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Water Stress on Cotton Plants as Affected by Potassium and Nano Chitosan-NPK Fertilizer

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ABSTRACT

The present work was aimed to investigate using of potassium fertilizer as well as nano chitosan-NPK to alleviate the negative effect of water stress and its effect on cotton plant and some water relations. Two field experiments were conducted to study the possibility of using potassium fertilizer and nano chitosan-NPK to eliminate the negative impacts of water stress. The design of the experiment was split design plot, where number of irrigation treatments (6 and 9) were arranged in main plots, while potassium fertilization, i.e., K_1= 96 kg K/ha as potassium sulphate, K_2= 96 kg K/ha + twice foliar application of 2% potassium sulphate, K_3= 96 kg K/ha + twice foliar application with 2% nano chitosan-NPK, K_4= four times of foliar application with 2% potassium sulphate, and K_5= four times of foliar application with 2% nano chitosan-NPK. The results obtained indicated that K_3 followed by K_2 which achieved the favourable values of plant height, first fruiting node, number of fruiting branches/plant, number of open bolls/plant, boll weight, seed index, lint percentage, seed cotton yield. Neither potassium fertilization nor irrigation number altered fiber properties. The data of the interaction showed the combined 96 kg K/ha as potassium sulphate + twice foliar application with 2% nano chitosan-NPK can diminish the negative effect of drought stress under deficit conditions, with higher seed cotton yield nearly equal to those obtained under full irrigation. It could be concluded that potassium fertilization and nano chitosan-NPK can improve cotton plant tolerance to water stress and enhance cotton productivity.

KEYWORDS: Cotton, Potassium, Irrigation number, Nano chitosan-NPK, Foliar Application.

1. INTRODUCTION

With limited natural resources for future generation, the biggest challenge facing sustainable agriculture is to produce enough food to satisfy a growing population, while protecting the agroecosystem (Lopez-Valdez and Fernandez-Luqueno, 2018; Abd El-Azeim et al., 2020a). Melorose et al (2015) mentioned that world population being to reach about 9.6 billion by 2050. Therefore, the efforts should be applied to search for different solutions in agriculture to face this problem. In Egypt, water resources for irrigation are scarce reflecting an urgent need to improve water use efficiency, where limited irrigation water and improper irrigation regimes for plants has led to water stress and deficit in yield production. Flowering and boll setting are more sensitive to deficit irrigation (Shahzad et al 2019). In this situation, potassium application can help the plants to grow well under stress condition by controlling the stomata regulation, water relation, consequently increased the tolerance of plants to drought (Tsonev et al, 2011; Abdel-Mageed et al., 2018).

Chemical, organic and biofertilizers have been developed during last decades to maximize the agricultural production and healthy food. Therefore, the use of new alternative nanotechnology that are less harmful and more efficient was recently induced in agricultural production (Abd El-Azeim et al., 2020b). The effect of nano-particles fertilizers depends on minimizing its particles size which caused an increase in particle number/unit weight as well as increasing the specific surface area of fertilizer led to increase the contact of fertilizer with plants, consequently improved nutrient absorption (Liscano et al, 2000; Abd El-Azeim et al., 2020b). In general, the dimension of nano-particles fertilizer particles is below 100 nm, which resulting in fertilizer more efficient, less environmentally pollutant (Joseph and Morrisson, 2006, Manjunatha et al, 2016 and Suppan, 2017). In addition, De Rosa et al (2010) indicated that, plants uptake nutrients more rapidly and completely from nano fertilizers, resulting to save fertilizers consumption as well as increasing crop production and minimizing the environmental pollution. In this concern, Singh et al (2013) and Avramescu et al (2017) stated that the smaller size, the higher specific surface area and the reactivity of nano fertilizers may affect nutrient solubility, diffusion, consequently its availability to plants. Chitosan (derived from deacetylation of chitin) is a natural polymer, which may be obtained from insects, crustaceans and fungi (Boonsongrit et al., 2006). Chitosan was found to have a positive effect on the development of different crop plants (Chibu and Shibayama, 2001; Wanichpongpan et al., 2001). However, some experiments on chitosan were performed on conventional and organic crops with variable results (Walker et al., 2004). While application of chitosan resulted in yield increases of nearly 20% in tomato experiments, there was no significant difference in yield or average weight of carrot. They also found no significant differences among capsicum, cucumber, pea or beet-root plants. Walker et al. (2004) showed that chitosan foliar treatment had improved yield more than the yield from other treatments. Many workers stated the beneficial effects of nano-particles fertilizers on plant growth and development (Hamoda et al., 2016; Achari and Kowshik 2018; Raliya et al., 2018; Yoon et al., 2019 and Zulfiqar et al., 2019).

