Cotton Productivity and Fiber Quality Improvement by Nano Chitosan-NPK Fertilizer Integrated with Plant Growth Promoting Rhizobacteria Application in North Delta of Egypt

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ABSTRACT

It is vital to limit the loss of mineral NPK fertilizers during crops fertilization, especially in adverse soil conditions that reduce its availability to plants uptake and increase environmental pollution impact. This study aimed to reduce the soil application of the traditional NPK (T-NPK) fertilizers through partially adding foliar nano chitosan-NPK (NCS-NPK) with plant growth promoting rhizobacteria (PGPR) to boost cotton (*Gossypium Barbadense* L.) productivity and fiber quality. During the growing seasons of 2021 and 2022, field experiments were performed at the Sakha Agricultural Research Station, Kafr El-Sheikh, Egypt. A split-plot with four replicates based on a Randomized Complete Block design was used. Egyptian cotton cultivars Giza 97, 96 and promising hybrid G93xG71 were assigned to main plots, and seven foliar NCS-NPK and PGPR treatments were distributed in subplots.

Results showed superiority of Giza 97 cultivar in boll weight (3.38 g), seed cotton yield fed^{-1} (11.13 ken), maturity ratio (0.94) and fiber elongation (7.85%), while Giza 96 cultivar in uniformity index (86.62%) and fiber strength (46.57g/tex) and promising hybrid G93xG71 in plant height (146.7cm), sympodial branches plant^{-1} (15.26), seed index(10.84 g), lint% (36.08%), upper half mean (UHM) (35.48 mm), fiber fineness (3.17), and fiber brightness (reflectance degree Rd %, (76.40%). Foliar combined NCS-NPK with PGPR under 50% T-NPK gave the highest values of the most studied treats. There is evidence that the combined application of NCS-NPK with PGPR can reduce the application of T-NPK fertilizers, which sequentially reduce environmental pollution and enhance cotton production and fiber quality.

Kew words: Nano chitosan, NPK, cotton fiber, *Gossypium Barbadense* L., PGPR, nanoparticles fertilizer

INTRODUCTION

The ultimate goal of attaining sustainable agricultural output at low cost with great economic and environmental benefits is to reduce the usage of agrochemicals, particularly nitrogen, phosphorus, and potassium. Approximately 40-70% N, 80-90% P, and 50–70% K in soil applied with traditional fertilizers are lost to the environment and cannot be taken up by plants, resulting in not only significant economic and resource losses but also very serious environmental pollution (Trenkel, 1997; Ombódi and Saigusa, 2000). In recent years, the development of nanoparticle technologies in chemical fertilizers enhanced nutrient uptake, while decreasing the risk of adverse environmental effects (Sohair *et al*., 2018). Furthermore, enhance plant productivity and quality of several crops (El-saadony *et al*., 2021; El-Motaium *et al*., 2022; Rabeh & Elsokkary 2022; El-Kallawy *et al*., 2023 and Rabeh *et al*., 2023).

Chitin, which can be found in crustaceans, insects, fungi, and other living things, can be deacetylated to produce chitosan (Boonsongrit *et al*., 2006). Chitosan is a natural cationic polysaccharide containing D-glucosamine and N-acetyl-D-glucosamine and it is biodegradable, biocompatible polymer regarded as safe for human dietary use (Malerba and Cerana, 2016). In agriculture sector, since nano chitosan (NCS) has low toxicity, it can be used for the controlled release of fertilizers and pesticides (Kong *et al*., 2010; Campos *et al*., 2015; Kashyap *et al*., 2015 and Hernández-Téllez *et al*., 2017). Chitosan-NPK plays an essential function in boosting plant development and helping to reduce the environmental impact of intensive chemical fertilizers use. It caused significant increase in wheat yield and *Capsicum annuum* (Abdel-Aziz *et al*., 2016, 2018 and 2021), and significant increase of cotton yield and fiber quality (Khater *et al*., 2022 and Zakzok *et al*., 2022). NCS-NPK application significantly increased growth and yield parameters, photosynthetic pigments and chemical constituents of potato tuber yield (Elshamy *et al*., 2019).

Plant growth-promoting rhizobacteria (PGPR) are necessary to improve agricultural crop productivity by working as biofertilizers, phytostimulators, and biocontrol substances with the goal to sustain agro-ecosystems (Wu *et al*., 2005). Plant development is often aided both directly and indirectly by PGPR. Direct as include facilitating resource acquisition (NPK and other nutrients) and altering plant hormone levels (Vikram *et al*., 2007). Indirect as include the inhibition of pathogens by the production of biocontrol agents such as cyanide, siderophore (Suresh *et al*., 2010),

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phosphate solubilizing enzymes, antimicrobials, and antifungal activity (Glick, 1995). In agriculture, PGPR can be a great tool to help mitigate the negative effects of abiotic stress, such as drought and excessive salinity, by taking the place of costly inorganic fertilisers that are harmful for the environment (Vocciante *et al*., 2022). According to Patel and Minocheherhomji (2020), PGPR help cotton seeds germinate, improve crop productivity, and serve as an alternative to chemical fertilizers.

Therefore, the purpose of this research was to investigate the effects of foliar nano-chitosan-NPK and plant growth-promoting rhizobacteria (PGPR) on cotton productivity and fiber quality.

MATERIALS AND METHODS

field experiments were conducted at Sakha Agricultural Research Station, Kafr El-Sheikh Governorate, Egypt (latitude: 31º 30' 85" N, longitude: 31º 30' 84") during 2021 and 2022, to evaluate foliar of nano chitosan-NPK (NCS-NPK) and plant growth-promoting rhizobacteria (PGPR) under various rates of T-NPK soil application on the productivity and fiber quality of Egyptian cotton (*Gossypium Barbadense* L.). A split plot with four replicates that based on a Randomized Complete Block Design (RCBD) was set up. In the main plots, cotton cultivars (Giza 97 long staple, Giza 96 extra-long staple, and promising cotton hybrid cross Giza93 extra-long staple x Giza71 extra fine) were distributed, and seven treatments (Table 1) arranged in sub-plots. The plot size was 12.96 m^2 (six ridges, 3.6 m long and 0.6 m apart). The recommended fertilization dose (RFD) soil applied per feddan (feddan (Fed.) = 4200 m^2) was 62 kg N (as ammonium nitrate, 33.5% N), 22.5 kg P_2O_5 (as single superphosphate, 15.5% P_2O_5), and 50 kg K_2O (as potassium sulphate, 48% K_2O) as a control. Phosphorus fertilizer was applied during seed bed preparation and before sowing. Soil application of traditional N, K fertilizers were divided into four splits (while foliar solution of NCS-NPK and PGPR repeated four times in the same concentration) and were added before the first, the second, the third and the fourth irrigation, respectively.

