Influence of Integrated Nano-Calcium and K-Humate Foliar Spray on Growth, Yield and Fiber Quality of Cotton Grown in Alluvial Non-Saline Soil

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ABSTRACT

Calcium (Ca^{2+}) is one of the essential elements for plants and the changes in soil properties reduce its availability for plants as a result of forming insoluble compounds. The aim of this study was to evaluate the effect of foliar application of Nano-Ca (N-Ca) combined with potassium humate (K-H) on improving the cotton growth parameters, yield components and fiber quality. Two split-plot design field experiments (2019 and 2020) in a randomized complete block design arrangement with four replicates were laid out. Three cotton cultivars (Giza 92, 94 and 95) and six fertilizers treatments (control; traditional-CaO (T-Ca); Nano-CaO (N-Ca); K-H; T-Ca+K-H; and N-Ca+K-H) were applied. The foliar spray was performed four times (30 days after sowing, at squaring, beginning of flowering and 15 days later). Results indicated the superiority of Giza 95 was in the yield while Giza 92 and 94 cotton cultivars were in the quality of fiber.

Individual foliar applications of N-Ca and K-H had a significant increase in plant height, yield components (sympodial branches, total and open bolls, boll weight, seed index, lint% and seed cotton yield) and fiber quality (fiber length, uniformity index, fiber strength, fiber fineness and reflectance (Rd %)) and decrease yellowness (+b) compared with the control. Foliar N-Ca was more efficient as fertilizer than T-Ca. N-Ca combined with K-H achieved a higher increase of most previous traits than T-Ca with K-H. Application of N-Ca combined with K-H could be recommended to improve cotton production and fiber quality.

Key words: Nano calcium fertilizer; humic substances; potassium humate; foliar application; cotton yield; fiber quality.

INTRODUCTION

Cotton fiber is important in fabrics and many other industries around the world. There is an important role of convenient nutrition in cotton growth, yield and fiber quality. Calcium is an essential nutrient for plant growth (Marschner, 1995), it is functioning as a constituent of cell walls, enhancing cell division, protein synthesis, transporting nutrients into and within the plant, facilitating metabolic activities by neutralizing cell acids, and allowing more erect stems (White and Broadley, 2003; Stevens, 2019). In addition, enhance plant tolerant for different biotic and abiotic stress (Singh et al., 2017).

The calcium in soils is found in relatively insoluble forms such as $CaCO_3$ under high pH conditions (Malavolta, 2006). While, the low pH of the soil causes a high concentration of cations such as Mg^{+2}, NH_4^+, Fe^{+2} and Al^{+3}, those decreasing the calcium uptake by plants due to antagonistic effects (Läuchli and Grattan, 2012).

Nanomaterials have a high specific surface area and chemical reactivity (Kale and Gawade, 2016), thus increasing the availability of nutrients for plant uptake (Nair et al., 2010; Chhipa, 2017). Nanomaterials entering plant cells through the stomata when applied as foliar because the granularity is far smaller than the stomata diameter (Kara and Sabir, 2010; Avila-Quezada et al., 2022). Nanofertilizers play an important role in plant growth, development and improving crop production (Basavegowda and Baek, 2021), increase the efficient uptake of appropriate quantities of micro- and macro-nutrients compared with conventional fertilizers and help to minimize nutrients losses (Guo et al., 2018; Sohair et al., 2018a, b). Nanofertilizers prevent the most severe hazard effect on the environment (Raghib et al., 2020; Predoi et al., 2020; Khan et al., 2021).

There are limited studies on the effect of Nano-Ca on the growth and yield of crops. Liu et al. (2005) found that Nano-Ca fertilizers have a high potential for peanut yield. El-Motaium et al. (2022) applied calcium oxide as Nano-Ca to evaluate nitrogen uptake in mango trees and found Nano-calcium proves to be more efficient as fertilizer than conventional calcium. Kumara et al. (2017) showed that the foliar application of Nano-calcite has positive effects on growth, yield and seed quality in rice.

Humic substances are natural organic substances derived from various sources that potentially impact their use in improving the physical, chemical and biological properties of soils, therefore increasing

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nutrients uptake and plant yield (Abd-All et al., 2017; Ibrahim and Ali, 2018; Tan, 2003 and Nardi et al., 2002; Jones et al., 2007). Humic substances enhance cell membrane permeability and regulate carbon cycle, protein synthesis and activates biomass production (Eshwaret al., 2017 and Ulukan, 2008).

Both foliar spraying on plants or as soil application of K-H can be used (Idrees et al., 2018). Compared to the control, K-H significantly increased cotton plant height and number of bolls per plant (Wei et al., 2021), improved wheat and rice growth and grains yield (Khan et al., 2018; Rabeh et al., 2021a), enhanced the chilli yield (Pavani et al., 2022), and improved seed, lint cotton yields and fiber quality (Rady et al., 2016). The soil K-H application and foliar application of humic acid improved plant height, fruiting branches number, number of open balls, boll weight, seed index, and seed cotton yield (Gebaly, 2012; Mohamed and El- Mgaed, 2020).

Liu et al. (2005) reported that applying Nano-Ca mixed with humic acid achieved the maximum seedling growth in peanut (dry biomass reached 5.78 g per plant, by 30% increase over that for the control and 14% over that for the Nano-Ca alone). Mohammadbagheri and Naderi (2017) indicated that the application of calcium nanoparticles increased cut flower number, diameter, height and wet weight compared to control. The application of combined Nano-Ca with HA (2000 mg/l) was the most effective for improved Gerbera cut flowers growth and biochemical traits (Mohamed et al., 2020).

Therefore, the present study aimed to evaluate the effect of individual and combination foliar applications of Nano-calcium and K-H to enhance Egyptian cotton growth, yield, and fiber quality.

MATERIAL AND METHODS

Field experiments were carried out to investigate the influence of foliar spray by different Calcium forms on the growth of cotton (*Gossypium barbadence* L) plants grown in alluvial soil of the Agricultural Research Station, Faculty of Agriculture, Cairo University, (31º 11' 33.43'E, 30º 1' 36.16' N), during two successive summer growing seasons of 2019 and 2020.

Studied plant (Cotton cultivars):

Three cotton cultivars were used including extra-long staple Giza 92, long staple Giza 94 and Giza 95. Egyptian clover (Berseem: *Trifolium Alexandrinum* L) were the preceding field crop of cotton at the two growing seasons.

