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Response of Two Cotton Genotypes to Organic and Inorganic Fertilizers in Two Locations in Sulaymaniyah Province

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Abstract

Cotton plants have a wide range of industrial uses. However, various factors affect crop quality, necessitating the use of different approaches to achieve optimal crop production. In this study, the BM 455 and Golda genotypes were cultivated at two locations (TazaDe and Kani Panka) to evaluate the effects of applying organic (500 kg ha^{-1}) and inorganic (NPK-15:15:15; 200 kg ha^{-1}) fertilizers. NPK application significantly increased growth and yield in BM 455, whereas organic fertilizer was more effective for textile quality in both genotypes. The BM 455 had superior values, whereas Golda recorded the highest values in biological yield, fiber uniformity, elongation, and reflectance in both locations. There were significant differences across all parameters, with TazaDe being more suitable for cultivation than Kani Panka, except for biological yield. Depending on the phenotype and fertilizers, the growth and yield of the BM 455 genotype responded to NPK fertilizers, whereas both genotypes showed significant effects on quality characteristics under organic fertilizers. The untreated plants constituted a minority in this study. These findings will aid growers in cultivating the ideal genotypes under appropriate fertilization and optimal environmental conditions.

Keywords: Gossypium hirsutum, Fiber quality, Textile industry, Productivity, Phenotype, Sumac.

استجابة نوعين من أصناف القطن للأسمدة العضوية وغير العضوية في موقعين مختلفين ضمن محافظة السليمانية

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الخلاصة

يعد القطن من أهم محاصيل الألياف، لذا يجب الاهتمام به كونه محصولا اقتصاديا، وتحديد العوامل التي تؤدي إلى زيادة إنتاجيته. لذلك، أجريت هذه التجربة لمعرفة التأثير الفسيولوجي لكل من السماد العضوي (500 كجم هكتار$^{-1}$) والسماد NPK (200 كجم هكتار$^{-1}$) في صفات النمو والحاصل لصنفين من محصول القطن (BM 455) و(Golda)، نفذت التجربة في موقعين (TazaDe و(Kani Panka). طبقت التجربة العاملية للقطاعات العشوائية وبثلاث مكررات لكلا الموقعين. تشير النتائج إلى أن سماد NPK أدى إلى زيادة معنوية في صفات النمو والإنتاجية لصنف BM 455، أما السماد العضوي فقد أدى إلى زيادة معنوية في صفات الألياف لكلا الصنفين، مع تسجيل الصنف (Golda) أعلى القيم بالنسبة للحاصل البيولوجي. من حيث تجانس الألياف والاستطالة، تشير النتائج إلى أن موقع (TazaDe) كان أفضل من موقع (Kani Panka)، باستثناء الحاصل البيولوجي حيث تفوق موقع (Kani Panka). الصفات النمو والإنتاجية لصنف (BM 455) كانت أكثر استجابة لسماد NPK مقارنة بالسماد العضوي، بينما أظهرت كلا الصنفين تحسنا في جودة الألياف عند استخدام الأسمدة العضوية. هذه الدراسة تساعد المزارعين في اختيار أفضل الأصناف والأسمدة المناسبة لتحقيق إنتاجية وجودة أعلى في ظل الظروف البيئية المختلفة.

كلمات مفتاحية: Gossypium hirsutum، جودة الألياف، صناعة النسيج، الإنتاجية، النمط الظاهري.

Introduction

Cotton is an important industrial crop cultivated under diverse soil and climatic conditions (44). It belongs to the genus *Gossypium* and is a perennial plant of tropical and subtropical origin, although it is primarily grown as an annual crop to produce lint, seed oil, and animal feed (39). The cotton plant exhibits thermophilic, halophilic, and intermediate growth habits, with its vegetative and reproductive growth occurring simultaneously. Cotton germination and seedling growth depend on soil physicochemical properties and environmental conditions (9). Fluctuating climate and environmental conditions significantly impact cotton productivity (23) while other factors influence the plant's growth and development and thereby, productivity, including fertilization (18). Fertilizers enhance agricultural productivity and the quality of agricultural products (16). To achieve optimum crop productivity, it is essential to manage nutrients effectively by judiciously applying inorganic and organic fertilizers (24). Fertilizers, such as nitrogen (N), phosphorus (P), and potassium (K), are essential for the plant life cycle (42). Nitrogen promotes vegetative growth (21), whereas phosphorus supports root development and provides energy by forming ATP (36). Potassium is crucial in carbohydrate metabolism, enzyme activation, and osmotic regulation (46).

The use of organic fertilizers is a promising alternative to inorganic fertilizers for supplying essential nutrients vital to plant growth. Research shows that organic fertilization enhances nutrient uptake, stimulates plant growth and development, and improves crop productivity, quality, and environmental sustainability (13). Essential nutrients are important for cotton production (2), and adding them improves cotton growth and lint yield (26). Inadequate application of essential nutrients can decrease boll production (3), while excessive use can delay cotton maturity and increase vegetative growth (22). Therefore, the appropriate amounts of essential nutrients must be applied to achieve optimal cotton yields. Optimum nutrient application also improves crop root activity, antioxidant enzyme activity, and leaf pigment content (11), as well as increases water and fertilizer conservation, and enhances crop yield and stress resistance (33). This study investigated the effectiveness of organic and inorganic fertilizers in two cotton genotypes commonly grown in the Kurdistan region of Iraq.

Materials and Methods

Experimental Site: The study was conducted in agricultural fields in TazaDe in Qara Dagh (35º 15' N, 45º 29' E) and Kani Panka (35º 22' N, 45º 42' E), in Sulaymaniyah Province, Kurdistan Region, Iraq (Figure 1). The region experiences a semi-arid climate characterized by hot, dry summers and cold, wet winters. The research initiative began with soil preparation, including plowing, followed by the use of a rotary rotavator to homogenize and uniformly mix the soil. Soil samples were collected from agricultural fields in both areas at depths of 0–30 cm. The soil was air-dried and sieved through a 2-mm sieve. Table 1 summarizes the soil properties.

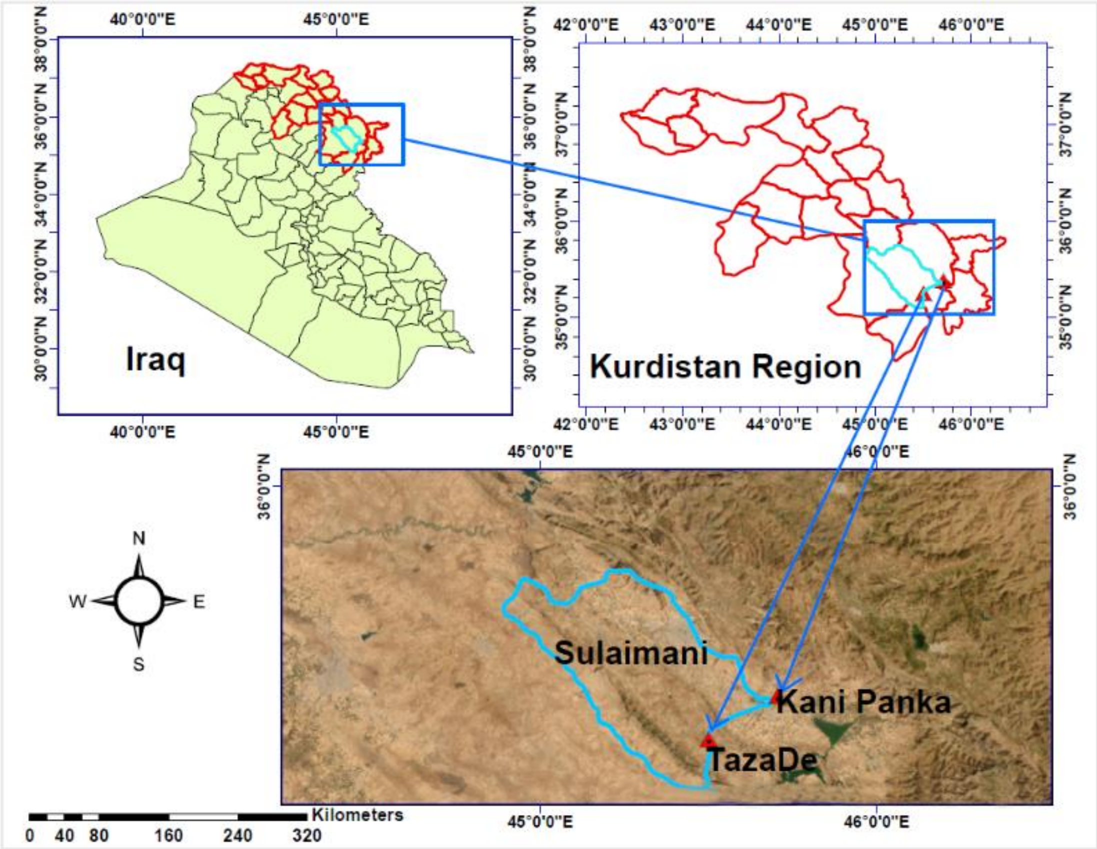

Fig. 1: The agricultural farms in TazaDe in Qara Dagh and Kani Panka, in Sulaymaniyah Province, Kurdistan Region, Iraq.