The rate of foliar solution was 400 litters of NCS-NPK included 5 litter PGPR per feddan. NCS-NPK (310 ppm N, 60 ppm P and 120 ppm K) fertilizers were prepared at laser Institute, Cairo University according to procedure of Corradini *et al*. (2010) with a few adjustments. A commercial multi strains of the bio-fertilizer plant growth promoting rhizobacteria (PGPR) of *Pseudomonas putida*, *Bacillus megatherium*, *Azospirillum brasilense* produced by culture collection in Agricultural Microbiology Department, Agricultural Research Center Giza, Egypt. The concentration was adjusted to 10^8 (cfu/ml) for all treatments and sprayed in the recommended times of cotton fertilization. In the seasons of 2021 and 2022, the cotton seeds were planted on May 8 and 10, respectively.

Soil sampling and analysis

Composite soil samples were collected before conducting the experiments and processed in the lab to determine some selected physical and chemical parameters. The particle size distribution was determined according to Black (1965), soil pH in 1: 2.5 soil-water suspensions and electrical conductivity (EC) in soil paste extract and available NPK in soil were measured according to standard methods by Jackson (1973). Total $CaCO_3$ and organic matter (OM) were determined according to procedure of Keeney and Nelson (1982). Obtained analysis data of soil properties are listed in (Table 2).

Table 1. The Applied treatments during the experiments and their abbreviations

Fertilizer treatments	Description*	Abbreviation
T1	Traditional NPK 100% RFD (control) soil application	control
T2	Traditional NPK 25% from RFD + foliar PGPR	T-NPK25%+PGPR
T3	Traditional NPK 25% from RFD + foliar Nano chitosan-NPK	T-NPK25%+NCS-NPK
T4	Traditional NPK 25% from RFD + foliar PGPR + Nano chitosan-NPK	T-NPK25%+PGPR+NCS-NPK
T5	Traditional NPK 50% from RFD + foliar PGPR	T-NPK50%+PGPR
T6	Traditional NPK 50% from RFD + foliar Nano chitosan-NPK	T-NPK50%+ NCS-NPK
T7	Traditional NPK 50% from RFD + foliar PGPR + Nano chitosan-NPK	T-NPK50%+PGPR+NCS-NPK

*RFD= Recommended fertilizer dose

Table 2. The experiment soil (0-30 cm depth) properties during cotton growing seasons 2021 and 2022

Soil characteristics		Seasons	
		2021	2022
Physical properties			
Sand (%)		20.9	16.5
Silt (%)		33.5	37.1
Clay (%)		45.6	46.4
	Texture	clay	clay
Chemical properties			
pH		8.10	7.90
EC (dSm^{-1})		3.44	3.31
Total $CaCO_3$ (%)		2.68	2.62
Organic matter (%)		1.67	1.72
Plant available nutrients ($mg\ kg^{-1}$)			
Nitrogen		20.50	19.2
Phosphorus		6.85	7.13
Potassium		125.6	138.2

Collection of experimental data

During the harvest dates (25th of September and 27th September in 2021 and 2022, respectively), ten plants were randomly collected from the inner ridges to determine plant height (cm), fruiting branches plant^{-1}, boll weight (g), lint percentage (%), seed index (as 100 seeds weight in g) and seed cotton yield plant^{-1} (g). The two inner ridges plants were harvested to estimate seed cotton yield feddan^{-1} (Ken = 157.5 kg).

Cotton fiber properties

Fiber upper half mean (UHM) (mm), fiber uniformity index (UI), micronaire value, fiber maturity ratio, fiber strength (g/tex), the percentage of fiber elongation, fiber reflectance degree (brightness) (Rd %) , and fiber yellowness degree (+b) were measured under standard conditions of relative humidity (65%±2) and room temperature (21C°±2) in the laboratory of the Cotton Research Institute, Giza, Egypt according to the American Society for Testing and Materials (A.S.T.M., 2012).

Statistical analysis

The gathered data were statistically evaluated in accordance with the procedure described by Snedecor and Cochron (1981). Examining differences between means and determining the significance variations among variables were done using the Least Significant Differences test (LSD) at 5% level $P \leq 0.05$. Finally, all statistical analyses were carried out using the "MSTAT-C" computer software package (Freed *et al*., 1989).

RESULTS AND DISCUSSIONS

Vegetative growth parameter

Plant height

Plant height was significantly affected ($p \leq 0.05$) by cotton cultivars (A), foliar NCS-NPK, PGPR treatments (B), and their interactions under various rates of T-NPK soil application in both seasons (Fig. 1 and table 3). As an average, hybrid G93X G71 achieved a higher value (146.7 cm), which reflects increases of 2.94% and 5.02% in comparison to Giza 97 (142.5 cm) and Giza 96 (139.6 cm), respectively. Generally foliar application of NCS-NPK and PGPR directly affects cotton plant height, whereas the highest increase (5.99%) resulted from foliar combined NCS-NPK with PGPR application at 50% T-NPK soil application, followed by individual NCS-NPK (2.60%) at 50% T-NPK soil application, relative to control. This might be the result of a notable increase in the length of each main stem internode. These results are congruent with those obtained by Monir *et al*. (2012), Shuaib *et al*. (2015), Sohair *et al*. (2018) and Rabeh *et al*. (2021) who reported that the application of either individual NPK or combined with PGPR boosted plant height. The interaction between cultivars (A) and treatments (B) had a significant effect on plant height (Table 3). Hybrid G93X G71 recorded the highest plant height (158.2 cm) with the combination of NCS-NPK and PGPR treatment at 50% T-NPK, while Giza 97 cultivar recorded the lowest plant height (127.2 cm) with PGPR at 25% T-NPK. This might be related to the nanofertilizers can change biological processes that affect a plant's growth and development (Meena *et al*., 2017 and Rabeh *et al*., 2023).