Calcium treatments:

Calcium oxide (CaO) was used as a source for traditional calcium (T-Ca) and Nano calcium (N-Ca); as foliar solution at concentration of 0.5 g Ca L^{-1} (500 mg L^{-1}). Liquid K-humate (K-H); (humic plus 20®, 10% K_2O, Techno green industrial production company, Egypt) was applied at a rate of 3 L fed^{-1}(fed = 4200 m^2). The concentration of K^+ in foliar solution of K-H was calculated and separately added as KCl to the other treatments (T-Ca and N-Ca) to avoid its absence in these two solutions. Nano-particles of CaO were prepared by ball-milling machine (Photon Company, Egypt) according to Sohair et al. (2018a). The obtained particles size were measured by Transmission Electron Microscopy (TEM) using a JEOL transmission electron microscope (JEM-1400 TEM, Japan) according to Wang et al. (2014). The obtained particle size of N-Ca range from 4.40 to 12.30 nm. The treatments were: control, T-Ca, N-Ca, K-H, T-Ca+K-H and N-Ca+K-H.

Experimental Layout:

The experimental design was laid out in a split plot arranged in a Randomized Complete Block Design (RCBD) with four replicates. The cotton cultivars were allocated in the main plots, and six treatments were in the sub plots. Seeds of cotton were planted at the 1st week of April in both growing seasons, in rows 60 cm apart and in hills 20 cm apart. The cotton plants were thinned to two plants per hill. Thus the experiment plot consists of six ridges, each 0.6 m in width and 4.0 m in length. The usual and common agriculture practices were conducted with cultivation plants. All plants received basal fertilizers to the soil which included super phosphate fertilizer (15.5% P_2O_5) at a rate of 30 kg P_2O_5 fed^{-1} (broadcasting before seed sowing during land preparation for cultivation), Ammonium sulfate fertilizer (21% N) at a rate of 60 kg N fed^{-1}, and potassium sulfate fertilizer (48% K_2O) at a rate of 48 kg K_2O fed^{-1}, which were partly split and side dressed directly before the 1st and 2nd irrigations.

The foliar spray (200 liter fed^{-1}) was performed four times (30 days after sowing, at squaring, beginning of flowering, and 15 days later). The surfactant: super film ® was added to the foliar solution before foliar spray application, including control. Foliar spray was carried out between 09:00 and 11:00 AM., using a knapsack sprayer. In both seasons harvesting of the first and second pick of seed cotton yield was performed by hand at second and fourth weeks of September, respectively.

Soil sampling and analysis:

Composite soil samples (0-30 cm) were collected from the experimental field before cultivation, air dried, ground to pass 2 mm sieve and kept for analysis, according to standard methods (Jackson, 1973; Keeney and Nelson, 1982). The particle size distribution of the soil (sand, silt and clay) was carried out by pipet method. The pH of the soil was measured in 1:2.5 (soil: water) suspension by pH-meter. The electrical conductivity (EC) was measured in the saturated soil paste extract by conductivity meter, total carbonate ($CaCO_3$) by Calcimeter method, organic matter (OM) by dichromate method of Walkley and Black, the amount of available nitrogen (N) by Kjeldahl procedure, available phosphorus (P) in the extract of 0.5 M $NaHCO_3$ at pH 8.5 (Olsen method) and was measured colorimetrically, amount of available potassium (K) in soil extract of ammonium acetate of pH 7 by flame photometer. The analysis of the field experimental soil shown in Table (1).

Collection of experimental data

Cotton plant growth parameters and yield components were estimated as follows: at harvest; Ten plants were collected randomly from the outer two ridges (no. 2 and 5) of each plot to measure plant height (cm), the position of 1st sympodial node, sympodial branches per plant, total and open bolls per plant, boll weight (g), seed index (g) and seed cotton yield per plant (g), lint cotton% (lint weight to seed cotton weight expressed as %). The seed cotton yield as kentar per feddan (the Kentar of seed cotton yield =157.5 Kg, Kantar of lint yield=50 Kg, was calculated as the sum of the 1st and 2nd pick from the two central ridges (no. 3 and 4) of each plot after multiplying by the appropriate conversion factor.

Fiber quality properties

Fiber length, uniformity index, fiber strength, micronaire reading and the color attribute values i.e. Reflectance (Rd %) and Yellowness (+b %) were measured in the laboratory of the Cotton Research Institute, Agricultural Research Institute, Agricultural Research Center, Ministry of Agricultural and Land Reclamation, El-Giza, Egypt; under constant conditions of temperature (70 ± 2 F) and relative humidity (65 ± 2 %) according to the American Society for Testing and Materials (A.S.T.M., 2012).

Statistical analysis

Obtained data were subjected to statistical analysis according to the procedure described by Snedecor and Cochron (1981). Significance of differences among variables was done according to the Least Significant Differences test (LSD) at 5% level $P \leq 0.05$) to compare differences between the means. Finally, all statistical analyses were carried out using the "MSTAT-C" computer software package (Freed et al., 1989).

RESULTS AND DISCUSSION

Plant growth parameters

Plant height and position of the first sympodial node

Cotton cultivars, the application of N-Ca, K-H foliar spray and their interactions had a significant effect ($P \leq 0.05$) on plant height, while only cultivars had a significant effect on the first sympodial node position (Fig. 1 and Table 2).

Table 1. The main physical and chemical characteristics of the field Experiments soil in the two growing seasons 2019 and 2020.

Soil Characteristics	Seasons	
	2019	**2020**
Particle size distribution (%)		
Coarse sand	4.7	5.2
Fine sand	35.0	34.8
Silt	27.3	28.4
Clay	33.0	31.6
Soil texture	clay loam	clay loam
Soil bulk density (g cm^{-3})	1.27	1.23
pH*	7.78	7.89
EC (dSm^{-1})**	2.11	2.22
Total carbonate (%)	3.35	3.33
Organic matter (%)	1.96	2.00
Available N (mg kg^{-1})	32.10	29.39
Available P (mg kg^{-1})	8.20	8.62
Available K (mg kg^{-1})	246	241