Table 1: Physical and chemical properties of the soil in both locations.

Soil properties	Location (Values)		Units
	TazaDe	Kani Panka	
Sand	471.9	42.60	g kg^{-1}
Silt	302.2	431.2	
Clay	225.9	526.2	
Textured class	Loam	Clay	
pH	7.50	7.61	----
EC	0.60	0.52	d ms^{-1}
Ca^{2+}	26.65	1.71	Mmole L^{-1}
Mg^{2+}	1.81	2.52	
Co_3^{2-}	0.00	0.00	
Na^+	0.17	0.47	
SO_4^{2-}	0.84	0.81	
Cl^-	0.48	0.45	
HCO_3^{2-}	2.91	2.98	
K^+	0.42	0.15	
Total N	1.15	1.01	g kg^{-1}
Available phosphate	5.02	5.43	mg kg^{-1}
$CaCO_3$	26.76	119.6	g kg^{-1}
Organic matter	29.6	27.78	

Two genotypes intensively cultivated in the region, namely the Bobilyon May 455 (BM 455) and Golda, were planted in furrows and spaced 50 cm between rows, with a row length of 5 meters. The experimental units were arranged in triplicate in a randomized complete block design (RCBD) throughout the open field area.

Throughout the study, the cotton plants were managed with comprehensive crop practices to enhance agricultural productivity. These included optimized irrigation, effective weed control, and pathogen management to promote optimal growth. Eighteen treatments were implemented, consisting of organic fertilizer at 500 kg ha^{-1} and inorganic (NPK) fertilizer at 200 kg ha^{-1}, each applied individually, along with a control (without either fertilizer). The organic fertilizer contained humic acid (21.5%), fulvic acid (3.5%), organic matter (40%), total nitrogen (5%), and pH (3-4), while the NPK fertilizer with a 15:15:15 ratio had equal parts of nitrogen, phosphorus, and potassium.

Data collection: Various parameters were assessed using different methods. The harvest index (HI), representing seed yield (ton ha^{-1}) at maturity, was computed by dividing the mean seed weight of five plant samples per plot (g $plant^{-1}$) and converting it into tons per hectare. Similarly, the calculation for biological yield (ton ha^{-1}) involved determining the average weight of five plant samples per plot, excluding roots (g $plant^{-1}$), and converting the outcome to ton ha^{-1} (40), as based on the following equation:

$$\text{Harvest Index (\%)} = \frac{\text{economic yield}}{\text{biological yield}} \times 100$$

After harvesting, ginning was performed using a roller-gin machine, and 50 grams of fiber from each treatment were used for analysis. The technological characteristics of the trial fiber were examined using an HVI 1000 device from Uster Technologies, Switzerland, while moisture properties were determined using the standard ASTM method (D 2495-19) (17).

Statistical analysis: Analysis of variance (two-way ANOVA) and Duncan's new multiple range test at $p \leq 0.05$ using XLSTAT software (version 2019.2.2) were employed for statistical analysis of the data.

Results and Discussion

Growth and yield characteristics of cotton plants: The findings indicated significant effects of both genotypes and fertilizers on these characteristics at the $p \leq 0.05$ significance level (see Table 2). The statistical analysis of the data revealed significant differences in genotype attributes across fertilizer applications. Specifically, BM 455 exhibited the highest values across various parameters when applied with NPK fertilizer, involving number of balls per plant 44.34, weight of balls (232.8 g $plant^{-1}$), number of seeds per ball 29.50, weight of seeds per ball (2.70 g), biological yield (8.36-ton ha^{-1}), harvest index (0.51%), and weight of fiber (1.57 g $plant^{-1}$).

Inorganic fertilizers, including NPK formulations, play a crucial role in the growth and yield of cotton plants (2). The balanced application of NPK fertilizers is essential for maximizing cotton yield. Nitrogen promotes vegetative growth and canopy development, optimizing light interception and photosynthetic efficiency (43). Phosphorus enhances root proliferation and reproductive processes (20). Potassium improves stress tolerance and fiber quality, ensuring higher yields of premium-grade cotton fiber (5). The synergistic interaction between NPK influences numerous physiological and biochemical pathways essential for yield formation. From early vegetative growth to boll maturation, properly assimilating and utilizing these nutrients is critical for achieving optimal yield potential in cotton crops (2). Furthermore, because organic fertilizers typically contain lower nutrient concentrations than synthetic fertilizers, they contribute to soil health, microbial activity, and nutrient cycling (32) and offer a sustainable alternative that may affect fiber quality. Studies suggest that organic fertilization promotes longer and stronger cotton fibers by enhancing soil structure and nutrient availability (45). Increased soil organic matter content improves water retention and nutrient availability, supporting sustained plant growth throughout the growing season (30).

Table 2: Interaction of genotypes and fertilizers on growth and yield.

Genotype	Fertilizer	Balls per plant	Weight of balls (g (plant^{-1}	Seeds per ball	Weight of seeds per (ball (g	Biological yield (ton (ha^{-1}	Harvest index ((%	Weight of fiber (g (plant^{-1}	Moisture of fiber ((%
BM 455	**Control**	20.89 ± 0.80 d	139.9 ± 2.72 c	22.82 ± 1.35 c	1.90 ± 0.17 b	5.52 ± 0.38 d	0.29 ± 0.19 b	1.19 ± 0.08 d	7.69 ± 0.10 ab
	Organic	40.39 ± 5.61 b	206.4 ± 9.86 a	27.28 ± 0.77 b	2.57 ± 0.05 a	7.39 ± 0.73 b	0.43 ± 0.36 a	1.52 ± 0.27 ab	7.80 ± 0.21 a
	NPK	44.34 ± 7.40 a	232.8 ± 5.21 a	29.50 ± 0.64 a	2.70 ± 0.10 a	8.36 ± 1.20 a	0.51 ± 0.42 a	1.57 ± 0.35 a	6.91 ± 0.44 d
Golda	**Control**	31.64 ± 1.34 c	149.0 ± 3.36 bc	25.52 ± 1.69 b	2.14 ± 0.35 b	6.69 ± 1.21 c	0.25 ± 0.15 b	1.30 ± 0.30 cd	7.31 ± 0.12 c
	Organic	39.72 ± 2.35 b	205.8 ± 7.88 a	27.15 ± 2.88 b	2.56 ± 0.31 a	7.51 ± 1.82 b	0.43 ± 0.34 a	1.44 ± 0.31 abc	7.36 ± 0.33 bc
	NPK	37.89 ± 3.55 b	170.4 ± 5.57 b	25.94 ± 0.75 b	2.48 ± 0.24 a	8.24 ± 1.08 a	0.31 ± 0.25 b	1.40 ± 0.11 bc	7.16 ± 0.11 cd

Conversely, BM 455 had the lowest values for these characteristics (20.89, 139.9 g plant^{-1}, 22.82, 1.90 g, 5.52-ton ha^{-1}, and 1.19 g plant^{-1}, respectively), while the lowest harvest index percentage (0.25%) was produced by the Golda genotype under untreated plants. In terms of moisture of fiber, the highest value (7.80%) was recorded for BM 455 under organic fertilizer, while the lowest, at 6.91%, was observed under NPK dose application.

The results indicated that genotype and location significantly impact the reported traits (Figure 2). As seen in Figure 2 (a, b, f, and g), BM 455 at TazaDe recorded significantly higher values for the maximum number of balls per plant 39.24, weight of balls (203.37 g plant^{-1}), harvest index (0.73%), and weight of fiber (1.63 g plant^{-1}). In contrast, when cultivated at Kani Panka, BM 455 produced the minimum number of balls per plant 31.17, while Golda exhibited the lowest weight of balls (159.8 g plant^{-1}) at TazaDe and the lowest harvest index (0.09%) and weight of fiber (1.18 g plant^{-1}) at Kani Panka Moreover, Golda showed significant superiority in biological yield, producing the highest production (7.99 tons ha^{-1}) at Kani Panka. Conversely, the lowest production (6.43 tons ha^{-1}) was observed for the BM 455 genotype at TazaDe (Figure 2e). Notably, no statistically significant differences were observed in the number and weight of seeds per ball, or in fiber moisture, across phenotypes (Figure 2c, d, and h). Accordingly, the characteristics were affected by genotypes and geographical locations. According to the researchers, cotton genotypes grown in regions with optimal soil fertility and moisture levels tend to produce fibers of superior quality, characterized by longer staple length, higher tensile strength, and finer micronaire (8).