Yield components and productivity

Sympodial branches per plant and boll weight

Significant differences in the number of sympodial branches per plant and boll weight were found across the three cotton cultivars in both seasons (Fig. 1). On average for both seasons, sympodial branches per plant in hybrid G93xG71 (15.26) was higher than Giza 97 (13.90) and Giza 96 (13.93), this increase represented 9.76 and 9.57%, respectively. A significant positive correlation (r = 0.837**, P < 0.01) between plant height and sympodial branches per plant was found (Fig. 1). While, boll weight in Giza 97 cultivar (3.38 g) was higher than Giza 96 (2.93 g) and hybrid G93X G71 (3.07 g), this increase represented 15.24 and 10.14%, respectively. Foliar application of NCS-NPK or PGPR affected sympodial branches per plant and boll weight (Fig. 1). Whereas, combination of NCS-NPK with PGPR resulted the highest percentage increase by 17.44 and 12.53% followed by individual NCS-NPK by 4.63 and 4.58% for sympodial branches per plant and boll weight, respectively, at 50% T-NPK soil application. The interaction between cultivars (A) and treatments (B) had a significant effect on sympodial branches per plant and boll weight (Table 3).

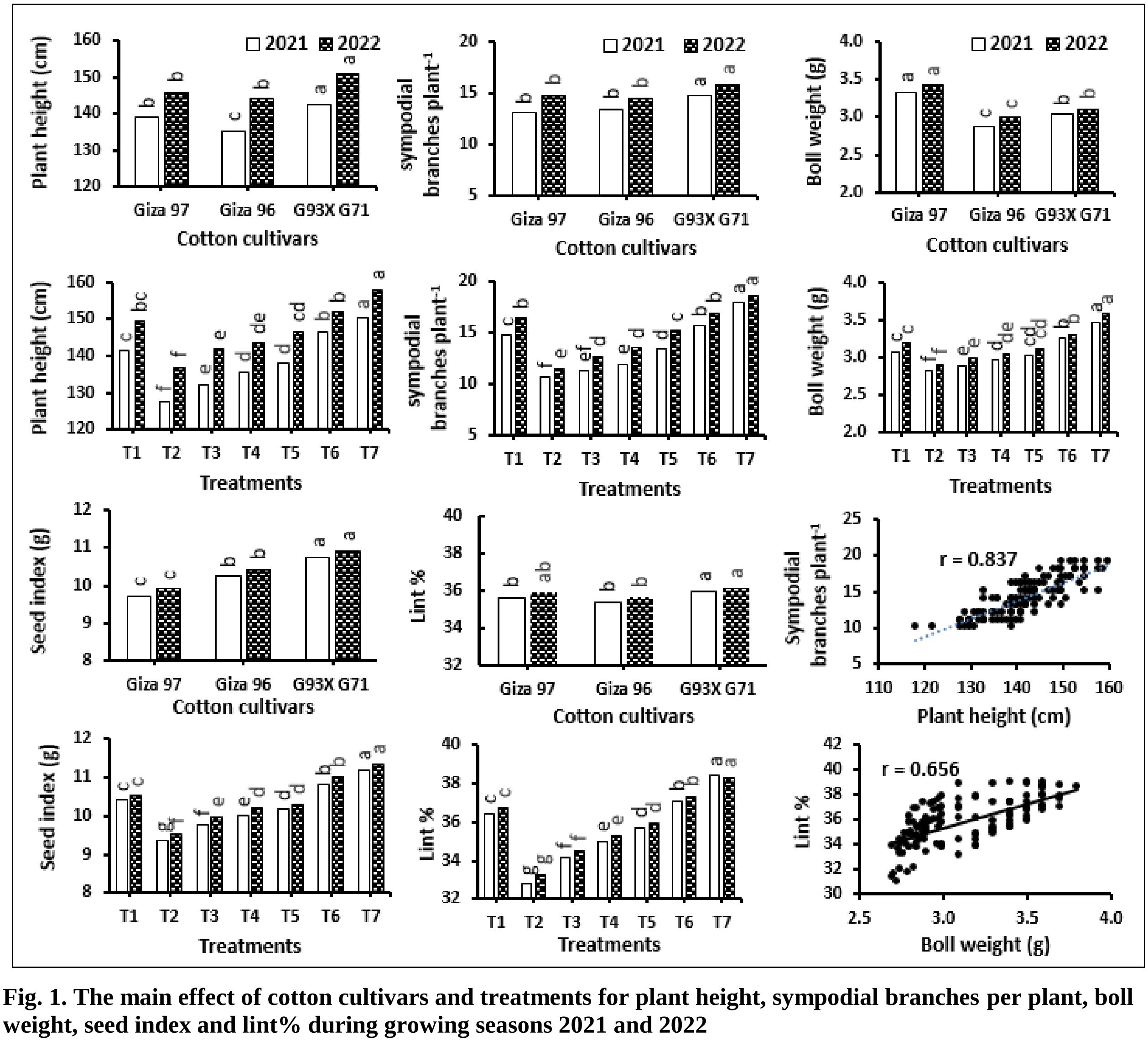

Fig. 1. The main effect of cotton cultivars and treatments for plant height, sympodial branches per plant, boll weight, seed index and lint% during growing seasons 2021 and 2022

Means sharing different letters differ significantly from each other at p (≤ 0.05).
T1=T-NPK100% (control); T2=T-NPK25%+PGPR; T3=T-NPK25%+NCS-NPK; T4=T-NPK25%+PGPR+NCS-NPK; T5=TNPK50%+PGPR; T6=T-NPK50%+NCS-NPK; T7=T-NPK50%RFD+PGPR+NCS-NPK

Table 3. The interaction between cultivars and treatments (AXB) effect on plant height, sympodial branches per plant, boll weight, seed index and lint% during 2021 (1st) and 2022 (2nd) seasons