***Measured in 1: 2.5 soil water suspension, ** Measured in saturated soil paste extract

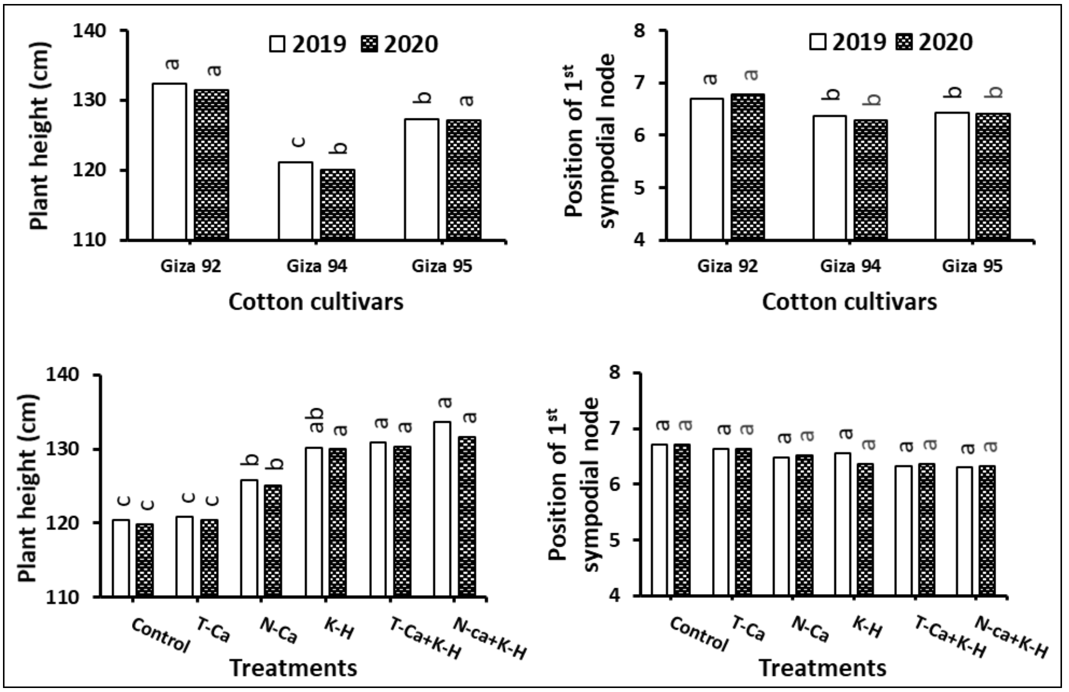

Fig. 1. The main effect of cotton cultivars and different treatments for plant height and the position of 1st sympodial node during growing seasons.

Means followed by the same letter are statistically insignificant at $P \leq 0.05$.

Table 2. Mean values of the interactions between cotton cultivars and different treatments for plant height and position of 1st sympodial node during growing seasons.

Cultivars	Treatments	Plant height (cm)		Position of 1st Sympodial node	
		Growing seasons			
		2019	2020	2019	2020
Giza 92	Control	126.0	125.5	7.00	7.11
	T-Ca	127.0	126.4	6.89	7.00
	N-Ca	131.3	130.6	6.56	6.78
	K-H	135.7	135.2	6.78	6.56
	T-Ca+K-H	136.3	135.4	6.44	6.56
	N-Ca+K-H	137.6	135.3	6.56	6.67
Giza 94	Control	114.1	113.3	6.56	6.56
	T-Ca	115.1	114.0	6.44	6.44
	N-Ca	119.6	119.8	6.44	6.33
	K-H	123.6	122.9	6.44	6.22
	T-Ca+K-H	125.3	123.3	6.21	6.11
	N-Ca+K-H	129.4	127.2	6.11	6.00
Giza 95	Control	121.1	120.6	6.56	6.44
	T-Ca	120.2	120.8	6.56	6.44
	N-Ca	126.3	124.9	6.44	6.44
	K-H	131.3	131.7	6.44	6.33
	T-Ca+K-H	131.0	132.4	6.33	6.44
	N-Ca+K-H	133.8	132.4	6.22	6.33
LSD ($P \leq 0.05$)		8.27	8.15	NS	NS

Giza 92 cotton cultivar achieved the highest plant height value (131.9 cm) which increased by 9.34 and 3.65% compared to Giza 94 (120.6 cm) and Giza 95 (127.2 cm), respectively. Compared with the control, individual foliar applications of N-Ca and K-H increased plant height by 4.42 and 8.28%, respectively. The highest increase in plant height was recorded with K-H compared with other individual treatments, and N-Ca was higher by 4.01% than T-Ca treatment. These findings agree with Kumara et al. (2017) were found that the application of Nano calcite foliar fertilizer had positive effects in rice growth. Mohamed and El-Mgaed (2020) reported that foliar application of humic acid improved plant height. Combination each of T-Ca or N-Ca with K-H significantly increased plant height by 8.75 and 10.42 % respectively, compared with the control.

The interactions between cotton cultivars and the different treatments had a significant effect. A maximum plant height value at 136.5 cm was recorded by Giza 92 with N-Ca+K-H treatment, while a minimum value at 114.6 cm by Giza 94 with T-Ca treatment. These results are in agreement with Osman and Rady (2012); Seadh et al. (2012) and Wei et al. (2021) they found that the application of humic acid (HA) resulted in a significant increase in plant height. Calcium is highly involved in cell elongation and is required for the cell division process and cell wall strength (Heidaria et al., 2022).

Seed cotton yield and its components

Sympodial branches and number of total and open bolls per plant

Significant differences among cotton cultivars and foliar applications of different treatments in the number of total and open bolls per plant (Fig. 2 and Table 3). As an average in both seasons, sympodial branches per plant in Giza 92 (15.05) were higher than Giza 94 (13.99) by 7.62 while, sympodial branches per plant in Giza 92 at par with Giza 95 (14.69). Sympodial branches per plant significantly positively correlated with plant height (R^2 = 0.57, Fig. 3) this improves bolls bearing that are directly involved in producing seed cotton. The highest number of total and open bolls per plant (28.20 and 24.79) was recorded for Giza 95 cotton cultivar, then Giza 94 (21.47 and 18.11) and the lowest values (18.69 and 15.77) for Giza 92, respectively. The relationship between the number of total and open bolls per plant was a significant positive correlation (R^2 = 0.964, Fig. 3).

Individual foliar applications of K-H increased sympodial branches by 13.08%, relative to the control treatment. While, total and open bolls per plant ascending increased by 3.11 and 5.36 for T-Ca, 7.89 and 10.50 for N-Ca and 13.52 and 16.70% for K-H, respectively, compared with the control. As an average, N-Ca was higher than T-Ca by 4.64 for total bolls and 4.88% for open bolls per plant.