Potassium is one of the most important macronutrients which play many important functions in plant. It plays as an enzyme activator for metabolism, regulating the water use by plants, maintaining the balance of electrical charges, enhance the translocation of photosynthesis for biomass of plants or fruits and roots, induce in protein synthesis and protect the plants from diseases as well as improved crop quality (Uchida, 2009). Supplied fertilizers as foliar application is mostly preferred due to the small amounts are used. Foliar application has improved crop production in sustainable agriculture, meanwhile, decrease the ground water pollution and it is more effective in producing crops economically (Ali et al., 2008 and Hamayu et al., 2011; Abd El-Azeim et al., 2020). In this connection, Tarafdar (2010) reported that foliar application of nano-particles fertilizer led to enhance the nutrient use efficiency and the rapidity of nutrient absorption, consequently maximizing cotton production.

Therefore, the present work was aimed to investigate using of potassium fertilizer as well as nano chitosan-NPK to alleviate the negative effect of water stress and its effect on growth, yield and yield components, fiber properties and nutrient status of cotton plant (Giza 95) as well as on some water relations.

2. MATERIALS AND METHODS

Field experiment for two successive seasons of 2019 and 2020 was conducted at the Agricultural Farm of Sids Agricultural Research Station, ARC, Beni Suef Governorate (Lat. 29º 4\ N, log. 31º 6\ E and about 30-40 m above the mean sea level), Egypt. This research aimed to study the effect of potassium foliar fertilization and nano chitosan-NPK on improving the tolerance of cotton plant to water stress and its effect on cotton productivity. Some physical and chemical properties of the experimental site were determined according to A.O.A.C (1985) and Klute (1986) are listed in Tables 1 and 2.

Table 1. Some physical and chemical properties of soil (0-30 cm) at the experimental site.

Seasons	Particle size distribution				Chemical properties					
	Clay (%)	Silt (%)	Sand (%)	Texture grade	Soil pH 1:2.5 soil-water suspension	EC, (dSm^{-1}) soil paste	Soil organic matter ($g\ kg^{-1}$)	Soil available ($\mu g g^{-1}$) N	P	K
2019	52.3	29.7	18.0	Clay	7.92	1.02	18.6	25.1	16.01	195.2
2020	51.9	28.8	19.3	Clay	8.01	1.08	19.5	24.7	15.8	189.6

Table 2. Some soil-water constants and bulk density of the studied soil.

Seasons	Soil depth (cm)	Field capacity (%, w/w)	Wilting point (%, w/w)	Available water (%, w/w)	Bulk density ($g\ cm^3$)
2019	0.0-15	45.61	22.96	22.65	1.181
	15-30	36.92	18.05	18.87	1.301
	30-45	34.19	17.36	16.83	1.371
	45-60	31.97	16.19	15.78	1.385
Mean		37.17	18.64	18.54	1.310
2020	0.0-15	49.01	24.11	24.90	1.131
	15-30	40.85	19.36	21.49	1.317
	30-45	35.96	17.01	18.95	1.425
	45-60	33.12	16.63	16.49	1.539
Mean		39.76	19.28	20.46	1.353

2.1. Preparation and characterization of nano chitosan NPK fertilizers

Chitosan poly-methacrylic acid (CS-PMAA) nanoparticles were obtained by polymerization of methacrylic acid (MAA) in chitosan (CS) solution in a two-step process according to Hasaneen et al. (2014). Nitrogen, phosphorus and potassium (NPK) were loaded on the CS-PMAA nanoparticles using the following concentrations 500, 60, 400 ppm respectively (100% concentration stands for 500 ppm of N, 60 ppm of P and 400 ppm of K in both nano and normal NPK solutions and other concentrations were made from these stock solutions). All chemicals used were purchased from Sigma Aldrich, Germany.