Cultivars (A)	Treatments (B)	Plant height (cm)		Sympodial branches plant^{-1}		Boll weight (g)		Seed index (g)		Lint cotton (%)	
		Growing seasons									
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Giza 97	T1	145.0bc	151.3d	13.67de	15.67de	3.43b	3.53ab	9.73ij	9.87kl	36.40de	36.80e
	T2	122.7j	131.7g	10.33j	11.67hi	3.00ef	3.13ef	9.27l	9.37no	33.40k	33.83j
	T3	130.7ghi	142.0ef	10.67ij	12.33h	3.10e	3.27de	9.43kl	9.60mn	33.14j	34.49i
	T4	134.7efgh	143.0ef	11.67ghi	14.00fg	3.27d	3.37cd	9.37kl	9.57mn	35.03hi	35.40gh
	T5	138.3def	144.7e	12.33fgh	15.00def	3.37cd	3.47bc	9.50k	9.70lm	35.73fg	36.00fg
	T6	149.0ab	152.3cd	14.67cd	16.33cd	3.53ab	3.60ab	10.33fg	10.57gh	36.87cd	36.93de
	T7	152.0a	157.3abc	17.67ab	18.67ab	3.60a	3.60ab	10.47ef	10.70efg	37.60b	37.90bc
Giza 96	T1	136.0efg	144.3ef	15.00c	16.33cd	2.85ghij	2.95ghi	10.60de	10.77defg	36.37de	36.87de
	T2	129.0i	138.7f	10.33j	10.67i	2.71k	2.79j	8.93m	9.17o	31.33l	31.93k
	T3	130.3hi	140.0ef	10.67ij	11.67hi	2.74jk	2.86ij	9.57jk	9.77lm	33.70k	34.03j
	T4	133.3fghi	142.7ef	11.33hij	12.67gh	2.77ijk	2.89ij	9.97h	10.20ij	34.70ij	34.93hi
	T5	133.3fghi	143.0ef	13.33ef	15.33def	2.81hijk	2.87ij	10.20g	10.37hi	35.47fgh	35.83fg
	T6	140.0cde	144.7e	15.33c	16.33cd	2.94fgh	3.07fg	10.87c	11.07c	37.23bc	37.47cd
	T7	145.3bc	154.3bcd	17.67ab	18.33ab	3.27d	3.50bc	11.57a	11.67a	38.93a	38.30ab
G93xG71	T1	143.3cd	153.0bcd	15.67c	17.33bc	2.97efg	3.10f	10.87c	10.97cd	36.57d	36.70e
	T2	131.7ghi	140.3ef	11.33hij	12.33h	2.75ijk	2.82ij	9.87hi	10.10jk	33.60k	34.07j
	T3	136.0efg	143.7ef	12.67efg	14.33ef	2.85ghij	2.88ij	10.27fg	10.60fgh	34.40j	34.70i
	T4	139.3de	145.0e	13.00ef	14.00fg	2.87fghi	2.92hij	10.67cde	10.90cde	35.27ghi	35.57fg
	T5	142.3cd	152.7cd	14.67cd	15.33def	2.91fgh	3.03fgh	10.80cd	10.83cdef	35.93ef	36.03f
	T6	151.0a	158.7ab	17.00b	18.33ab	3.30d	3.27de	11.20b	11.40b	37.20bc	37.60c
	T7	153.7a	162.7a	18.67a	19.00a	3.57a	3.67a	11.57a	11.67a	38.77a	38.73a

Means sharing different letters differ significantly from each other at p ($\leq$ 0.05).
T1=T-NPK100% (control); T2=T-NPK25%+PGPR; T3=T-NPK25%+NCS-NPK; T4=T-NPK25%+PGPR+NCS-NPK; T5=TNPK50%+PGPR; T6=T-NPK50%+NCS-NPK; T7=T-NPK50%RFD+PGPR+NCS-NPK

Combination of NCS-NPK with PGPR treatment at 50% T-NPK recorded a higher value of sympodial branches per plant (18.83) for hybrid G93X G71 and boll weight (3.60 g) for Giza 97. While, the minimum sympodial branches per plant (10.50) and boll weight (2.75 g) recorded for Giza 96 at PGPR under 25% T-NPK. These results agree with those obtained by Zakzok *et al*. (2022) for NCS-NPK -fertilization that significantly improved boll weight, Sohair *et al*. (2018) for the application of nano NPK which boosted sympodial branches per plant and boll weight also, Zewail and Ahmed (2015) for the application of PGPR which boosted sympodial branches per plant.

Seed index and lint%

According to data in Fig. (1), seed index and lint% significantly varied ($P \leq 0.05$) for cotton cultivars in both seasons. Whereas the G93X G71 hybrid had the highest values of seed index and lint% (10.84 g and 36.08%), as opposed to Giza 97 (9.82 g and 35.78%) and Giza 96 (10.34 g and 35.51%), respectively. A significant positive correlation ($r = 0.656^{**}$, $P < 0.01$) between boll weight and lint% was found (Fig. 1). Results showed that seed index and lint% are directly influenced by foliar treatments of NCS-NPK and PGPR (Fig. 1), for seed index and lint%, respectively, at 50% T-NPK soil treatment, the combination of NCS-NPK and PGPR showed the highest improvements (7.70 and 4.79%), followed by the individual NCS-NPK (4.19 and 1.64%) compared with the control treatment. The interaction between the two factors under study significantly impacted the seed index and lint% (Table 3). The hybrid G93X G71 with the combined NCS-NPK and PGPR at 50% T-NPK attained the highest values of seed index (11.62 g) and lint% (38.75%), while Giza 96 cultivar with PGPR at 25% T-NPK recorded the lowest values of seed index (9.05 g) and lint% (31.63%).