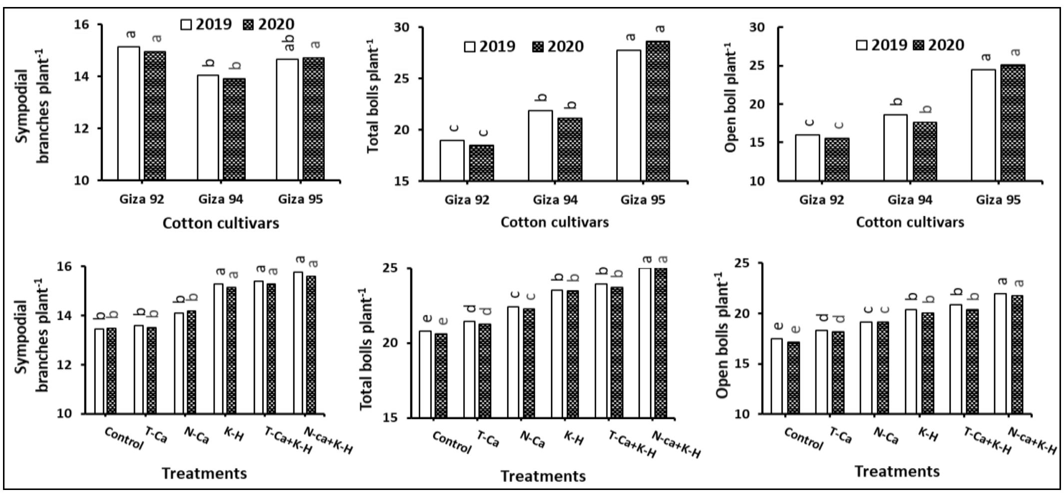

Fig. 2. The main effect of cotton cultivars and different treatments for sympodial branches per plant, total and open bolls per plant during growing seasons.

Means followed by the same letter are statistically insignificant at P ≤ 0.05.

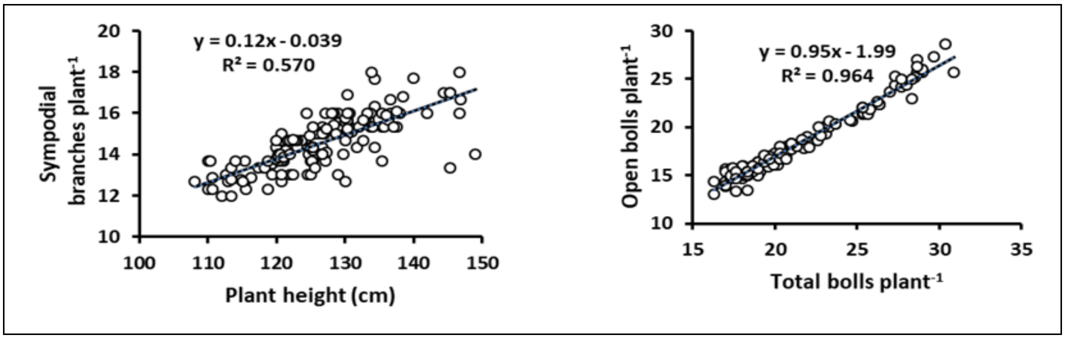

Fig. 3. Relationships between cotton plant height with sympodial branches per plant and number of total with open bolls per plant.

Table 3. Mean values of the interactions between cotton cultivars and different treatments for sympodial branches, total and open bolls per plant during growing seasons.

Cultivars	Treatments	Sympodial branches plant^{-1}		Total bolls plant^{-1}		Open bolls plant^{-1}	
		Growing seasons					
		2019	2020	2019	2020	2019	2020
Giza 92	Control	14.00	13.89	17.33	17.00	14.44	13.89
	T-Ca	14.22	13.89	18.03	17.43	15.25	15.03
	N-Ca	14.78	14.78	18.50	18.07	15.36	15.14
	K-H	15.67	15.56	18.83	18.50	16.03	15.68
	T-Ca+K-H	16.00	15.78	19.82	19.14	16.89	16.11
	N-Ca+K-H	16.11	15.89	21.11	20.78	17.83	17.61
Giza 94	Control	12.78	12.67	19.22	18.33	16.11	15.11
	T-Ca	12.89	12.78	20.03	19.32	17.03	16.36
	N-Ca	13.33	13.78	21.07	20.61	17.82	17.14
	K-H	14.68	14.22	23.17	21.67	19.82	18.25
	T-Ca+K-H	15.11	14.89	23.07	22.18	19.92	18.68
	N-Ca+K-H	15.44	15.22	24.43	24.00	20.93	20.17
Giza 95	Control	13.56	13.89	25.78	26.57	21.89	22.44
	T-Ca	13.67	13.89	26.22	27.00	22.67	23.11
	N-Ca	14.22	14.00	27.67	28.11	24.22	25.11
	K-H	15.56	15.67	28.56	29.78	25.22	26.22
	T-Ca+K-H	15.11	15.22	28.89	29.89	25.67	26.33
	N-Ca+K-H	15.78	15.67	29.44	30.44	26.57	27.33
LSD at $P \leq 0.05$		NS	NS	1.02	1.04	0.95	1.04

The results agree with Zakaria et al. (1997) who reported that number of opened bolls per plant increased with application of Ca. Gebaly (2012); Mohamed and El- Mgaed (2020) and Wei et al. (2021) reported that the foliar application of K-H or humic acid (HA) significantly increased and improved the number of fruiting branches and open balls per plant.

Combination each of T-Ca or N-Ca with K-H significantly increased sympodial branches, total and open bolls per plant compared with the control. Obtained results showed that the treatment of N-Ca combined with K-H recorded increase by 4.87 and 6.13% higher than T-Ca combined with K-H for total and open bolls per plant, respectively. The results are in the same line with Seadh et al. (2012) who found that foliar application of HA resulted in a significant increase in number of fruiting branches per plant.

The interaction between cultivars and different treatments was significant in total and open bolls per plant. Giza 95 under N-Ca combined with K-H achieved the highest values (29.94 and 26.95) and Giza 92 with T-Ca was the lowest one (17.61 and 15.14) for the number of total and open bolls per plant, respectively (Table 3).

Boll weight, seed index and lint percentage

Analysis of variance of both seasons showed that cotton cultivars, foliar application of different treatments and their interactions recorded a significant effect on boll weight, seed index and lint% (Fig. 4 and Table 4). Cotton cultivar Giza 95 recorded the highest value of boll weight (2.62 g) and lint % (40.63) however, Giza 94 cultivar recorded the highest value in the seed index (10.66 g) compared with other cultivars. These differences are related to genetic variation between cotton cultivars, also, increasing boll weight is contributed to improve seed cotton yield.

Individual foliar applications of N-Ca and K-H increased boll weight (7.47 and 12.63%), seed index (3.56 and 4.99%), respectively, also N-Ca increased lint% (2.42%) compared to the control treatment. This reflects that N-Ca and K-H had higher effect than T-Ca.

There was a significant increase in boll weight, seed index and lint% as a result of application of T-Ca or N-Ca combined with K-H compared with the control. N-Ca combined with K-H recorded an increase in boll weight by 3.36% compared with T-Ca combined with K-H. Similar results were obtained by Zakaria et al. (1997); Rady et al (2016) and Sawan (2018) who indicated that boll weight, seed index and lint% increased with the foliar application of calcium and humic acid on Egyptian cotton plants.