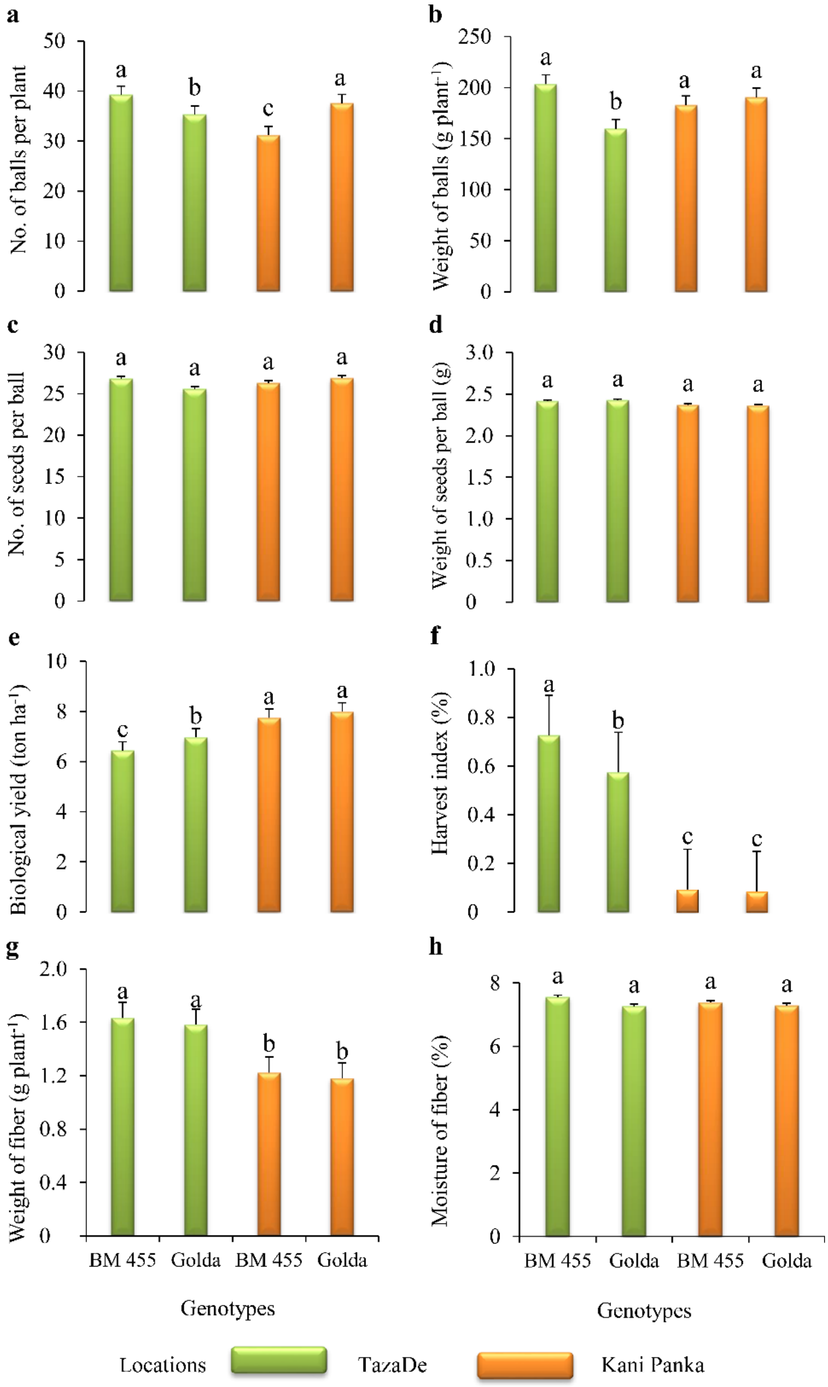

Fig. 2: Effect of phenotypes on growth and yield variables.

Column bars represent the mean ± SD (n=3) of the data, and different letters indicate significant differences between the treatments at 5% level, as determined by Duncan's test.

Figure 3 shows that cotton plants cultivated under all required conditions for growth and development were influenced by the geographical and environmental conditions of the two locations, including growth and yield characteristics. TazaDe showed a dominant influence, with the highest mean values for the number of balls per plant (37.25), harvest index (0.65%), and fiber weight (1.61 g plant^{-1}). In contrast, cotton plants cultivated at Kani Panka exhibited a significant decrease in the descriptive data and average values at 34.37, 0.09%, and 1.20 g plant^{-1}, respectively (Figure 3a, f, and g). Specific locations and an increasing production rate enhanced biological yield. Kani Panka is distinguished by its significant effect, which substantially increased average yield (7.87 tons ha^{-1}), whereas TazaDe obtained the lowest production (6.70 tons ha^{-1}), as shown in Figure 3e. Furthermore, as shown in Figures 3b, c, d, and h, location did not significantly affect the weight of balls per plant, the number and weight of seeds per ball, or fiber moisture, as indicated by p-values ≤ 0.05.

Latitude, altitude, and soil type influence the cotton plant's growth, architecture, and development patterns (4). Environmental variables, including temperature, precipitation, and photoperiod, shape morphological traits such as leaf size, branching pattern, and fruiting behavior. Cotton genotypes adapted to specific climatic conditions may exhibit traits optimized for resource utilization and environmental stress tolerance, influencing overall plant growth (29 and 38).

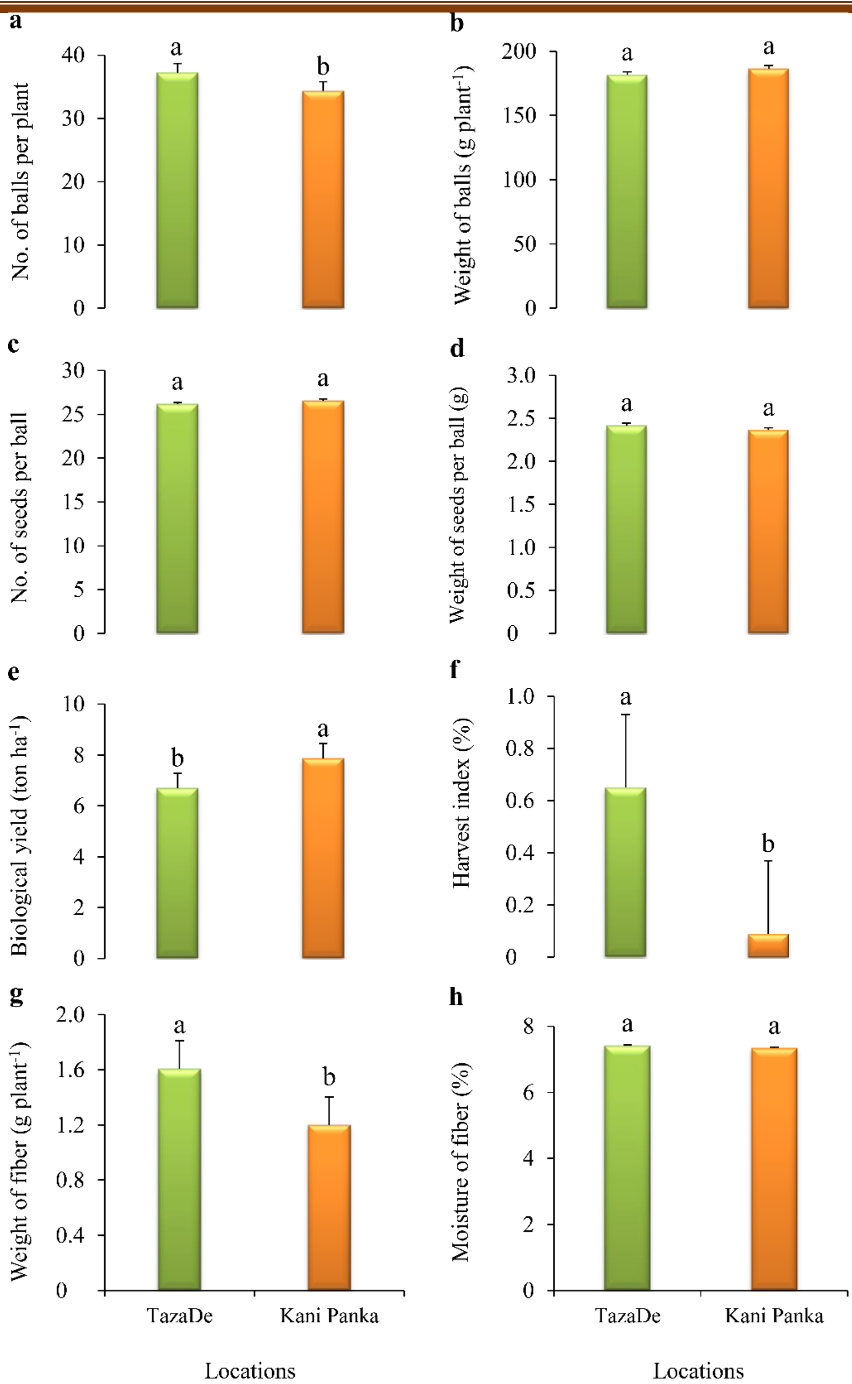

Fig. 3: Effect of locations on growth and yield variables.