Seed cotton yield

Results in Fig. (2) and Table (4) demonstrate that cotton cultivars, individual and combined of NCS-NPK, PGPR foliar application under various levels of T-NPK soil applications and their interactions significantly influenced seed cotton yield per plant and per feddan. The hybrid G93X G71 gave a considerable increase (4.85%) in seed cotton yield per plant compared to the Giza 96 cultivar and did not record a significant increase with Giza 97 cultivar on average in both seasons. However, Giza 97 cultivar achieved a significant increase of seed cotton yield per feddan (11.13 ken) higher than the hybrid G93XG71 (10.66 ken) and Giza 96 cultivar (10.46 ken); this increase in yield represented 4.37 and 6.47%, respectively. Results showed that the previously studied characteristics had a positive effect on the seed cotton yield, Fig. 2 cleared that a substantial positive association between seed cotton yield per plant with sympodial branches per plant ($r = 0.830^{**}$, $p < 0.01$), lint percentage ($r = 0.784^{**}$, $p < 0.01$) and boll weight ($r = 0.608^{**}$, $p < 0.01$). These findings confirmed that each increase in sympodial branches produces more bolls and boll weight that directly contributes to increase cotton yield. Moreover seed cotton yield per feddan significantly positively correlated with yield per plant ($r = 0.922^{**}$, $p < 0.01$). Foliar combined of NCS-NPK and PGPR at 50% T-NPK soil treatment (Fig. 2) achieved the highest mean value in seed cotton yield per plant (80.13 g) and per feddan (12.75 Ken) representing 9.91 and 12.45%, followed by foliar individual of NCS-NPK at 50% T-NPK soil treatment in seed cotton yield per plant (74.82 g) and per feddan (11.79 Ken) representing 2.62 and 4.02%, respectively compared with the control. This indicated that by using individual or combined of NCS-NPK and PGPR foliar application resulted in a reduction of traditional NPK which could decrease the environment pollution hazard effect. Our results agree with Kanjana (2020), Rabeh & Elsokkary (2022) and Rabeh *et al*. (2023) who found that nanofertilizers enhanced seed cotton production. The ability of PGPR to convert insoluble phosphorus (P) to an available uptake by plant that helps to increase plant yields (Zaidi *et al*., 2009 and Pindi *et al*., 2014). The interaction between the two factors (AxB) significantly impacted the seed cotton yield per plant and per feddan (Table 4). The combined NCS-NPK and PGPR at 50% T-NPK attained the highest values of seed cotton yield per plant (88.50 g) and per feddan (14.00 ken) for Giza 97 cultivar.

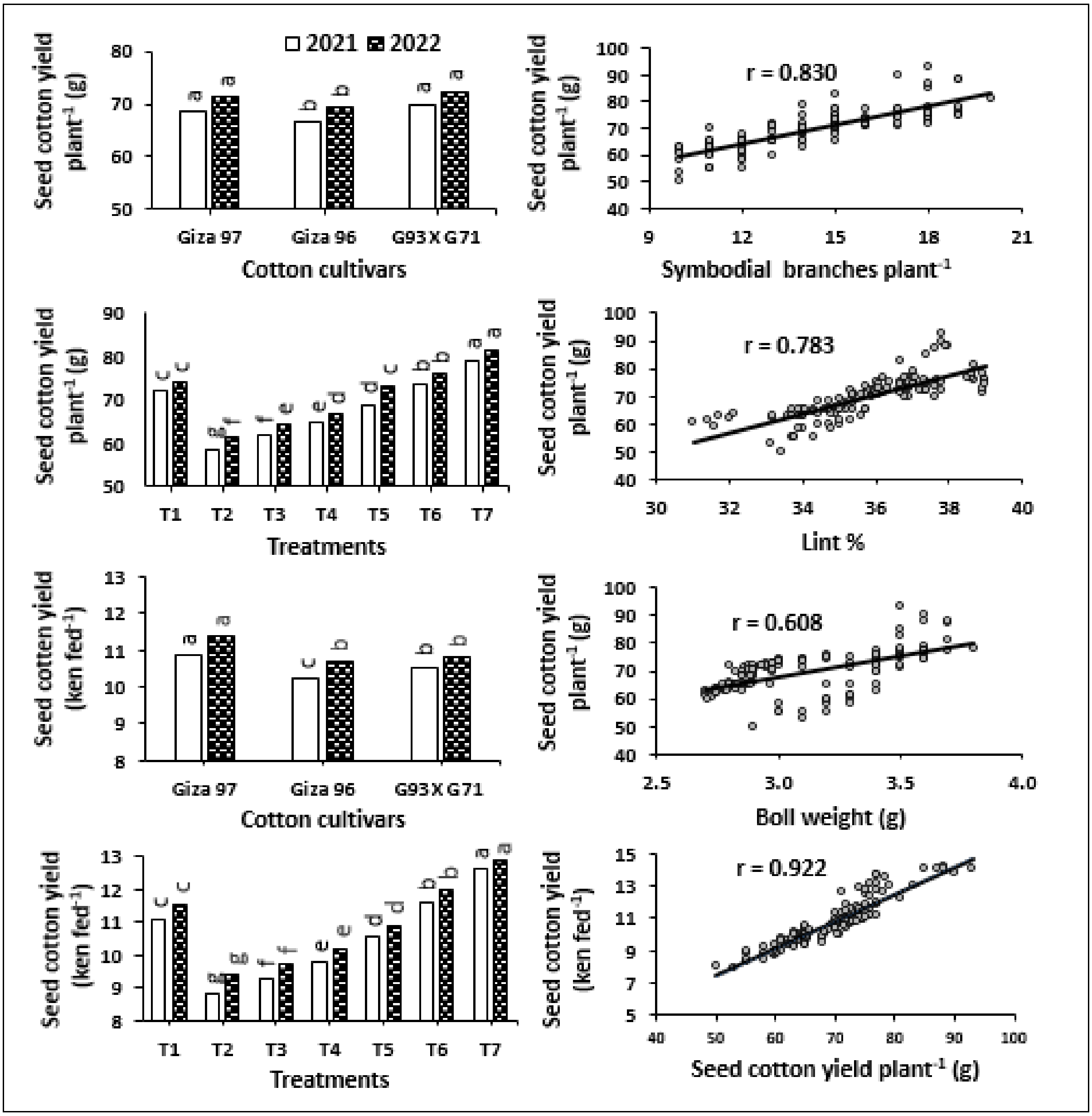

Fig. 2. The cotton cultivars and treatments main effect for seed cotton yield per plant, and per feddan during growing seasons 2021 and 2022

Means sharing different letters differ significantly from each other at p (≤ 0.05).
T1=T-NPK100% (control); T2=T-NPK25%+PGPR; T3=T-NPK25%+NCS-NPK; T4=T-NPK25%+PGPR+NCS-NPK; T5=TNPK50%+PGPR; T6=T-NPK50%+NCS-NPK; T7=T-NPK50%RFD+PGPR+NCS-NPK