2.2. Experimental design

The design of the experiment was split plot in completely randomized block in four replications, where irrigation number, i.e., 6 irrigations (I1) and 9 irrigations (I2) arranged in main plots and potassium fertilization 48 kg K/ha as potassium sulphate (K2SO4) (K1), 96 kg K/ha + twice foliar application with 2% potassium sulphate solution (K2), 96 kg K/ha + twice foliar application with 2% nano chitosan-NPK solution (K3), four times of foliar application with 2% potassium sulphate solution (K4), and four times of foliar application with 2% nano chitosan-NPK solution (K5) were allocated in sub plots.

The irrigation treatments were started after the fixing irrigation using surface irrigation system. On the other hand, the soil application of potassium treatments was applied after thinning as potassium sulphate 48% K_2O, while foliar application treatments were done at squaring and at flowering stages (twice) as well as at after thinning, at squaring, at start of flowering and at top of flowering (four irrigations). The foliar application treatments were done at rates of 960 L/ha.

Cotton seeds (*Gossypium barbadense*, variety Giza 95) were sown on 2 and 4 April in both seasons, respectively. The plot area was 12 m^2 (4 x 3.0 m) contain 5 ridges, each ridge was 4.0 m long, 60 cm width with hills of 20 cm a part in one side of the ridge. Hills were thinning to two plants after 21 days. All plants supplied with 23.23 kg P/ha as superphosphate (15.5% P_2O_5) before planting and 144 kg N/ha as ammonium nitrate (33.5% N) in two equal doses, one after thinning and the second after 30 days later. All other agricultural practices were performed as recommended for cotton production in this district. The quantity of applied water was measured by using submerged flow orifice with known dimension according to the equation of Michael (1978) as follow:

$$Q = CA\sqrt{2gh}$$

Where: Q = the discharge of water (L/sec)
C = Discharge coefficient (0.61)
A = the orifice cross section area (cm^2)
g = Gravity acceleration (981 cm/sec^2)
h = Pressure head (cm)

The time needed for each plot was recorded.

From each plot, ten representative plants from the three inner ridges were randomly taken at harvest to determine the following parameters: growth parameters (plant height, first fruiting node and number of fruiting branches/plant), yield components, i.e., number of open bolls/plant, boll weight and 100-seed weight), yield parameters, i.e., earliness % , lint % and seed cotton yield, and fiber properties (according to A.S.T.M., 1986), namely, pressely index, micronaire reading, fiber length (mm) and uniformity index (%). Also, represent leaves sample from the top fourth node leaves were randomly taken at 15 days after full flowering stage to determine N, P and K concentrations according to Chapman and Pratt (1978) as well as chlorophyll a and b according to Arnon (1949) and carotenoids according to Rolbelen (1957).

2.3. Crop-water relations:

2.3.1. Water consumptive use (CU) (m3/ha)

Soil samples were taken at 48 hours after irrigation and just before next irrigation every 15 cm depth until 60 cm along in the soil profile to measure the moisture content and then water consumptive use were determined according to Israelsen and Hansen (1962) as the following equation:

$$CU = \frac{D\ Bd\ (Q2 - Q1)}{100}$$

Where:
CU = Actual consumptive use (cm).
D = Effective root zone depth (cm), about 60 cm for cotton.
Bd = Bulk density of depth (g cm^{-3}).
Q2 = Soil moisture content (%wt/wt) at 48 hours after irrigation (field capacity).
Q1 = Soil moisture content (%wt/wt) just before the next irrigation.