Column bars represent the mean ± SD (n=3) of the data, and different letters indicate significant differences between the treatments at 5% level, as determined by Duncan's test.

Table 3 presents the effects of different environmental locations and the use of organic and NPK fertilizers on the growth and yield traits of the two cotton genotypes. BM 455, cultivated in the agricultural farm of TazaDe and treated with NPK fertilizer, recorded the maximum values in number of balls per plant (51.34), weight of balls (234.9 g plant^{-1}), harvest index (0.93%), and weight of fiber (1.92 g plant^{-1}) while the untreated plant had the minimum number of balls per plant (20.59). Additionally, the untreated Golda genotype produced the lowest ball weight (131.7 g plant^{-1}) at the same location and the lowest fiber weight (1.10 g plant^{-1}) at Kani Panka. However, the NPK-treated Golda had a lower harvest index of 0.06%.

The BM 455 genotype receiving NPK fertilizer at the Kani Panka location recorded the highest number and weight of seeds per ball (51.34 and 234.9 g plant^{-1}, respectively) and the highest biological yield (9.54 tons ha^{-1}). Conversely, when cultivated at the same farm under controlled conditions, the same genotype produced the lowest seed attributes: 21.88 for seed attributes and 1.78 g of seeds per ball. Furthermore, the biological yield was lowest (5.38 tons ha^{-1}) when the same genotype was shifted to the TazaDe location and left untreated. Moreover, the fiber moisture content was measured to assess the effects of integrating the BM 455 genotype and organic fertilizer in the TazaDe environment. The results indicated that this combination produced the highest percentage, increasing by 8.00%. Conversely, BM 455 under inorganic (NPK) fertilizer recorded the lowest percentage at the same location, at 6.87%. The data show that location, genotypes, and fertilizer application play crucial roles in achieving optimal growth and yield in cotton plants. These factors significantly influence the industrial quality of cotton.

Table 3: Interaction of phenotypes and fertilizers on growth and yield.

Location	Variety	Fertilizer	Balls per plant	Weight of balls (g plant^{-1})	Seeds per ball	Weight of seeds per ball (g)	Biological yield (ton ha^{-1})	Harvest index (%)	Weight of fiber (g plant^{-1})	Moisture of fiber (%)
TazaDe	BM 455	Control	20.59 ± 0.45 h	141.3 ± 2.12 ef	23.76 ± 0.79 fg	2.02 ± 0.03 cd	5.38 ± 0.26 d	0.47 ± 0.09 cd	1.19 ± 0.01 c	7.79 ± 0.03 ab
		Organic	45.78 ± 2.04 b	233.9 ± 6.52 a	27.53 ± 0.71 abcd	2.61 ± 0.04 ab	6.74 ± 0.26 c	0.78 ± 0.09 b	1.79 ± 0.02 a	8.00 ± 0.06 a
		NPK	51.34 ± 3.14 a	234.9 ± 7.51 a	29.09 ± 0.51 ab	2.60 ± 0.02 ab	7.18 ± 0.24 bc	0.93 ± 0.06 a	1.92 ± 0.02 a	6.87 ± 0.56 e
	Golda	Control	32.22 ± 1.55 fg	131.7 ± 2.04 f	24.44 ± 0.46 efg	2.24 ± 0.02 bcd	7.84 ± 0.52 b	0.40 ± 0.02 d	1.50 ± 0.31 b	7.40 ± 0.07 bcd
		Organic	39.11 ± 2.46 cd	197.7 ± 2.91 abcd	25.76 ± 0.48 cdef	2.51 ± 0.17 abc	5.79 ± 0.04 d	0.76 ± 0.12 b	1.74 ± 0.06 a	7.25 ± 0.18 cde
		NPK	34.44 ± 1.10 efg	149.9 ± 2.04 ef	26.44 ± 0.08 bcdef	2.52 ± 0.25 abc	7.26 ± 0.53 bc	0.56 ± 0.05 c	1.51 ± 0.04 b	7.14 ± 0.03 cde
Kani Panka	BM 455	Control	21.18 ± 0.94 h	138.4 ± 2.46 ef	21.88 ± 1.13 g	1.78 ± 0.16 d	5.66 ± 0.43 d	0.11 ± 0.04 e	1.19 ± 0.12 c	7.59 ± 0.02 abc
		Organic	35.00 ± 0.82 ef	179.0 ± 1.96 cde	27.03 ± 0.73 abcde	2.53 ± 0.02 abc	8.04 ± 0.37 b	0.08 ± 0.01 e	1.26 ± 0.06 c	7.60 ± 0.04 abc
		NPK	37.33 ± 1.25 de	230.7 ± 6.32 ab	29.92 ± 0.45 a	2.79 ± 0.04 a	9.54 ± 0.26 a	0.09 ± 0.02 e	1.22 ± 0.01 c	6.96 ± 0.24 de
	Golda	Control	31.06 ± 0.74 g	166.3 ± 2.26 def	26.59 ± 1.79 bcdef	2.04 ± 0.47 cd	5.54 ± 0.11 d	0.10 ± 0.01 e	1.10 ± 0.00 c	7.21 ± 0.05 cde
		Organic	40.33 ± 2.06 cd	214.0 ± 5.76 abc	28.55 ± 3.53 abc	2.61 ± 0.42 ab	9.23 ± 0.83 a	0.10 ± 0.01 e	1.14 ± 0.01 c	7.48 ± 0.40 bcd
		NPK	41.33 ± 0.47 c	190.8 ± 1.62 bcd	25.44 ± 0.78 def	2.43 ± 0.21abc	9.21 ± 0.39 a	0.06 ± 0.00 e	1.30 ± 0.02 bc	7.19 ± 0.14 cde

Industrial-quality characteristics of cotton plants: Based on the data in Table 4, it can be observed that the genotypes BM 455 and Golda, when treated with organic and inorganic (NPK) fertilizers, significantly affected fiber quality. Applying NPK fertilizer to the BM 455 genotype produced the highest upper half mean length (UHML; 27.30 mm) and the highest fiber yellowness (13.15 +b). Conversely, Golda, under control conditions, exhibited the shortest UHML (25.46 mm) and the lowest yellowness (11.13 +b). Moreover, fiber yellowness is related to cotton pigmentation and determines color quality; thus, yellowness (+b) is an undesirable feature, and reducing it enhances industrial quality. Statistically, Golda's exposure to organic fertilizers produced diverse outcomes, with the most significant effects observed for fiber mean length (22.11 mm), fiber uniformity (83.26%), fiber elongation (6.58%), and fiber reflectance (75.29 Rd).

The untreated Golda exhibited the shortest fiber mean length (20.61 mm) and the lowest fiber uniformity (81.87%) when treated with NPK fertilizer. Additionally, BM 455 treated with NPK fertilizer registered the lowest fiber elongation (6.37%). Fiber reflectance, associated with the brightness of cotton and important in pricing cotton, showed the lowest reflectance (71.00 Rd) in BM 455 under control conditions. Fiber strength and fineness can potentially determine the quality of cotton plants. Both parameters reached their peak potential, with BM 455 under organic fertilizer showing the highest values (11.00 g tex^{-1} for fiber strength and 4.67 mic for fineness). In contrast, Golda, under controlled conditions, exhibited the lowest quality (8.50 g tex^{-1} and 3.70 mic), respectively, among all treatments.

The prudent management of NPK fertilizers is essential for sustainable cotton production, ensuring economic viability while minimizing environmental impacts (47). Continuing research and innovation in nutrient management practices will be essential for meeting the growing demand for cotton fiber quality worldwide (27). Also, organic fertilizer enhances root development and nutrient uptake, resulting in healthier plants with robust fiber-producing structures, leading to longer and stronger cotton fibers (37). In addition to length and strength, fiber fineness and uniformity are critical determinants of cotton fiber quality (7 and 34). Organic fertilizers produce finer and more uniform cotton fibers by influencing plant physiology and environmental conditions (31).

Table 4: Interaction of genotypes and fertilizers on quality characteristics.