Table 4. The interaction between cultivars and treatments (AXB) effect on studied seed cotton yield during 2021 (1st) and 2022 (2nd) seasons

Cultivars (A)	Treatments (B)	Seed cotton yield plant^{-1} (g)		Seed cotton yield fed^{-1} (Ken.)	
		Growing seasons			
		1st	2nd	1st	2nd
Giza97	T1	72.67cd	75.33c	12.03c	12.83c
	T2	52.67k	56.00j	8.10m	8.93k
	T3	57.67j	59.67i	8.50m	9.27j
	T4	62.00hi	64.33h	9.50jk	10.20g
	T5	70.33def	74.67cd	10.97e	11.17e
	T6	77.00b	79.00b	13.03b	13.23b
	T7	87.33a	89.67a	13.93a	14.07a
Giza96	T1	70.00ef	72.33def	10.60efg	10.90ef
	T2	60.23i	62.93h	8.93l	9.60i
	T3	62.63hi	64.23h	9.57ijk	9.97gh
	T4	63.60gh	65.27h	9.97hi	10.27g
	T5	65.13g	71.33ef	10.20gh	10.73f
	T6	70.97cde	73.17cde	10.87ef	11.53d
	T7	73.10c	75.33c	11.50d	11.80d
G93 X G71	T1	72.80c	74.33cd	10.73ef	10.93ef
	T2	63.10gh	65.23h	9.40k	9.70hi
	T3	65.40g	68.40g	9.80hijk	9.97gh
	T4	68.03f	70.43fg	9.90hij	10.13g
	T5	71.20cde	73.27cde	10.53fg	10.83f
	T6	73.23c	75.57c	10.93ef	11.17e
	T7	76.23b	79.13b	12.43c	12.77c

Means sharing different letters differ significantly from each other at p ($\leq$ 0.05).
T1=T-NPK100% (control); T2=T-NPK25%+PGPR; T3=T-NPK25%+NCS-NPK; T4=T-NPK25%+PGPR+NCS-NPK; T5=TNPK50%+PGPR; T6=T-NPK50%+NCS-NPK; T7=T-NPK50%RFD+PGPR+NCS-NPK

Fiber characteristics

In both seasons, the upper half mean UHM (mm), uniformity index (UI), micronaire reading, strength (g/tex), elongation percentage, brightness (RD%) and yellowness degree (+b) of cotton fibers were significantly influenced by cotton cultivars, treatments, and their interactions, as shown in Figure (3) and Table (5). The hybrid G93X G71 had the highest UHM (35.48 mm), brightness (RD %) (76.40%) and the finest fibers (Micronaire reading 3.17), while Giza97 had the highest fiber elongation (7.85%), maturity ratio (0.94) and yellowness degree (+b) (10.21), and Giza 96 had the highest values for fiber strength (46.57 g/tex) and UI (86.62%). These findings agreed with Rabeh *et al*. (2021) and Zakzok *et al*. (2022) who revealed that the predominant influence on various fiber qualities of cotton cultivars related to their intrinsic genetic traits.

On average at 50% T-NPK soil application, the combined NCS-NPK with PGPR foliar application resulted in the highest mean values, followed by individual NCS-NPK of studied fiber properties as follow; 36.09 and 35.48 mm for fiber length (UHM), 87.93 and 86.77% for UI, 4.16 and 3.97 for micronaire reading, 48.04 and 46.97 g/tex for strength , 7.79 and 7.42% for elongation percentage, 74.83 and 73.65% for RD%, and the lowest values of yellowness degree (+b) (8.77 and 9.05), respectively. Zakzok *et al*. (2022) and Rabeh *et al*. (2023) found that nano-fertilizers enhanced photosynthesis processes, reproductive stage, and physiological activities which contributed in improving the properties of cotton fibers.