2.3.2. Water use efficiency (WUE, kg/m3)

Water productivity is expressed as kilogram seed cotton yield obtained from one unit of applied water (Fao, 2003) as the following equation:

$$WUE\ (kg/m3) = \frac{Seed\ cotton\ yield\ (kg/ha)}{Consumptive\ use\ (m3/ha)}$$

2.3.3. Water productivity (WP)

Water productivity was determined (according to Jensen, 1983) as the following equation:

$$WP\ (kg/m3) = \frac{Seed\ cotton\ yield\ (kg/ha)}{Water\ applied\ (m3/ha)}$$

2.4. Statistical analysis

The obtained data were subjected to the statistically analysis according to Snedecor and Cochran (1980). The difference between the treatment's means were compared using least significant differences (L.S.D.) at 5% probability level.

3. RESULTS AND DISCUSSIONS

3.1. Growth characteristics and yield components

Data of the effects of potassium, nano chitosan-NPK and irrigation treatments on some growth characteristics and yield components of cotton plants, namely, plant height, first fruiting node, number of fruiting branches/plant, number of open bolls/plant, boll weight and seed index are given in Tables 3 and 4.

Table 3. Growth parameters as affected by chemical and nano-particles potassium fertilization and irrigation number.

Treatments		Plant height (cm)		First fruiting node		No. of fruiting branches/plant	
Number of irrigation (A)	K-fertilization (B)	2019	2020	2019	2020	2019	2020
9 irrigations (I_1)	K_1*	125.9	123.6	8.9	9.0	14.5	14.7
	K_2	127.3	125.1	8.5	8.6	16.6	16.8
	K_3	127.9	125.7	8.5	8.6	16.8	17.0
	K_4	126.0	124.2	8.7	8.8	16.2	16.4
	K5	126.6	124.8	8.7	8.8	16.4	16.6
Mean		126.7	124.7	8.7	8.8	16.1	16.3
6 irrigations (I_2)	K_1	116.7	113.1	9.2	9.4	11.6	12.9
	K_2	127.2	125.6	8.8	8.9	13.7	13.9
	K_3	127.8	125.5	8.8	8.9	13.9	14.2
	K_4	124.1	122.8	9.0	9.1	13.3	13.5
	K_5	124.7	123.4	9.0	9.1	13.6	13.8
Mean		124.1	122.0	9.0	9.1	13.2	13.7
Mean of K	K_1	121.3	118.4	9.1	9.2	13.1	13.8
	K_2	127.3	125.1	8.7	8.8	15.2	15.4
	K_3	127.9	125.6	8.7	8.8	15.4	15.6
	K_4	125.1	123.5	8.9	9.0	14.8	15.0
	K_5	125.7	124.1	8.9	9.0	15.0	15.2
L.S.D at 0.05	A	1.03	1.01	0.11	0.12	0.85	0.87
	B	1.01	1.00	0.12	0.12	0.83	0.85
	AB	1.45	1.37	0.15	0.17	1.12	1.29

*K_1= 96 kg K/ha. K_2= 96 kg K/ha + foliar application of 2% potassium sulphate twice. K_3= 96 kg K/ha + foliar application of 2% nano chitosan-NPK twice. K_4= foliar application of 2% potassium sulphate four times. K_5= foliar application of 2% nano chitosan-NPK four times.

Data clearly revealed that, these traits were significantly affected by potassium fertilization. The effect of potassium treatments on improving these traits could be arranged on the descending order as follow: 96 kg K/ha + foliar application of 2% nano chitosan-NPK solution twice (K_3) > 96 kg K/ha + foliar application of 2% potassium sulphate solution twice (K_2) > foliar application of nano chitosan-NPK solution four times (K_5) > foliar application of potassium sulphate solution four times (K_4) > 96 kg K/ha (K_1). It is obvious to notice that the effect of using nano chitosan-NPK was slightly surpassed the effect of potassium sulphate as foliar application, but the differences between them did not reach to the significance values. Furthermore, combined potassium sulphate as soil application with foliar application, whether nano chitosan-NPK or potassium sulphate gave best values of growth and yield components parameters than foliar application four times only. The positive effect of potassium application on these traits comparing with control may be due to potassium is consider as enzymes activators which enhances plant metabolism, accordingly, improved the vegetative growth of cotton plant (Hamoda et al, 2016). The enhancement of nano chitosan-NPK on cotton

Table 4. Yield components as affected by chemical and nano-particles potassium fertilization and irrigation number.