The interaction between cultivars and treatments significantly affected boll weight, seed index and lint% in both seasons (Table 4). Maximum values of boll weight (2.79 g) and lint% (41.38%) were found in Giza 95 cultivar when treated with N-Ca+K-H and seed index (10.88 g) in Giza 94 under N-Ca+K-H treatment, while minimum values of boll weight (1.99 g), seed index (8.47 g) and lint% (34.9%) were obtained by Giza 92 cultivar under T-Ca treatment as an average in both seasons (Table 4).

Seed cotton yield

Data in Fig. (5) and Table (5) show that in both seasons, seed cotton yield per plant and per feddan (fed.) were significantly influenced by cotton cultivars, foliar N-Ca and K-H treatments and their interactions.

The average data of both seasons showed that, the three tested cotton cultivars significantly varied in seed cotton yield. Seed cotton yield per plant (g) in Giza 95 cultivar recorded the highest value (53.97), compared with Giza 94 (33.61) and Giza 92 (32.22). The same trend was observed for yield per feddan (kentar) whereas Giza 95 cultivar recorded the highest value (11.98) compared with Giza 94 (9.04) and Giza 92 (8.45). These results may be due to Giza 95 cotton cultivar recorded the best values of total and open bolls per plant. These findings agree with Rabeh et al. (2021b) who found that Giza 95 cotton cultivar was a superior in cotton yield and its components.

As an average of the field experiments for the two seasons, individual foliar application of N-Ca and K-H significantly increased the seed cotton yield per plant by 8.07 and 13.75 and per feddan by 2.92 and 6.66 % over the control treatment, respectively. Seed cotton yield per plant was higher in the treatment of N-Ca by 6.76% and per feddan by 2.19% than T-Ca. However combination of T-Ca or N-Ca with K-H significantly increased seed cotton yield per plant and per feddan compared with the control. N-Ca combined with K-H increased seed cotton yield per plant by 2.97 and per feddan by 1.57% compared with T-Ca combined with K-H.

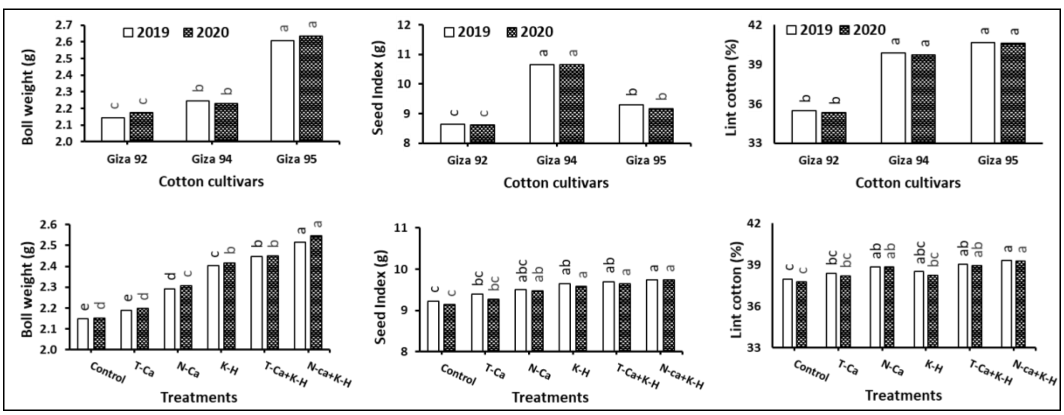

Fig. 4. The main effect of cotton cultivars and different treatments for boll weight, seed index and lint (%) during growing seasons.

Means followed by the same letter are statistically insignificant at $P \leq 0.05$.

Table 4. Mean values of the interactions between cotton cultivars and different treatments for cotton boll weight, seed index and lint cotton percent during growing seasons.

Cultivars	Treatments	Boll weight (g)		Seed index (g)		Lint cotton (%)	
		Growing seasons					
		2019	2020	2019	2020	2019	2020
Giza 92	Control	1.93	1.91	8.31	8.37	34.84	34.28
	T-Ca	1.99	1.98	8.52	8.43	35.04	34.76
	N-Ca	2.09	2.13	8.59	8.54	35.68	35.85
	K-H	2.23	2.29	8.78	8.62	35.43	35.16
	T-Ca+K-H	2.29	2.33	8.80	8.76	35.82	35.68
	N-Ca+K-H	2.34	2.41	8.81	8.92	35.93	36.14
Giza 94	Control	2.03	2.04	10.37	10.51	39.27	39.19
	T-Ca	2.08	2.09	10.49	10.53	39.53	39.40
	N-Ca	2.26	2.23	10.63	10.60	40.03	39.98
	K-H	2.35	2.28	10.77	10.71	39.64	39.44
	T-Ca+K-H	2.35	2.30	10.84	10.74	40.17	39.97
	N-Ca+K-H	2.41	2.44	10.91	10.85	40.53	40.39
Giza 95	Control	2.48	2.50	9.00	8.54	39.80	39.84
	T-Ca	2.50	2.53	9.17	8.84	40.58	40.45
	N-Ca	2.53	2.57	9.28	9.30	40.75	40.67
	K-H	2.64	2.69	9.41	9.43	40.43	40.08
	T-Ca+K-H	2.71	2.72	9.46	9.44	41.07	41.13
	N-Ca+K-H	2.80	2.79	9.50	9.44	41.43	41.34
LSD at P ≤ 0.05		0.08	0.10	0.55	0.53	1.46	1.71