Genotype	Fertilizer	UHML ((mm	Mean fiber (length (mm	Fiber strength (g (tex^{-1}	Fiber uniformity ((%	Fiber Elongation ((%	Fiber fineness ((micronaire	Fiber reflectance ((Rd	Fiber Yellowness ((+b
BM 455	Control	25.75 ± 0.63 b	21.10 ± 0.42 bc	8.61 ± 0.25 d	82.46 ± 0.47 b	6.42 ± 0.07 bc	3.74 ± 0.49 b	71.00 ± 1.06 e	12.08 ± 0.56 c
	Organic	26.69 ± 0.43 a	21.57 ± 0.59 ab	11.00 ± 0.73 a	82.22 ± 0.55 b	6.48 ± 0.07 abc	4.67 ± 0.34 a	73.59 ± 0.98 b	12.92 ± 0.34 ab
	NPK	27.30 ± 1.26 a	21.84 ± 0.87 a	10.34 ± 1.11 b	82.09 ± 0.54 b	6.37 ± 0.27 c	4.20 ± 0.61 ab	72.77 ± 0.38 cd	13.15 ± 0.50 a
Golda	Control	25.46 ± 0.51 b	20.61 ± 0.53 c	8.50 ± 0.42 d	81.90 ± 1.15 b	6.40 ± 0.08 bc	3.70 ± 0.53 b	72.99 ± 1.16 bc	11.13 ± 0.38 d
	Organic	26.95 ± 0.50 a	22.11 ± 0.58 a	10.02 ± 0.53 b	83.26 ± 0.96 a	6.58 ± 0.13 a	3.70 ± 0.16 b	75.29 ± 0.59 a	12.24 ± 0.49 c
	NPK	26.66 ± 0.61 a	22.09 ± 0.60 a	9.31 ± 0.24 c	81.87 ± 0.69 b	6.51 ± 0.07 ab	4.03 0.20 b	72.07 ± 2.95 d	12.49 ± 0.38 bc

The fiber quality characteristics of cotton plants were influenced by phenotype (Figure 4). According to Figure 4a and h, BM 455 cultivated at the Kani Panka location showed potential quality in UHML and fiber yellowness, recording maximum values of 26.88 mm and 12.83 +b, respectively. However, it registered a minimum value of 26.28 mm UHML at TazaDe. Additionally, Golda at TazaDe exhibited decreased fiber yellowness (11.83 +b) and increased trade quality. Notably, no significant statistical improvement in fiber mean length was observed under the phenotype (Figure 4b). Moreover, the BM 455 phenotype significantly improved fiber quality, achieving the highest strength (10.58 g tex^{-1}) and fineness (4.37 mic) when cultivated at TazaDe. Conversely, Golda decreased quality for both parameters, with strength (9.22 g tex^{-1}) at Kani Panka and fineness (3.63 mic) at TazaDe (Figure 4c and f).

The Golda genotype at Tazade exhibited higher fiber uniformity (83.16%) and elongation (6.52%), as well as higher reflectance (74.94 Rd). Nevertheless, when treated at Kani Panka, its uniformity values and reflectance quality decreased to 81.52% and 71.95 Rd, respectively, while BM 455 at the same location decreased its elongation percentage to 6.33% (Figure 4d, e, and g). Based on these data, phenotype affects industrial quality. Genotype determines the inherent traits of a plant, whereas geographical location affects how those traits manifest in response to local environmental conditions, such as climate, soil, and altitude. This interplay between genotype and environment underscores the complex relationship that determines the industrial-quality phenotype of cotton plants across regions.

Environmental stressors such as water scarcity, nutrient deficiencies, and heat stress can compromise cotton plant traits, including fiber quality, leading to shorter, weaker fibers with lower spinning efficiency (35). Understanding the complex interactions between genotype, environment, and agronomic practices is essential for optimizing cotton production and fiber quality across diverse geographical regions (15). By adapting cultivation practices and selecting appropriate genotypes, growers can mitigate the adverse effects of environmental variability, ensuring sustainable cotton production for the textile industry.

Industrial parameters are crucial in determining cotton fiber quality, impacting its processing, strength, and market value. Fiber moisture content is a critical parameter influencing fiber quality and processing efficiency. Maintaining moisture below a certain threshold is essential to prevent fiber degradation and microbial growth during storage and transportation (14). Fiber bundle strength and UHML are typically reliable indicators of cotton fiber quality, and producers can command premium prices for longer and stronger fibers. Long and strong fibers are highly desirable for their faster processing speeds, leading to increased production, reduced cost per unit, and enhanced yarn quality (7). Fiber length is a key factor in the adoption of cotton in the textile industry. It is also one of the most significant physical features. Fiber length substantially impacts the quality and properties of textiles, influencing components such as strength, durability, and overall performance of the end products (6). It is a critical attribute of cotton end products, essential for both producers, in terms of income, and traders in supplying the appropriate material to ensure the production of high-quality products (19 and 41).

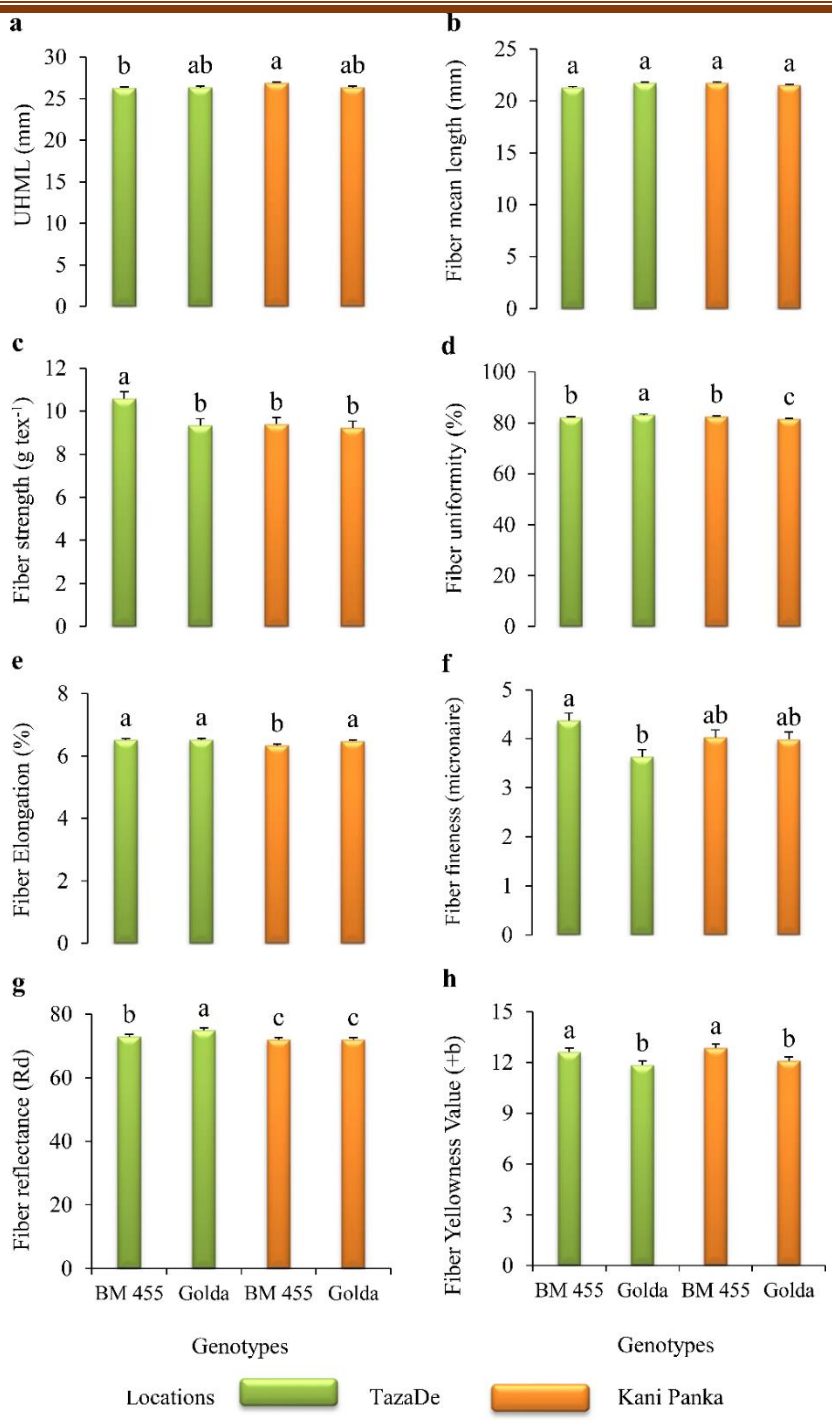

Fig. 4: Effect of phenotypes on quality variables.

Column bars represent the mean ± SD (n=3) of the data, and different letters indicate significant differences between the treatments at 5% level, as determined by Duncan's test.

The fiber quality of cotton plants across all treatments was measured at both locations in this study and was found to significantly influence yarn quality (Figure 5). Cotton plants cultivated at TazaDe demonstrated statistically superior qualities compared with those at Kani Panka, producing the highest average values for strength (9.96 g tex^{-1}), uniformity (82.64%), elongation (6.52%), and reflectance (73.94 Rd). In contrast, Kani Panka's geographical location yielded the lowest values at 9.31 g tex^{-1}, 81.96%, 6.40%, and 71.96 Rd, respectively (Figure 5c, d, e, and g). No statistically significant differences were observed among the locations, according to the descriptive statistics. Mean values for fiber quality parameters such as UHML, mean length, fineness, and yellowness were not significantly affected by climate, soil, or altitude under any treatment at $p \leq 0.05$ (Figure 5a, b, f, and h). The industrial quality of cotton fiber, encompassing traits such as length, strength, micronaire, and uniformity, is influenced by location-specific environmental factors (32). Soil fertility, moisture availability, and temperature regimes profoundly impact fiber development and characteristics (10).