Treatments		No. of open bolls/plant		Boll weight (g)		Seed index (g)	
Number of irrigation (A)	K-fertilization (B)	2019	2020	2019	2020	2019	2020
9 irrigations (I_1)	K_1*	14.3	14.7	2.69	2.71	9.04	9.03
	K_2	16.1	16.5	2.88	2.90	9.66	9.64
	K_3	16.5	16.9	2.92	2.93	9.66	9.65
	K_4	16.6	15.9	2.83	2.85	9.61	9.60
	K5	15.8	16.1	2.85	2.87	9.62	9.61
Mean		15.7	16.1	2.85	2.83	9.52	9.51
6 irrigations (I_2)	K_1	11.1	11.3	2.40	2.41	7.96	7.98
	K_2	16.0	16.4	2.87	2.90	9.65	9.64
	K_3	16.3	16.7	2.90	2.92	9.65	9.65
	K_4	14.1	11.4	2.66	2.68	9.38	9.37
	K_5	14.4	14.7	2.70	2.71	9.40	9.38
Mean		14.4	14.7	2.72	2.71	9.21	9.20
Mean of K	K_1	12.7	13.0	2.55	2.56	8.50	8.51
	K_2	16.1	16.5	2.88	2.90	9.66	9.64
	K_3	16.4	16.8	2.91	2.93	9.66	9.65
	K_4	14.9	15.2	2.75	2.77	9.50	9.49
	K_5	15.1	15.4	2.78	2.79	9.51	9.50
L.S.D at 0.05	A	0.79	0.82	0.07	0.08	0.09	0.11
	B	0.71	0.76	0.07	0.06	0.08	0.10
	AB	0.94	0.98	0.10	0.11	0.15	0.18

*K_1= 96 kg K/ha. K_2= 96 kg K/ha + foliar application of 2% potassium sulphate twice. K_3= 96 kg K/ha + foliar application of 2% nano chitosan-NPK twice. K_4= foliar application of 2% potassium sulphate four times. K_5= foliar application of 2% nano chitosan-NPK four times.

growth is mainly due to its small size as well as physiochemical characteristics like shape, surface chemistry, electrical charge and agglomeration resulted by nanotechnology (Leon-Silva et al, 2018). These results agree with those obtained by Abdel-Aziz et al. (2018) for chitosan NPK fertilizer improve the growth and yield of wheat, Elayan et al. (2018) and Abd El-Hafeez and Abd El-Gayed (2019) for the effect of chemical potassium fertilizer on cotton growth, and Praveen and Tomar (2019) for nano-particles potassium fertilizer.

With regard to irrigation treatments, data clearly revealed that, under water stress condition, in term of irrigated 6 irrigations, the studied growth parameters were negatively affected in comparison with full irrigation treatment (irrigated 9 irrigations). The adverse effect on these parameters due to deficit water could be attributed to the decreasing in ability of plant to absorb the needed nutrients for optimal growth and development (Xiong and Zhu, 2002). On the other hand, it is recognized that water is very important for all biochemical activities of all cells as well as for meristemic activation and supply the plant with all growth requirements, accordingly higher vegetative growth parameter values (Hassan et al, 2016). These results are in a good agreement with those obtained by Hamoda et al (2014) and Abd El-Gayed and Bashandy (2018) who stated that the growth parameters and yield component of cotton plant were significantly reduced under drought condition.

As for the interaction effect, the data showed that growth and yield components characters were significantly affected by the interaction between potassium fertilization and irrigation treatment. Under drought stress treatment, added 96 kg K/ha + foliar application of potassium sulphate or nano chitosan-NPK solutions twice gave values of growth and yield component parameters, statistically equal to those received full irrigation water. This means that combined soil application of K with foliar application of potassium sulphate or nano chitosan-NPK could diminution the negative effects resulted by drought stress. The mechanism associated with this synergistic effect of K on alleviate the negative effect of drought can be explained by the fact that K application led to a reduction in transpiration rate that depends to osmotic potential of the mesophyll of cells and controlled the opening and closing of stomata

(Farrag et al, 2015). In addition, Roza et al (2013) mentioned that potassium has controlled water transport in plant, maintain cell pressure and regulate the closing and opening of the stomata. These results are in line with those obtained by Abd El-Gayed and Bashandy (2018), Shahzad et al (2019) and Zhao et al (2019) who stated that K-application eliminates the negative effect of drought conditions for cotton plant.