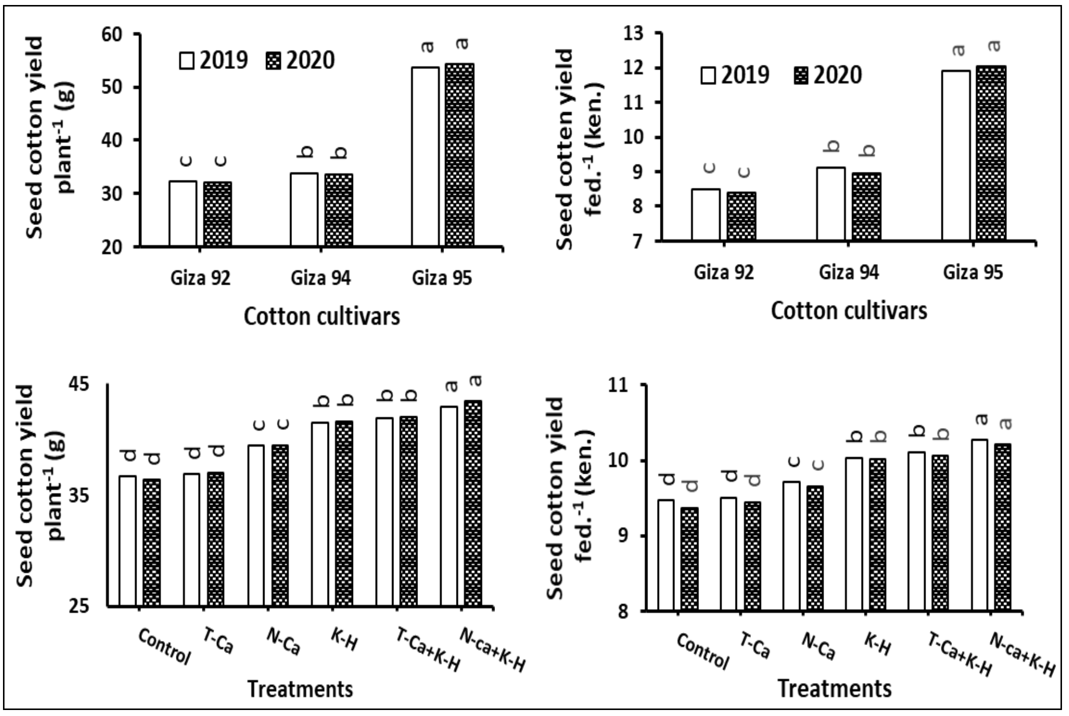

Fig. 5. The main effect of cotton cultivars and different treatments for seed cotton yield per plant and feddan during growing seasons.

Means followed by the same letter are statistically insignificant at $P \leq 0.05$.

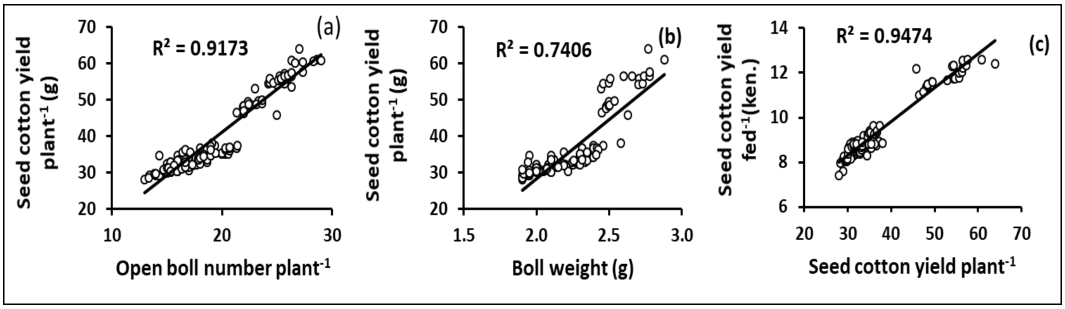

Fig. 6. Seed cotton yield per plant as a function of each open boll number (a), boll weight (b), and seed cotton yield per feddan as a function of seed cotton yield per plant (c).

Table 5. Mean values of the interactions between cotton cultivars and different treatments for seed cotton yield per plant, and feddan during growing seasons.

Cultivars	Treatments	Seed cotton yield plant^{-1} (g)		Seed cotton yield fed^{-1} (Ken.)	
		Growing seasons			
		2019	2020	2019	2020
Giza 92	Control	30.45	29.71	8.24	8.03
	T-Ca	30.62	30.03	8.28	8.07
	N-Ca	31.43	31.22	8.44	8.37
	K-H	33.02	33.24	8.61	8.51
	T-Ca+K-H	33.82	33.82	8.66	8.55
	N-Ca+K-H	34.26	35.07	8.82	8.79
Giza 94	Control	31.49	31.26	8.80	8.65
	T-Ca	31.60	32.49	8.83	8.71
	N-Ca	32.42	32.07	8.95	8.82
	K-H	34.97	34.04	9.33	9.20
	T-Ca+K-H	35.23	34.50	9.35	9.16
	N-Ca+K-H	36.73	36.58	9.41	9.27
Giza 95	Control	48.03	48.14	11.36	11.43
	T-Ca	48.44	48.59	11.41	11.57
	N-Ca	54.41	55.20	11.74	11.79
	K-H	56.40	57.52	12.15	12.35
	T-Ca+K-H	56.72	57.64	12.31	12.47
	N-Ca+K-H	57.84	58.73	12.57	12.59
LSD at $P \leq 0.05$		2.53	2.51	0.27	0.25

This indicated that, the highest seed cotton yield per plant and per feddan was obtained with N-Ca combined with K-H treatment. The obtained results agree with Kanjana (2020) who reported that nano-fertilizers increased seed cotton yield. The foliar application of calcium and humic acid on Egyptian cotton can increase yield of seed cotton (Zakaria et al., 1997; Rady et al., 2016; Sawan, 2018).

Cotton cultivars interactions with treatments were significant in both seasons, as an average in both seasons the highest mean value (58.29 g per plant and 12.58 ken. per fed.) was recorded by Giza 95 when treated with N-Ca+K-H and the lowest (30.33 g per plant and 8.18 ken. per fed.) was recorded by Giza 92 when treated with T-Ca (Table 5).

Seed cotton yield depends on the most previously studied parameters, significant relationship was found between seed cotton yield per plant and the number of open bolls per plant (R^2 = 0.917) and boll weight (R^2 = 0.741). Also, seed cotton yield per feddan highly significant relationship with seed cotton yield per plant (R^2 = 0.947, Fig. 6).

Cotton fiber properties

Fiber length, length uniformity index, and fiber bundle strength

Results in Figure (7) and Table (6) demonstrate that, only the main effect of cotton cultivars and foliar of different treatments was associated with a significant increase in fiber length, uniformity index and fiber bundle strength. In both seasons as an average, the highest value of fiber length (34.13 mm) was recorded for cultivar of Giza 92 resulted in an increase 6.58 and 8.11% comparing with Giza 94 (32.02 mm) and Giza 95 (31.57 mm), respectively. This due to that Giza 92 cotton cultivar belongs to the extra-long staple group and both of Giza 94 and 95 belong to long-staple cultivar according to Cotton Inc. (2013) classification.

Fiber length uniformity index (%) and fiber bundle strength (Presley index) in Giza 95 cotton cultivar were lower than those in both of Giza 92 and 94. However, insignificant differences found between Giza 92 and Giza 94.

Individual foliar spray of T-Ca, N-Ca and K-H led to a significant increase in fiber length, While, only K-H gave a significant increase in uniformity index and fiber bundle strength compared to the control treatment. Also, the effect of T-Ca combined with K-H was close to N-Ca combined with K-H which recorded a significant increase in each of fiber length, uniformity index and fiber bundle strength. These findings agree with those of Zakaria et al. (1997); Sawan (2018) who reported that fiber length (2.5 % span length) increased by application of Ca compared to control. Calcium is highly involved in cell elongation and is required for the cell division process and cell wall strength (Heidaria et al., 2022).