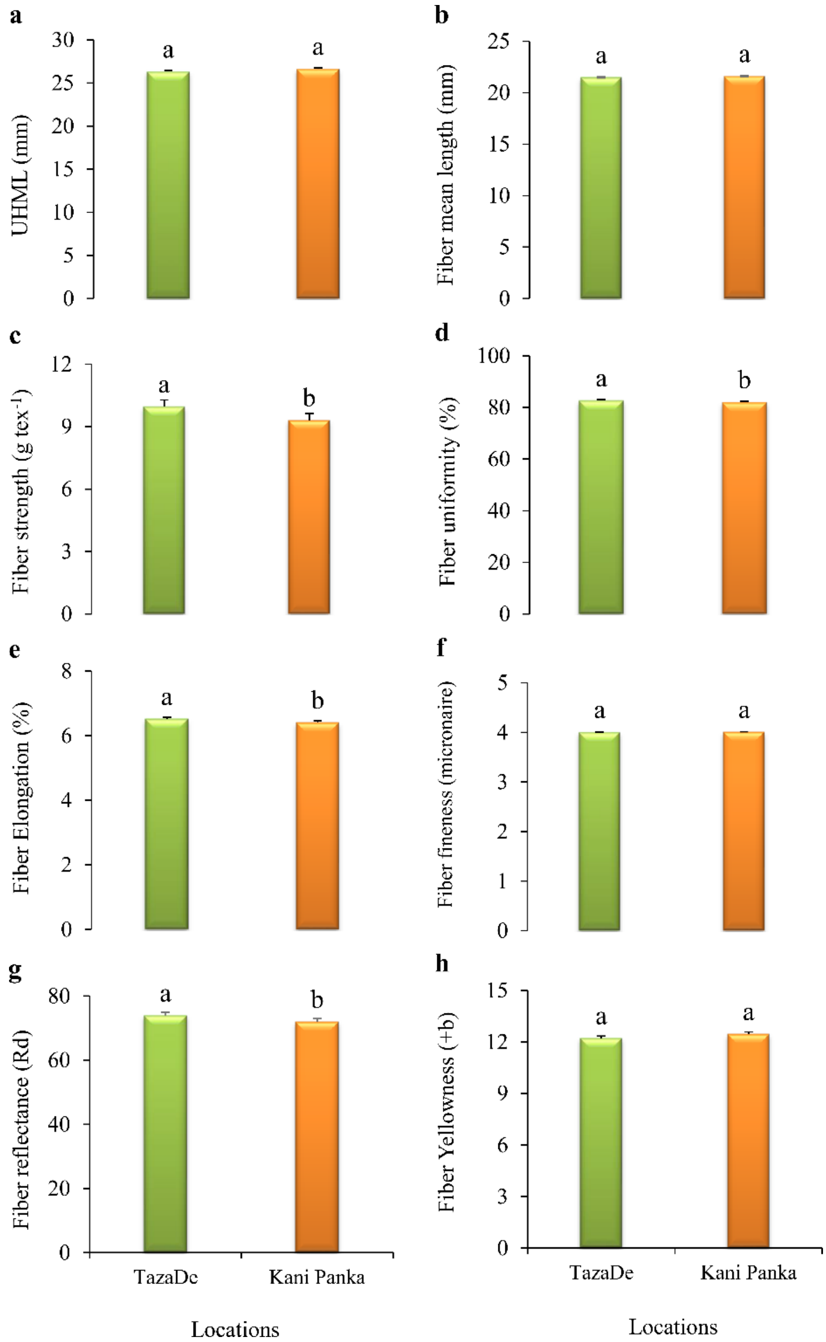

Fig. 5: Effect of locations on quality variables.

Column bars represent the mean ± SD (n=3) of the data, and different letters indicate significant differences between the treatments at 5% level, as determined by Duncan's test.

Table 5 depicts the effect of phenotype and fertilizer applications on the yarn quality of cotton plants. The BM 455 genotype cultivated at the Kani Panka farm and treated with NPK fertilizer showed significantly improved UHML (28.47 mm) and increased yellowness (13.57 +b). However, under controlled conditions, Golda recorded a minimum UHML (25.30 mm) and a decreasing yellow color (11.00 +b). Thus, yellowness affected the trading aspect of cotton. The longest fiber mean length at 22.64 mm was observed in NPK-treated Golda at the Kani Panka location, while the shortest (20.17 mm) was in the control plants. More precisely, the application of organic fertilizer increases fiber quality. BM 455 under organic fertilizer had significantly improved average length (11.65 g tex^{-1}) and fiber fineness (5.01 mic). These values significantly decreased for the untreated Golda genotype, reaching 8.30 g tex^{-1} and 3.44 mic, respectively, at the TazaDe farm.

Correspondingly, Golda subjected to organic fertilizer application showed increased fiber values for uniformity (84.20%), elongation (6.70%), and reflectance (75.80 Rd). In contrast, uniformity decreased to a minimum (80.82%) when it was exposed to the Kani Panka location under control conditions, whereas fiber reflectance declined to the lowest level (69.13 Rd) under NPK application. BM 455 exhibited the shortest elongation (6.13%) when NPK was applied at the Kani Panka location. As such, the interplay between phenotype and fertilizer application can significantly impact the industrial textile quality of fiber. Phenotypic characteristics, influenced by genetic makeup and environmental factors, dictate fiber properties such as length, strength, and fineness. Fertilizer usage further modulates these traits by affecting plant growth, nutrient uptake, and fiber development. Understanding and optimizing this relationship is crucial for enhancing fiber quality in industrial textile production, ensuring desirable properties such as durability, uniformity, and processing efficiency.

The degree of fiber elongation is of significant importance in textile manufacturing. Throughout the ginning process, the ability of fibers to withstand mechanical procedures is crucial in preventing fiber breakage. This characteristic facilitates the effective spinning of fibers (12 and 28), ensuring smooth processing and enhancing the quality of the final textile products. The fineness of cotton fibers is an important factor influencing the overall quality of final products. Micronaire, a quality parameter linked to the fineness and maturity of fibers, serves as a noteworthy signal in this context (1). Fiber color is a fundamental criterion for classifying cotton into grades under the Universal Cotton Standards (UCS). The grading process is regulated by two attributes: reflectance (Rd) and yellowness (+b). Yellowness is intricately linked to cotton pigmentation, while reflectance is associated with the brightness of cotton, a parameter of considerable significance in determining cotton pricing. The color of cotton plays a critical role in the absorption and retention of dyes in the final product. Hence, the efficacy of the dyeing process heavily depends on these two parameters (25).

Table 5: Interaction of phenotypes and fertilizers on quality characteristics.