3.2 Cotton yield parameters

Data in Table 5 represent the response of earliness percentage, lint percentage and seed cotton yield to potassium, nano chitosan-NPK and irrigation treatments as well as their interaction. As for the main effect of potassium fertilization, the data indicate that comparing with control (K_1) potassium application increased all studied yield parameters, except earliness (%) which adversely affected. The maximum seed cotton yield was achieved from the treatment of 96 kg K/ha + foliar application of 2% nano chitosan-NPK solution twice (K_3) followed by 96 kg K/fed + foliar application of 2% potassium sulphate solution twice (K_2), which increased by about 50.45 and 39.73% over control (K_1) in the first season, respectively. Similar trends were obtained in second season. It is worthy to notice that potassium treatments (K_2, K_3, K_4 and K_5) unaffected earliness and lint percentages, where the difference among its effect not reached to the significance values. The beneficial effect of potassium on seed cotton yield could explained by the increases in number of bolls/plant and boll weight through increased carbohydrate flow to the developing boll load, meanwhile reduced shedding of young bolls (Coker et al, 2009). Whereas, the promotive effect of potassium comparing with control on lint (%) may be due to the direct role of potassium on RNA synthesis and consequently on protein formation, hence effects fiber growth (Darwish, 1991).

Table 5. Yield parameters as affected by chemical and nano-particles potassium fertilization and irrigation number.

Treatments		Earliness (%)		Lint (%)		Seed cotton yield (kentar/ha)	
Number of irrigation (A)	K-fertilization (B)	2019	2020	2019	2020	2019	2020
9 irrigations (I_1)	K_1*	81.5	79.3	38.9	39.2	18.16	18.92
	K_2	78.3	76.6	40.5	41.4	21.44	22.40
	K_3	78.6	76.4	40.6	41.3	23.16	24.09
	K_4	78.5	76.5	40.6	41.3	19.66	20.59
	K5	78.7	76.4	40.7	41.4	20.49	21.30
Mean		79.1	77.0	40.3	41.92	20.59	21.47
6 irrigations (I_2)	K_1	84.3	82.6	35.2	36.6	12.23	13.07
	K_2	81.2	79.8	40.4	41.3	21.42	22.28
	K_3	81.3	79.6	40.5	41.1	22.87	24.04
	K_4	81.3	79.6	40.5	41.2	15.78	15.83
	K_5	81.5	79.6	40.6	41.2	16.47	16.61
Mean		81.9	80.2	39.4	40.3	17.76	18.37
Mean of K	K_1	82.9	81.0	37.1	37.9	15.21	15.99
	K_2	79.8	78.3	40.5	41.4	21.44	22.35
	K_3	80.0	78.0	40.6	41.2	23.01	24.06
	K_4	79.9	78.1	40.6	41.3	17.73	18.21
	K_5	80.1	78.0	40.7	41.3	18.49	18.97
L.S.D at 0.05	A	0.86	0.82	0.55	0.57	1.00	1.14
	B	0.72	0.70	0.52	0.54	0.98	1.07
	AB	Ns	Ns	0.81	0.86	1.50	1.64

*K_1= 96 kg K/ha. K_2= 96 kg K/ha + foliar application of 2% potassium sulphate twice. K_3= 96 kg K/ha + foliar application of 2% nano chitosan-NPK twice. K_4= foliar application of 2% potassium sulphate four times. K_5= foliar application of 2% nano chitosan-NPK four times.

The negative effect of potassium application on earliness% may be due to K application led to increase vegetative growth as discussed before, consequently delayed the start of flowering, hence delayed the maturing of lint (Elayan et al, 2018). In addition, potassium fertilization enhanced absorption of nitrogen, consequently led to vigorous growth, which in turn delayed lint maturity (Ali et al, 2007).