Fiber fineness and Color attributes

Data in figure (8) and Table (7) show significant differences of the main effect of cotton cultivars and foliar spray of treatments in fiber fineness, degree of reflectance (Rd %) and yellowness degree (+b). The highest fiber fineness (micronaire reading 3.44) recorded in Giza 92 cultivar compared with Giza 94 and Giza 95. Whereas, the highest brightness (Rd %) (78.84%) and the lowest yellowness (8.06) found in Giza 94 compared with other cultivars. Foliar spray of T-Ca, N-Ca and K-H individually resulted in a significant decrease in micronaire reading and increase degree of reflectance (Rd %) while, N-Ca and K-H significantly decreased yellowness degree (+b) compared with the control treatment. Combintion of T-Ca or N-Ca with K-H was closely to each other for micronaire reading and yellowness degree (+b), while degree of reflectance (Rd %) in first season only. The foliar application of calcium and humic acid on Egyptian cotton can improve fiber properties (Zakaria et al., 1997; Rady et al., 2016; Sawan, 2018). The interaction between cultivars and different treatments was insignificant in micronaire reading but it was significant in reflectance (Rd %) and yellowness degree (+b). The highest brightness (Rd %) value (79.43%) and the lowest yellowness degree (+b) (7.96) was recorded by Giza 94 under N-Ca combined with K-H treatment. On the other hand, the lowest brightness (Rd %) value (66.84%) and the highest yellowness degree (+b) (11.47) was recorded by Giza 95 with T-Ca treatment.

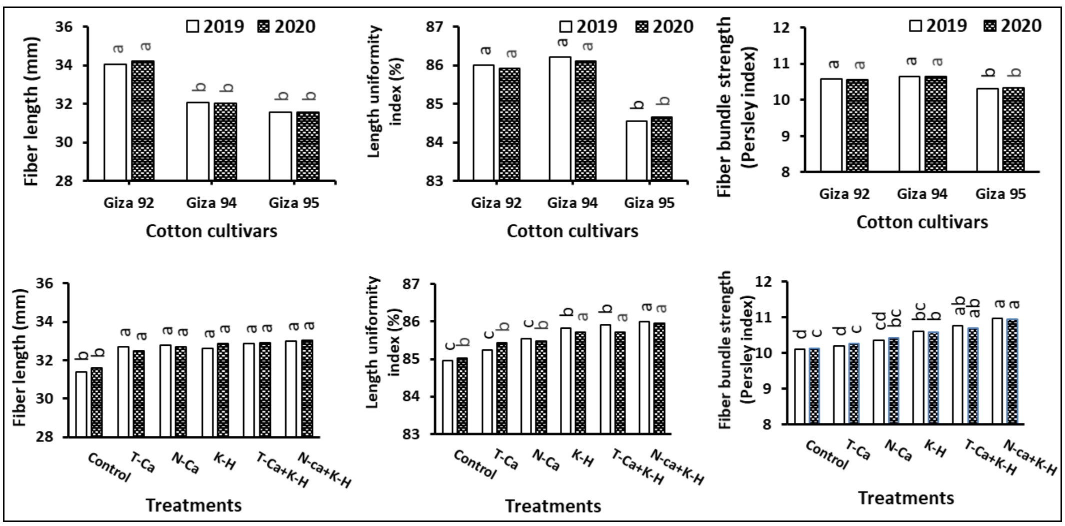

Fig. 7. The main effect of cotton cultivars and different treatments for cotton fiber length, length uniformity index and fiber bundle strength during growing seasons.

Means followed by the same letter are statistically insignificant at $P \leq 0.05$.

Table 6. Mean values of the interactions between cotton cultivars and different treatments for cotton fiber length, length uniformity index and fiber bundle strength during growing seasons.

Cultivars	Treatments	Fiber length (mm)		Length uniformity Index (%)		Fiber bundle strength (Presley index)	
		Growing seasons					
		2019	2020	2019	2020	2019	2020
Giza 92	Control	32.90	32.95	85.25	85.35	10.20	10.20
	T-Ca	34.03	34.03	85.63	85.83	10.30	10.40
	N-Ca	34.25	34.53	86.08	85.93	10.40	10.57
	K-H	34.11	34.51	86.00	86.10	10.50	10.60
	T-Ca+K-H	34.41	34.42	86.50	85.93	10.50	10.60
	N-Ca+K-H	34.58	34.87	86.53	86.33	10.98	10.98
Giza 94	Control	31.50	31.15	85.85	85.73	10.23	10.30
	T-Ca	32.20	32.09	86.08	86.18	10.30	10.30
	N-Ca	32.01	32.09	86.35	86.20	10.38	10.38
	K-H	32.20	32.29	86.28	86.10	11.03	10.88
	T-Ca+K-H	32.10	32.20	86.25	86.13	10.98	10.98
	N-Ca+K-H	32.26	32.20	86.45	86.30	11.03	11.00
Giza 95	Control	29.79	30.65	83.78	84.03	9.88	9.90
	T-Ca	31.90	31.40	84.05	84.30	9.98	10.10
	N-Ca	32.05	31.48	84.23	84.30	10.30	10.30
	K-H	31.50	31.75	85.23	84.98	10.30	10.28
	T-Ca+K-H	32.08	32.13	85.00	85.10	10.80	10.50
	N-Ca+K-H	32.10	32.05	85.00	85.23	10.93	10.88
LSD at $P \leq 0.05$		NS	NS	NS	NS	NS	NS