Location	Variety	Fertilizer	UHML (mm)	Mean fiber length (mm)	Fiber strength (g tex^{-1})	Fiber uniformity (%)	Fiber Elongation (%)	Fiber fineness (micronaire)	Fiber reflectance (Rd)	Fiber Yellowness (+b)
TazaDe	BM 455	Control	26.04 ± 0.74 cde	21.31 ± 0.35 c	8.66 ± 0.16 de	82.62 ± 0.59 bc	6.43 ± 0.05 b	3.62 ± 0.44 cd	71.90 ± 0.70 d	11.83 ± 0.48 de
		Organic	26.67 ± 0.13 bc	21.40 ± 0.14 c	11.65 ± 0.40 a	82.01 ± 0.63 bcd	6.50 ± 0.08 b	5.01 ± 0.09 a	74.17 ± 0.90 b	13.23 ± 0.17 ab
		NPK	26.13 ± 0.48 cde	21.11 ± 0.57 c	11.44 ± 0.24 a	81.70 ± 0.14 cde	6.60 ± 0.08 ab	4.49 ± 0.31 ab	72.73 ± 0.45 d	12.73 ± 0.20 bc
	Golda	Control	25.61 ± 0.67 de	21.04 ± 0.41 c	8.30 ± 0.28 e	82.98 ± 0.22 b	6.40 ± 0.08 b	3.44 ± 0.40 d	74.03 ± 0.37 bc	11.27 ± 0.21 ef
		Organic	27.36 ± 0.26 b	22.55 ± 0.52 ab	10.46 ± 0.35 b	84.20 ± 0.16 a	6.70 ± 0.08 a	3.59 ± 0.15 cd	75.80 ± 0.29 a	12.10 ± 0.65 cd
		NPK	26.08 ± 0.11 cde	21.53 ± 0.02 c	9.23 ± 0.26 cd	82.30 ± 0.36 bcd	6.47 ± 0.05 b	3.87 ± 0.04 bcd	75.00 ± 0.28 ab	12.13 ± 0.19 cd
Kani Panka	BM 455	Control	25.46 ± 0.30 e	20.88 ± 0.37 cd	8.57 ± 0.31 e	82.30 ± 0.22 bcd	6.40 ± 0.08 b	3.86 ± 0.51 bcd	70.10 ± 0.38 e	12.33 ± 0.53 cd
		Organic	26.72 ± 0.59 bc	21.73 ± 0.79 bc	10.36 ± 0.29 b	82.43 ± 0.34 bc	6.47 ± 0.05 b	4.34 ± 0.03 abc	73.00 ± 0.65 cd	12.60 ± 0.08 bcd
		NPK	28.47 ± 0.48 a	22.57 ± 0.32 ab	9.25 ± 0.11 cd	82.47 ± 0.52 bc	6.13 ± 0.19 c	3.90 ± 0.69 bcd	72.80 ± 0.28 d	13.57 ± 0.33 a
	Golda	Control	25.30 ± 0.15 e	20.17 ± 0.12 d	8.70 ± 0.43 de	80.82 ± 0.48 e	6.40 ± 0.08 b	3.97 ± 0.51 bcd	71.95 ± 0.61 d	11.00 ± 0.46 f
		Organic	26.54 ± 0.32 bcd	21.67 ± 0.16 c	9.58 ± 0.22 c	82.31 ± 0.23 bcd	6.47 ± 0.05 b	3.81 ± 0.07 bcd	74.77 ± 0.26 ab	12.38 ± 0.10 cd
		NPK	27.23 ± 0.26 b	22.64 ± 0.30 a	9.38 ± 0.20 c	81.44 ± 0.68 de	6.56 ± 0.05 ab	4.18 ± 0.17 bcd	69.13 ± 0.34 e	12.85 ± 0.05 abc

Conclusions

This experiment investigated the responses of the BM 455 and Golda cotton plant genotypes to organic (500 kg ha^{-1}) and inorganic (NPK-15:15:15, 200 kg ha^{-1}) fertilizers in two locations in Sulaymaniyah province, focusing on growth and yield parameters and the enhancement of industrial textile quality. For BM 455, growth and yield were affected by applying 200 kg ha^{-1} of NPK fertilizer, among other treatments. Regarding quality attributes, both genotypes performed better under the 500 kg ha^{-1} application of organic fertilizer.

The findings reveal that BM 455 outperformed Golda in both TazaDe and Kani Panka, with the former leading except for biological yield. Across phenotypes and fertilizers, growth and yield responded significantly to NPK fertilizer, whereas fiber quality was more responsive to organic fertilizer. The control plants exhibited lower outcomes for most attributes in this study. The effects of NPK and organic fertilizers on cotton plants across diverse locations have major implications for growers, sustainability, and economics. NPK and organic fertilizers are essential for improving immediate yields, whereas additional organic and compound fertilizers should also be considered to enhance soil health, sustainability, and overall economic viability in cotton production.

Supplementary Materials:

No Supplementary Materials.

Author Contributions:

Authors 1, 2, and 3 planned the experiment and the practical method. Author 1 wrote the related parts in the methods section. Authors 2 and 3 designed and contributed methodological and conceptual ideas. Author 4 was primarily responsible for executing the cluster analysis and writing this research. All authors finalized and adapted the manuscript in accordance with the journal's guidelines. All authors read and approved the final manuscript.

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Data available upon request.

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The authors declare no conflict of interest.

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References

1. Abbas, Q., and Ahmad, S. (2018). Effect of different sowing times and cultivars on cotton fiber quality under stable cotton-wheat cropping system in Southern Punjab, Pakistan. Pakistan Journal of Life and Social Sciences, 16(2): 77- 84.
2. Ahmed, N., Ali, M. A., Danish, S., Chaudhry, U. K., Hussain, S., Hassan, W., Ahmad, F., and Ali, N. (2020). Role of macronutrients in cotton production. Cotton Production and Uses: Agronomy, Crop Protection, and Postharvest Technologies, 81-104.
3. Ahmed, N., Ali, M. A., Hussain, S., Hassan, W., Ahmad, F., and Danish, S. (2020). Essential Micronutrients for Cotton Production. In S. Ahmad and M. Hasanuzzaman (Eds.), *Cotton Production and Uses: Agronomy, Crop Protection, and Postharvest Technologies* (pp. 105-117). Springer Singapore. https://doi.org/10.1007/978-981-15-1472-2_7.
4. Ajayakumar, M., Umesh, M., Shivaleela, S., and Nidagundi, J. (2017). Light interception and yield response of cotton varieties to high density planting and fertilizers in sub-tropical India. Journal of Applied and Natural Science, 9(3): 1835-1839. https://doi.org/10.31018/jans.v9i3.1448.

5. Ashraf, M., Shahzad, S. M., Imtiaz, M., Rizwan, M. S., and Iqbal, M. M. (2017). Ameliorative effects of potassium nutrition on yield and fiber quality characteristics of cotton (*Gossypium hirsutum* L.) under NaCl stress. Soil Environ, 36(1): 51-58. https://doi.org/10.25252/SE/17/31054.
6. Avşar, Ö., and Karademir, E. (2022). Evaluation of quality parameters in cotton production (*Gossypium hirsutum* L.) under water stress conditions. Applied Life Sciences and Environment, 55(1): 45-61. https://doi.org/10.46909/alse-551045.
7. Beyer, B. M., Smith, C. W., Percy, R., Hague, S., and Hequet, E. F. (2014). Test cross evaluation of upland cotton accessions for selected fiber properties. Crop Science, 54(1): 60-67. https://doi.org/10.2135/cropsci2013.06.0374.
8. Bradow, J. M., and Davidonis, G. H. (2010). Effects of environment on fiber quality. Physiology of Cotton, 229-245. https://doi.org/10.1007/978-90-481-3195-2_21
9. Chen, Y., and Dong, H. (2016). Mechanisms and regulation of senescence and maturity performance in cotton. Field Crops Research, 189: 1-9. https://doi.org/10.1016/j.fcr.2016.02.003.
10. El-Feky, H. E. A., and Hassan, S. A. (2011). Effect of cultivar and growing location on ginning efficiency and cotton quality. Egyptian Journal of Agricultural Research, 89(2): 567-578. https://doi.org/10.21608/ejar.2011.175920.
11. ElAshmouny, A. A., El-Awady, R. A., and Kassem, M. (2025). Improvement of some soil properties and productivity of Egyptian cotton (*Gossypium barbadense* L.) super Giza 94 under salt stress conditions. Environment, Biodiversity and Soil Security, 9(2025): 1-23. https://dx.doi.org/10.21608/jenvbs.2025.343998.1261.
12. Elmogahzy, Y., and Farag, R. (2018). Tensile properties of cotton fibers: importance, research, and limitations. Chapter 7, Elsevier, 223- 273. https://doi.org/10.1016/B978-0-08-101272-7.00007-9.
13. Gao, C., El-Sawah, A. M., Ali, D. F. I., Alhaj Hamoud, Y., Shaghaleh, H., and Sheteiwy, M. S. (2020). The integration of bio and organic fertilizers improve plant growth, grain yield, quality and metabolism of hybrid maize (*Zea mays* L.). Agronomy, 10(3): 319. https://doi.org/10.3390/agronomy10030319.
14. Gao, Y., Zhu, G., Zhu, H., and Xia, Y. (2018). Experimental study of the non-monotonous moisture effect on upward flame spread over cotton fabric. Textile Research Journal, 88(20): 2379-2394. https://doi.org/10.1177/0040517517720498.
15. Gul, S., Khan, N., Batool, S., Baloch, M., Munir, M., Sajid, M., Khakwani, A., Ghaloo, S., Soomro, Z., and Kazmi, S. (2014). Genotype by environment interaction and association of morphoyield variables in upland cotton. Journal of Animal and Plant Sciences, 24(1): 262-271.
16. Hu, Y., Luo, Y., Tan, X., Wang, B., Zhou, C., and Xiang, Y. (2023). Rational zoning and optimization of agricultural distribution in Guangdong province based on resource carrying capacity. Acta Ecologica Sinica, 43(5): 820-834. https://doi.org/10.1016/j.chnaes.2022.11.001.
17. Ibrahim, I., El Bagoury, M., and Abdel Gaber, S. (2021). An Efficiency of Standard Procedures for Moisture Analysis Tests Used in The Egyptian Cotton Trade.

Egyptian Academic Journal of Biological Sciences, H. Botany, 12(1): 43-52. https://dx.doi.org/10.21608/eajbsh.2021.150754.