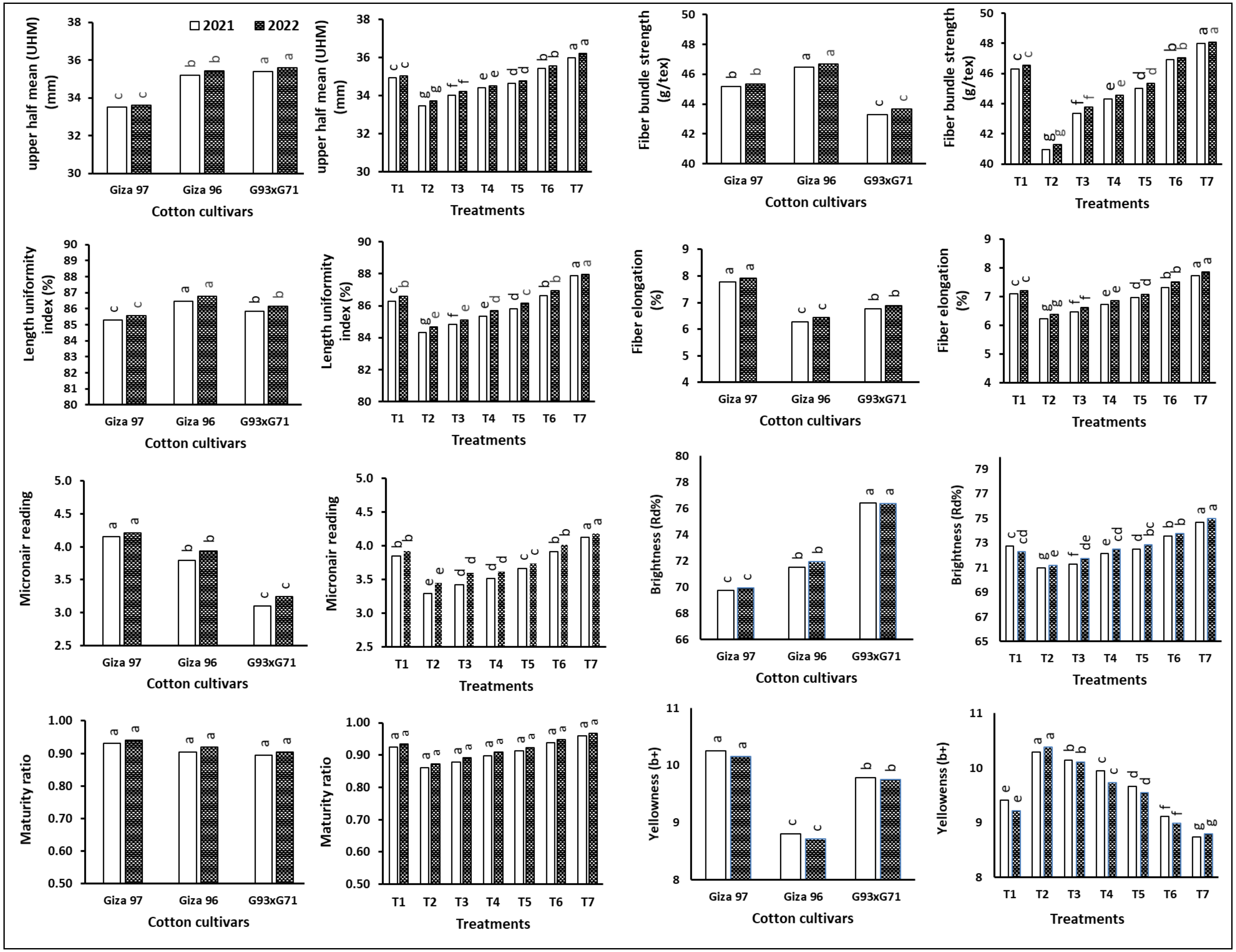

Fig. 3. The main effect of cotton cultivars and treatments for cotton fiber properties during growing seasons 2021 and 2022

Means sharing different letters differ significantly from each other at p (≤ 0.05).

T1=T-NPK100% (control); T2=T-NPK25%+PGPR; T3=T-NPK25%+NCS-NPK; T4=T-NPK25%+PGPR+NCS-NPK; T5=TNPK50%+PGPR; T6=T-NPK50%+NCS-NPK; T7=T-NPK50%RFD+PGPR+NCS-NPK

In terms of the AxB interaction impact, results in Table (5) show that, as an average, combined NCS-NPK with PGPR foliar at 50% T-NPK soil treatment produced the longest fibers (36.79 mm), UI (88.6%), and the highest fiber strength (48.75 g/tex) from Giza 96 cultivar, While the best RD% (77.73%) from hybrid G93X G71, and the highest fiber elongation (8.70%) and maturity ratio (0.97) from Giza 97 cotton cultivar. On the other hand, individual foliar PGPR at 25% T-NPK soil treatment produced the lowest fibers length (32.05 mm), UI (83.99%) and RD% (67.88%) for Giza 97 cultivar, while the lowest fiber strength (38.5 g/tex) for hybrid G93X G71, and fiber elongation (5.45%) for Giza 96 cultivar. These outcomes agree with Gebaly (2011) and Zakzok *et al*. (2022).

Table 5. The interaction between cultivars and treatments (AXB) effect on studied cotton fiber properties during 2021 (1st) and 2022 (2nd) seasons

Cultivars (A)	Treatments (B)	Upper half mean length (UHM) (mm)		Uniformity index (UI) (%)		Micronaire reading		Maturity ratio	
		Growing seasons							
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Giza 97	T1	33.73i	33.80h	85.57a	85.87a	4.47b	4.43a	0.94a	0.96a
	T2	31.97l	32.13k	83.90a	84.07a	3.63f	3.80ef	0.89a	0.90a
	T3	32.53k	32.97j	85.17a	84.70a	3.87de	3.97cde	0.91a	0.92a
	T4	33.00k	33.03j	84.83a	85.10a	3.93cde	4.03bcd	0.92a	0.93a
	T5	33.33j	33.40i	85.03a	85.37a	4.07c	4.13bc	0.91a	0.92a
	T6	34.67gh	34.80f	85.97a	86.27a	4.47b	4.53a	0.95a	0.96a
	T7	34.97fg	35.00ef	87.33a	87.57a	4.63a	4.60a	0.97a	0.97a
Giza 96	T1	35.37de	35.50d	87.03a	87.37a	4.00cd	4.17b	0.93a	0.94a
	T2	33.93i	34.30g	84.80a	85.27a	3.23ij	3.37gh	0.84a	0.86a
	T3	34.53h	34.83ef	85.17a	85.50a	3.43gh	3.63f	0.86a	0.88a
	T4	34.97fg	35.07e	85.90a	86.27a	3.57fg	3.70f	0.89a	0.91a
	T5	35.17ef	35.33d	86.47a	86.77a	3.83e	3.93de	0.91a	0.92a
	T6	35.70bc	35.90c	87.27a	87.70a	4.03c	4.20b	0.94a	0.96a
	T7	36.60a	36.97a	88.67a	88.53a	4.43b	4.57a	0.96a	0.98a
G93xG71	T1	35.67bcd	35.80c	86.23a	86.57a	3.07k	3.20hij	0.90a	0.91a
	T2	34.50h	34.77f	84.30a	84.73a	3.00k	3.20hij	0.85a	0.86a
	T3	34.67gh	34.87ef	84.90a	85.17a	2.97k	3.23ghij	0.86a	0.87a
	T4	35.23ef	35.43d	85.30a	85.70a	3.03k	3.13j	0.89a	0.89a
	T5	35.40cde	35.53d	85.93a	86.30a	3.10jk	3.17ij	0.90a	0.90a
	T6	35.87b	35.97c	86.60a	86.83a	3.23ij	3.33ghi	0.92a	0.93a
	T7	36.37a	36.63b	87.67a	87.80a	3.30hi	3.40g	0.95a	0.95a

Table 5. cont.