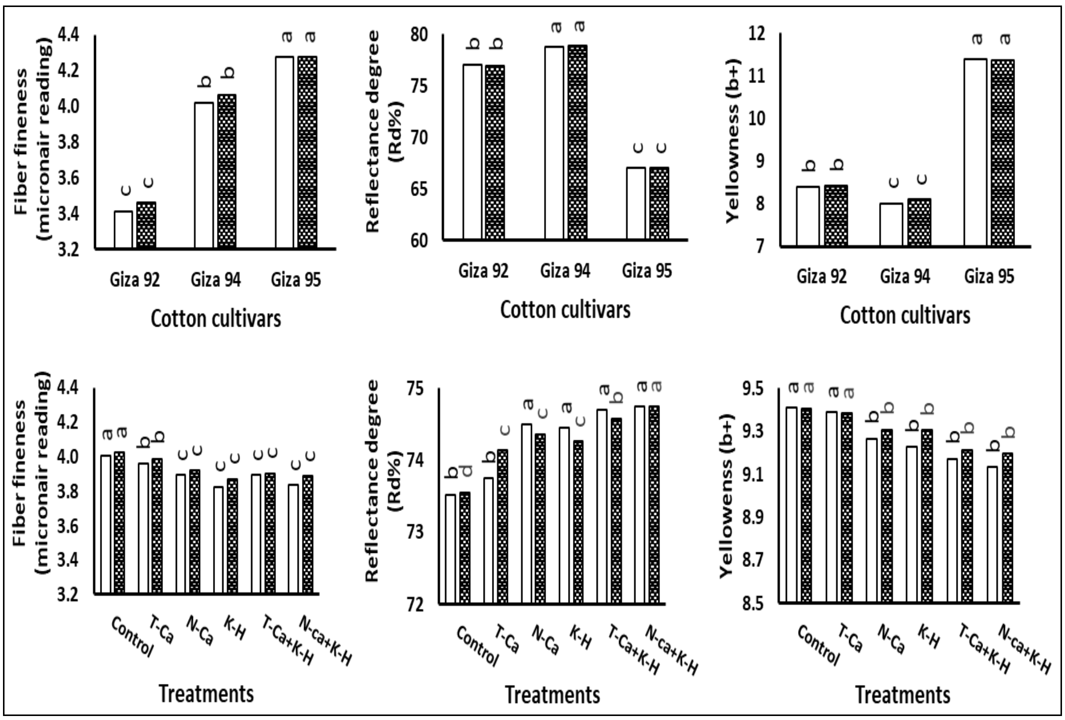

Fig. 8. The main effect of cotton cultivars and different treatments of fiber fineness, reflectance degree (Rd %) and yellowness (+b) during growing seasons.

Means followed by the same letter are statistically insignificant at $P \leq 0.05$.

Table 7. Mean values of the interactions between cotton cultivars and different treatments for cotton fiber fineness, reflectance degree (Rd%) and yellowness (+b) during growing seasons.

Cultivars	Treatments	Fiber fineness (micronaire reading)		Reflectance degree (Rd%)		Yellowness (+b)	
		Growing seasons					
		2019	2020	2019	2020	2019	2020
Giza 92	Control	3.45	3.49	76.23	76.47	8.63	8.60
	T-Ca	3.43	3.48	76.30	76.70	8.60	8.50
	N-Ca	3.40	3.48	77.20	76.88	8.40	8.40
	K-H	3.40	3.40	77.38	76.80	8.27	8.41
	T-Ca+K-H	3.40	3.43	77.40	77.20	8.23	8.30
	N-Ca+K-H	3.40	3.40	77.50	77.40	8.20	8.30
Giza 94	Control	4.20	4.23	77.88	77.48	8.10	8.20
	T-Ca	4.13	4.18	78.08	78.90	8.08	8.23
	N-Ca	4.10	4.08	79.10	79.10	8.00	8.10
	K-H	3.80	3.90	79.00	79.00	8.00	8.10
	T-Ca+K-H	4.00	4.08	79.40	79.33	8.00	8.01
	N-Ca+K-H	3.88	3.93	79.45	79.40	7.90	8.01
Giza 95	Control	4.38	4.36	66.48	66.70	11.50	11.43
	T-Ca	4.33	4.31	66.86	66.83	11.50	11.43
	N-Ca	4.18	4.21	67.20	67.00	11.40	11.43
	K-H	4.28	4.31	66.98	67.00	11.41	11.40
	T-Ca+K-H	4.28	4.21	67.30	67.20	11.29	11.33
	N-Ca+K-H	4.23	4.24	67.28	67.43	11.30	11.28
LSD at $P \leq 0.05$		NS	NS	0.98	0.95	0.20	0.23

CONCLUSIONS

Nano-Ca foliar spray fertilizer had a positive effect on cotton yield, yield components and fiber quality than traditional-Ca. Furthermore, the combined of foliar nano-Ca with potassium humate fertilizer achieved the highest results in the tested parameters. Therefore, this study recommend using nano-Ca with potassium humate for enhancing cotton yield. Also, more research is needed to examine and evaluate different sources of calcium.

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الملخص العربي

تأثير الرش الورقي للنانو كالسيوم بالتكامل مع هيومات البوتاسيوم على نمو ومحصول وجودة الألياف للقطن المزروع في تربة رسوبية غير ملحية

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يعتبر الكالسيوم (Ca^{2+}) أحد العناصر الأساسية للنباتات، وتؤدي التغيرات في خواص التربة إلى تقليل توافره للنباتات نتيجة تكوين مركبات غير قابلة للذوبان. تهدف هذه الدراسة إلى تقييم تأثيرالرش الورقي للكالسيوم النانوى مخلوطًا مع هيومات البوتاسيوم على تحسين نمو ومحصول وجودة ألياف القطن المصرى. أجريت تجربتين حقليتين لموسمين ٢٠١٩ و٢٠٢٠. استخدمت القطع المنشقة وفق تصميم القطاعات الكاملة العشوائية بأربعة مكررات. وزعت ثلاثة أصناف من القطن (جيزة ٩٢، ٩٤، ٩٥) فى القطع الرئيسية، بينما ستة معاملات سماد(كنترول، الكالسيوم التقليدى، كالسيوم نانوى، هيومات البوتاسيوم، الكالسيوم التقليدي + هيومات البوتاسيوم ، الكالسيوم النانوي + هيومات البوتاسيوم) فى القطع المنشقة. وتم الرش الورقي أربع مرات (٣٠ يومًا بعد الزراعة، مرحلة تكوين البرعم الزهرى، بداية الإزهار ثم بعده بخمسة عشر يومًا). أشارت النتائج إلى تفوق صنف جيزة ٩٥ في المحصول بينما تفوق صنفان جيزة ٩٢ و٩٤ في جودة الألياف. أدى الرش الورقى المنفرد لكل من الكالسيوم النانوى وهيومات البوتاسيوم إلى زيادة معنوية في ارتفاع النبات، مكونات المحصول (الأفرع الثمرية، اللوز الكلي والمتفتح، وزن اللوزة، دليل البذرة، نسبة الاليااف ومحصول القطن الزهر) وجودة الألياف (الطول، نسبة الانتظام، المتانة، النعومة، نصاعة وانعكاس لون الألياف (Rd%) وتقليل الاصفرار (b^{+}) مقارنة بالكنترول. سجلت معاملات الرش الورقي للكالسيوم النانوى زيادة أعلى من الكالسيوم التقليدي. حقق خلط الكالسيوم النانوى مع هيومات البوتاسيوم أعلى زيادة في معظم الصفات السابقة مقارنة بالكالسيوم التقليدى المخلوط. يمكن التوصية بالاستخدام الورقي للكالسيوم النانوى مخلوطا بهيومات البوتاسيوم لتحسين إنتاج القطن وجودة الألياف.

الكلمات المفتاحية: سماد نانو الكالسيوم؛ المواد الدبالية؛ هيومات البوتاسيوم؛ الرش الورقى؛ محصول القطن؛ جودة الألياف.