18. Ibrahim, M., and El-Hafeez, A. (2017). Impact of integrated mineral and organic fertilization and foliar spraying of some micronutrints on cotton productvity. Journal of Soil Sciences and Agricultural Engineering, 8(12): 829-835. https://doi.org/10.21608/jssae.2017.38401.
19. Islam, M. S., Fang, D. D., Thyssen, G. N., Delhom, C. D., Liu, Y., and Kim, H. J. (2016). Comparative fiber property and transcriptome analyses reveal key genes potentially related to high fiber strength in cotton (Gossypium hirsutum L.) line MD52ne. BMC plant biology, 16(1): 36. https://doi.org/10.1186/s12870-016-0727-2.
20. Jing, J., Zhang, S., Yuan, L., Li, Y., Zhang, Y., and Zhao, B. (2022). Synergistic effects of humic acid and phosphate fertilizer facilitate root proliferation and phosphorus uptake in low-fertility soil. Plant and Soil, 478(1): 491-503. https://doi.org/10.1007/s11104-022-05486-2.
21. Khan, N., Han, Y., Wang, Z., Wang, G., Feng, L., Yang, B., and Li, Y. (2019). Role of proper management of nitrogen in cotton growth and development. International Journal of Biosciences, 14(5): 483-496. http://dx.doi.org/10.12692/ijb/14.5.483-496.
22. Lee, J., Snider, J. L., Parkash, V., Virk, G., and Hand, L. C. (2023). Regulating Plant Growth in Cotton. Crops and Soils, 56(4): 38-43. https://doi.org/10.1002/crso.20298
23. Li, N., Li, Y., Yang, Q., Biswas, A., and Dong, H. (2024). Simulating climate change impacts on cotton using AquaCrop model in China. Agricultural Systems, 216: 103897. https://doi.org/10.1016/j.agsy.2024.103897.
24. Lin, S., Wang, Q., Wei, K., Zhao, X., Tao, W., Sun, Y., Su, L., and Deng, M. (2024). Comprehensive assessment of combined inorganic and organic fertilization strategies on cotton cultivation: implications for sustainable agriculture. *Journal of the Science of Food and Agriculture*, *104*(14), 8456-8468. https://doi.org/10.1002/jsfa.13673
25. Mathangadeera, R. W., Hequet, E. F., Kelly, B., Dever, J. K., and Kelly, C. M. (2020). Importance of cotton fiber elongation in fiber processing. Industrial Crops and Products, 147: 112217. https://doi.org/10.1016/j.indcrop.2020.112217.
26. Mng'omba, S. A., Akinnifesi, F. K., Kerr, A., Salipira, K., and Muchugi, A. (2017). Growth and yield responses of cotton (*Gossypium hirsutum*) to inorganic and organic fertilizers in southern Malawi. Agroforestry Systems, 91(2): 249-258. https://doi.org/10.1007/s10457-016-9924-0.
27. Mollaee, M., Mobli, A., Mutti, N. K., Manalil, S., and Chauhan, B. S. (2019). Challenges and opportunities in cotton production. Cotton production, 371-390. https://doi.org/10.1002/9781119385523.ch18.
28. Negm, M., and Sanad, S. (2020). Cotton fibres, picking, ginning, spinning and weaving. In: Handbook of Natural Fibres, Elsevier, 3-48. https://doi.org/10.1016/B978-0-12-818782-1.00001-8.
29. Patil, A. E., Deosarkar, D., Khatri, N., and Ubale, A. B. (2023). A comprehensive investigation of Genotype-Environment interaction effects on seed cotton yield

contributing traits in Gossypium hirsutum L. Using multivariate analysis and artificial neural network. Computers and Electronics in Agriculture, 211: 107966. https://doi.org/10.1016/j.compag.2023.107966.

30. Raheem, A., Bankole, O. O., Danso, F., Musa, M. O., Adegbite, T. A., and Simpson, V. B. (2025). Physical Management Strategies for Enhancing Soil Resilience to Climate Change: Insights From Africa. European Journal of Soil Science, 76(1): e70030. https://doi.org/10.1111/ejss.70030.
31. Rehman, A., and Farooq, M. (2019). Morphology, physiology and ecology of cotton. Cotton production, 23-46. https://doi.org/10.1002/9781119385523.ch2.
32. Roy Choudhury, A. (2014). Environmental impacts of the textile industry and its assessment through life cycle assessment. Roadmap to sustainable textiles and clothing: environmental and social aspects of textiles and clothing supply chain, 1-39. https://doi.org/10.1007/978-981-287-110-7_1.
33. Shi, Y., Niu, X., and Chen, B. (2023). Chemical fertilizer reduction combined with organic fertilizer affects the soil microbial community and diversity and yield of cotton. Frontiers in Microbiology, 14: 1295722. https://doi.org/10.3389/fmicb.2023.1295722.
34. Siddiqui, M. Q., Wang, H., and Memon, H. (2020). Cotton fiber testing. In: Cotton science and processing technology: Gene, ginning, garment and green recycling, By: Wang, H., and Memon, H. M., Chapter 6, Springer, 99-119. https://doi.org/10.1007/978-981-15-9169-3.
35. Slater, K. Environmental Impact of Textiles: Production, Processes and Protection; Woodhead Publishing: Cambridge, UK, 2003; Volume 27.
36. Sofi, S. O., Talabani, S. K., Sleman, S. M., Faraj, S. H. G., and Halshoy, H. S. (2024). Impact of Bio-based and Synthetic Phosphorus Application on Growth, Yield, and Protein Profile of Two Chickpea Genotypes. Agricultural Research, 14(3): 97-108. https://doi.org/10.1007/s40003-024-00753-3.
37. Tao, R., Wakelin, S. A., Liang, Y., and Chu, G. (2017). Organic fertilization enhances cotton productivity, nitrogen use efficiency, and soil nitrogen fertility under drip irrigated field. Agronomy Journal, 109(6): 2889-2897. https://doi.org/10.2134/agronj2017.01.0054.
38. Tuttolomondo, T., Virga, G., Rossini, F., Anastasi, U., Licata, M., Gresta, F., La Bella, S., and Santonoceto, C. (2020). Effects of environment and sowing time on growth and yield of upland cotton (*Gossypium hirsutum* L.) cultivars in Sicily (Italy). Plants, 9(9): 1209. https://doi.org/10.3390/plants9091209.
39. Viot, C. R., and Wendel, J. F. (2023). Evolution of the cotton genus, Gossypium, and its domestication in the Americas. Critical Reviews in Plant Sciences, 42(1): 1-33. https://doi.org/10.1080/07352689.2022.2156061.
40. Wang, G., Feng, L., Liu, L., Zhang, Y., Li, A., Wang, Z., Han, Y., Li, Y., Li, C., and Dong, H. (2021). Early relay intercropping of short-season cotton increases lint yield and earliness by improving the yield components and boll distribution under wheat-cotton double cropping. Agriculture, 11(12): 1294. https://doi.org/10.3390/agriculture11121294.
41. Wang, H., Siddiqui, M. Q., and Memon, H. (2020). Physical structure, properties and quality of cotton. In Cotton science and processing technology: Gene, ginning,

garment and green recycling, 79-97. https://doi.org/10.1007/978-981-15-9169-3_5.

42. Wang, X., Yang, J., Liu, H., Qu, X., and Xu, W. (2025). Influence of Long-Term Fertilization on Carbon, Nitrogen, and Phosphorus Allocation and Homeostasis in Cotton Under the Regulation of Phosphorus Availability. Agronomy, 15(12): 2886. https://doi.org/10.3390/agronomy15122886.
43. Wu, B., Zuo, W., Yang, P., and Zhang, W. (2023). Optimal water and nitrogen management increases cotton yield through improving leaf number and canopy light environment. Field Crops Research, 290: 108745. https://doi.org/10.1016/j.fcr.2022.108745.
44. Wu, J., Yang, X., and Zhu, Y. (2025). Climate-Smart Cotton Farming: Adapting Field Practices to Drought and Heat Stress. Field Crop, 8(5): 213-221. https://doi.org/10.5376/fc.2025.08.0021.
45. Yang, R., Su, Y., and Yang, Q. (2015). Crop Yields and Soil Nutrients in Response to Long-Term Fertilization in a Desert Oasis. Agronomy Journal, 107(1): 83-92. https://doi.org/10.2134/agronj14.0002.
46. Zahoor, R., Zhao, W., Abid, M., Dong, H., and Zhou, Z. (2017). Title: Potassium application regulates nitrogen metabolism and osmotic adjustment in cotton (*Gossypium hirsutum* L.) functional leaf under drought stress. Journal of Plant Physiology, 215: 30-38. https://doi.org/10.1016/j.jplph.2017.05.001
47. Zulfiquar, S., Yasin, M. A., Bakhsh, K., Ali, R., Samiullah, and Munir, S. (2019). Environmental and economic impacts of better cotton: a panel data analysis. Environmental Science and Pollution Research, 26: 18113-18123. https://doi.org/10.1007/s11356-019-05109-x.