The superiority of combined soil and foliar application of K (K_2 and K_3) is mainly due to soil application is the best method to supply nutrients including potassium, meanwhile the maximum need for K is during boll filling at late season, where cotton roots are less active. In this case, foliar application has been successfully used to partially supply with potassium for high yield (Coker et al, 2009). Similar results were obtained by Wang et al (2014) and Li et al (2020) for seed cotton yield, and Abd El-Gayed and Bashandy (2018) and Elayan et al (2018) for earliness and lint percentages. Moreover, Hussien et al (2015) and Eed et al (2018) reported that nano-particles potassium fertilizer increased cotton productivity.

With regard to the effect of irrigation treatment on seed yield parameters, the obtained data show that reducing number of irrigations resulted in markedly decrement in both lint percentage and seed cotton yield, while earliness percentage increased under drought stress conditions. Relative to well-water condition, the decreasing percentages in lint (%) and seed cotton yield caused by deficit irrigation reached to 2.2 and 13.8% in the first season and 3.9 and 14.4% in the second one, respectively. The negative effect of deficit irrigation on cotton productivity may be attributes to lack soil moisture led to reduce soil nutrient availability, in turn its absorption and translocation as well as restrict the photosynthesis processes. On the other hand, well-watered plants induce better root activity, which enhanced the ability of roots to absorbed nutrients (Wang et al, 2014). As for earliness (%), Soeda et al (2005) mentioned that deficit water condition resulted in changes in metabolism process direction by accelerating sucrose translocation from leaves to seeds. Also, Riboni et al (2013) stated that drought stress caused early flowering stage owing to elaborate network of floral signalling pathways. These results are in accordance with those obtained by Zhao et al (2019) and Li et al (2020) for lint percentage and seed cotton yield, and Hamoda et al (2014) and Abd El-Hafeez and Abd El-Gayed (2019) for earliness percentage. Also, Mohamed and Abd El-Gayed (2020) mentioned that nano-particles natural rock increased cotton yield components.

The data of the interaction between potassium and irrigation treatments reveal that lint percentage and seed cotton yield were significantly affected by the interaction between both treatments. Under the treatment of mixed soil and foliar application treatment, increased irrigation number from 6 to 9 did not negatively affect lint% and seed cotton yield. This means that potassium fertilization as soil and foliar application enhanced the tolerance of cotton to drought stress. Soil and foliar potassium application improved root growth, consequently, induce more survive for plant under deficit conditions as well as encourage the plant to absorb more nutrients (Pettigrew, 2008). In general, the highest values of seed cotton yield were obtained for the treatment of 96 kg K/ha + foliar application of 2% nano chitosan-NPK solution twice under full irrigation or drought stress conditions. While, the treatment 96 kg K/ha under deficit water exhibited the lowest seed cotton yield. These results are in parallel to those obtained by Zhang et al (2016) and Zhao et al (2019).

3.3 Cotton fiber properties

The data in Table 6 show the effect of potassium and irrigation treatments and their interaction on some fiber properties, namely, presley index, micronaire reading, fiber length and uniformity index. The obtained data reveal that all studied fiber properties unaffected by potassium and irrigation treatments as well as their interaction. Many workers reported that fiber properties did not respond to potassium or irrigation treatments such as Elayan et al (2018) and Shahzad et al (2019) for potassium and Zhang et al (2016) and Abd El-Hafeez and Abd El-Gayed (2019) for irrigation. In contrast, other authors found linear relationship between fiber properties and potassium or irrigation treatments, i.e., Read et al (2006), Pettigrew (2008) and Wang et al (2014) for potassium and Hamoda (2014), and Li et al (2020) for irrigation. These inconsistencies in the effect of potassium fertilization and water application on fiber properties of cotton plant may be due to the effect of these factors may be only exerts an indirect effect on fiber properties as well as these properties have a genetically effect (Pettigrew, 2008).

