using organic ameliorants before soil plowing at the rate of 3.5 t/ha and soil improver (350 kg/ha). In spring, the organic ameliorant was 0.5 t/ha, and the soil improver was 50 kg/ha. With the said organic variant, the soil bulk density reduced to 1.31, 1.32, and 1.33 g/cm^3 in the 0–10, 10–20, and 20–30 cm soil layers, respectively.

At the end of the cotton-growing season, the volumetric mass of the soil was 1.32, 1.33, and 1.34 g/cm^{3}in the 0–10, 10–20,and 20–30 cm soil layers, respectively.By comparing the soil bulk density in the middle soil layer (0–30 cm thick), the seasonal variations can be noticeable in the soil bulk density (Figure 4).The use of organic ameliorants (option 4) at the beginning of the growing season led to a decrease in soil density, which was a considerable positive indicator. For example, the optimal soil density in the 0–30 cm layer in spring was 1.32 g/cm^3, which is 0.11 g/cm^3 (8.0%) higher than in the control, where no use of organic ameliorants happened.

The application of organic fertilizers to the soil contributes to the formation of an optimal level of density of the arable layer. The optimal agro-physical layer of the soil contributes to the accumulation of more soil moisture and organic matter, increases soil microorganisms' zone of activity, enhances nutrient availability, and improves agro-physical conditions of plants' root zone. Thus, the use of organic ameliorants boosts the water-physical condition of the soil, reduces the density of the arable layer, promotes deep penetration of the cotton root system, and ensures high yields of cotton.

CONCLUSIONS

The study revealed the integrated application of organic ameliorants (3.5 t/ha) and soil improvers (350 kg/ha) significantly improved soil physical properties and cotton (*G.hirsutum*L.) productivity. This treatment effectively reduced the soil bulk density in the 0–30 cm layer to an optimal (1.32 g/cm³), representing an 8.0% improvement over the untreated control. Enhanced soil porosity stimulated robust root development, increasing dry root mass by 35.1% and promoting deeper penetration into the soil profile. Consequently, cultivar Maqtaaral-5027 achieved the highest seed cotton yield of 3.19 t/ha, with an average boll weight of 6.4 g. Furthermore, fiber quality displayed a substantial enhancement, reaching a length of 34.1 mm and a yield of 40.6%. The results confirmed that new-generation organic-biological ameliorants proved essential for sustainable cotton farming and soil degradation reversal in the Turkestan Region.

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