Cultivars (A)	Treatments (B)	Fiber strength (g/tex)		Fiber elongation (%)		Brightness (RD%)		Yellowness degree (+b)	
		Growing seasons							
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Giza 97	T1	46.20cdef	46.43def	8.03c	8.13c	70.17j	70.37fgh	9.87f	9.70de
	T2	40.07k	40.43k	6.87hi	7.00gh	67.83n	67.93i	11.00a	10.93a
	T3	44.63h	44.80h	7.07fg	7.30ef	68.50m	68.70hi	10.97ab	10.97a
	T4	45.10gh	45.33gh	7.53d	7.67d	69.40l	69.60ghi	10.83b	10.60b
	T5	45.87efg	45.90fg	7.97c	8.13c	72.49d	72.88bc	9.67d	9.54d
	T6	46.70cd	46.80cd	8.30b	8.43b	70.77i	70.97fg	9.83f	9.63de
	T7	47.63b	47.80b	8.67a	8.73a	71.70g	71.87ef	9.03jk	8.90hi
Giza 96	T1	46.97bc	47.23bc	6.47lm	6.63j	71.23h	71.87ef	8.73m	8.43kl
	T2	44.50h	44.80h	5.37q	5.53n	69.70kl	70.30fgh	9.37h	9.57def
	T3	45.10gh	45.33gh	5.77p	5.90m	70.03jk	70.47fgh	9.20i	9.13gh
	T4	46.00def	46.23def	6.03o	6.17l	70.77i	71.17fg	8.97kl	8.77ij
	T5	46.43cdef	46.70cd	6.27n	6.37k	71.07hi	71.53ef	8.87lm	8.60jk
	T6	47.50b	47.67b	6.73ijk	6.97gh	72.93f	73.13de	8.37n	8.30l
	T7	48.70a	48.80a	7.30e	7.47e	74.73e	75.20bc	8.13o	8.20l
G93xG71	T1	45.70fg	45.93efg	6.80hij	6.90hi	76.90b	74.60cd	9.63g	9.53ef
	T2	38.33l	38.67l	6.43mn	6.63j	75.47d	75.33bc	10.50c	10.63b
	T3	40.40k	41.17k	6.60klm	6.70j	75.27d	76.10abc	10.27d	10.23c
	T4	41.80j	42.17j	6.63jkl	6.73ij	76.20c	76.70ab	10.03e	9.83d
	T5	42.80i	43.47i	6.67jk	6.77ij	76.50bc	76.97ab	9.87f	9.67de
	T6	46.50cde	46.67cde	6.93gh	7.13fg	76.93b	77.17a	9.13ij	9.03ghi
	T7	47.63b	47.67b	7.23ef	7.37e	77.63a	77.83a	9.03jk	9.30fg

Means sharing different letters differ significantly from each other at p (≤ 0.05).
T1=T-NPK100% (control); T2=T-NPK25%+PGPR; T3=T-NPK25%+NCS-NPK; T4=T-NPK25%+PGPR+NCS-NPK; T5=TNPK50%+PGPR; T6=T-NPK50%+NCS-NPK; T7=T-NPK50%RFD+PGPR+NCS-NPK

CONCLUTION

By using nano-chitosan-NPK to increase cotton productivity and fiber quality, it is possible to reduce the amount of traditional NPK used in cotton fertilization and achieve sustainability in agriculture. This opens up new perspectives on agricultural practices. By applying a foliar solution containing nano chitosan-NPK + PGPR under traditional NPK fertilizer to the soil at a rate of 50% of the recommended dose, high cotton yields and fiber quality attributes were achieved. There is a need for more research on nano-fertilizers especially, of economy benefits and various pathways of metabolism in cotton plant.

Conflict of interest

The authors declare that they do not have any conflict of interest

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الملخص العربي

تحسين إنتاجية وجودة ألياف القطن باضافة سماد النانو كيتوزان للنتروجين والفوسفور والبوتاسيوم بالتكامل مع المحفزات البكتيرية المعززة لنمو النبات في شمال الدلتا – مصر

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نظراً للضرورة الملحة للحد من فقدان الأسمدة المعدنية للنتروجين والفوسفور والبوتاسيوم خلال عملية تسميد المحاصيل وخاصة في الظروف المعاكسة فى التربة والتي تحولها إلى صورغير ميسرة لامتصاص النبات وبالتبعية فانها تشكل مصدراً لتلوث البيئة. هدفت هذه الدراسة إلى تقليل الإضافة الأرضية للأسمدة المعدنية من خلال الاحلال الجزئى بأسمدة نانوشيتوزان لتلك العناصرالسمادية مع المحفزات البكتيرية المعززة لنمو النبات لتحسن إنتاجية وجودة ألياف القطن. خلال موسمى ٢٠٢١ و ٢٠٢٢ أجريت تجارب حقلية بمحطة البحوث الزراعية – سخا – محافظة كفرالشيخ – مصر. تم استخدام القطع المنشقة مرة واحدة وفق تصميم القطاعات الكاملة العشوائية فى اربع مكررات، وزعت أصناف القطن المصرى جيزة ٩٧، جيزة ٩٦، والهجين المبشر G93xG71 فى القطع الرئيسية، وسبع معاملات من نانوشيتوزان للنتروجين والفوسفور والبوتاسيوم مع المحفزات البكتيرية رشا في القطع الفرعية. أظهرت النتائج تفوق الصنف جيزة ٩٧ في وزن اللوزة (٣,٣٨ جم)، محصول القطن الزهر للفدان (١١,١٣ قنطار)، نسبة النضج (٠,٩٤) واستطالة الألياف (٧,٨٥٪)، بينما الصنف جيزة ٩٦ في معامل انتظام الألياف (٨٦,٦٢٪) ومتانة الألياف (٤٦,٥٧ جم / تكس) ، والهجين الواعد G93xG71 في ارتفاع النبات (١٤٦,٧ سم)، الأفرع الثمرية للنبات (١٥,٢٦)، دليل البذرة (١٠,٨٤ جم)، نسبة الألياف (٣٦,٠٨٪)، طول الألياف (٣٥,٤٨ ملم)، نعومة الألياف (٣,١٧)، درجة إنعكاس الألياف (76.40٪). وسجل الرش بأسمدة النانوشيتوزان مخلوطا مع المحفزات البكتيرية عند ٥٠٪ من الموصى به لأسمدة النتروجين والفوسفور والبوتاسيوم أعلى القيم فى معظم الصفات المدروسة. لذلك، دلت النتائج بوضوح على أن إضافة نانوشيتوزان للنتروجين والفوسفور والبوتاسيوم مع المحفزات البكتيرية مهم للغاية لتقليل إضافة الأسمدة التقليدية، والتي تقلل بالتتابع التلوث البيئي وتعزز إنتاج وجودة ألياف القطن.

كلمات افتتاحية: نانوشيتوزان، نتروجين، فوسفور، بوتاسيوم، ألياف القطن، القطن المصرى، محفزات النمو الحيوية، أسمدة النانو.