3.4. Leaf chemical contents:

The data of leaf chemical contents, i.e., N, P and K as well as chlorophyll a and b and carotenoids (Table 7) reveal that potassium fertilization was significantly affect these chemical contents, except phosphorus concentration. Comparing with control, potassium application increased N, K, chlorophyll a and b and carotenoids, where the treatment of 96 kg K/fed + 2% foliar application of nano chitosan-NPK solution twice seem to be the best treatment. The positive effect of potassium on the leaf chemical contents is mainly due to K application resulted in increased root growth rate, length, and surface, in turn improved nutrient uptake (Rosolen et al, 2003). In this respect, Pettigrew (2008) mentioned that K induced in many physiological processes, e.g., photosynthesis, assimilate nutrient translocate, water relation and protein formation, consequently improved pigments in leaves. In addition, Zhang (2009) reported that deficient potassium inhibited

Table 6. Some fiber properties as affected by chemical and nano-particles potassium fertilization and irrigation number.

Treatments		Pressley index		Micronaire reading		Fiber length 2.5%		Uniformity index	
Number of irrigation (A)	K-fertilization (B)	2019	2020	2019	2020	2019	2020	2019	2020
9 irrigations (I_1)	K_1*	9.3	9.4	4.3	4.4	31.2	31.4	82.4	82.6
	K_2	9.4	9.3	4.4	4.3	31.3	31.3	82.3	82.4
	K_3	9.5	9.4	4.3	4.4	31.4	31.5	82.3	82.4
	K_4	9.4	9.4	4.3	4.4	31.3	31.4	82.3	82.3
	K5	9.4	9.5	4.4	4.3	31.3	31.4	82.2	82.4
Mean		9.4	9.4	4.3	4.4	31.3	31.4	82.3	82.4
6 irrigations (I_2)	K_1	9.4	9.5	4.4	4.3	31.3	31.5	82.3	82.5
	K_2	9.3	9.4	4.3	4.4	31.4	31.4	82.4	82.6
	K_3	9.4	9.5	4.4	4.4	31.3	31.4	82.3	82.4
	K_4	9.5	9.3	4.4	4.3	31.4	31.3	82.3	82.4
	K_5	9.4	9.4	4.3	4.4	31.3	31.4	82.3	82.3
Mean		9.4	9.4	4.4	4.4	31.3	31.4	82.3	82.4
Mean of K	K_1	9.4	9.5	4.4	4.4	31.3	31.5	82.4	82.6
	K_2	9.4	9.4	4.4	4.4	31.4	31.4	82.4	82.5
	K_3	9.5	9.4	4.4	4.4	31.4	31.5	82.3	82.4
	K_4	9.5	9.4	4.4	4.4	31.4	31.4	82.3	82.4
	K_5	9.4	9.5	4.4	4.4	31.3	31.4	82.3	82.4
L.S.D at 0.05	A	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
	B	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
	AB	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns

*K_1= 96 kg K/ha. K_2= 96 kg K/ha + foliar application of 2% potassium sulphate twice. K_3= 96 kg K/ha + foliar application of 2% nano chitosan-NPK twice. K_4= foliar application of 2% potassium sulphate four times. K_5= foliar application of 2% nano chitosan-NPK four times.

root length and formation of lateral roots. These results agree with those obtained by Kadam et al (2017) and Abd El-Gayed and Bashandy (2018) for the effect on N and K concentration, and Yang et al (2017) for leaf pigments. The superiority of foliar application of nano chitosan-NPK is mainly due to its molecule is very small (less than 30 nm) and having higher specific surface area/unit size as mentioned before (Hussain et al, 2020).

As for the main effect of irrigation treatment, the data indicate that well-watered cotton plants contain higher N, P and K as well as chlorophyll a and b and carotenoids in its leaves than the plants under drought stress. The decrement in these constituents caused by reducing irrigation water may be due to deficit water led to decrease both nutrient uptake by roots and transport from roots to the vegetative organs (Helal et al, 2013). Also, the reduction in leaf pigments may be due to drought stress led to membrane disintegration and damage chloroplasts by overproduction of reactive oxygen species (Karimi, 2016). These results are in line with those obtained by Wang et al (2014) and Abd El-Hafeez and Abd El-Gayed (2019).

The leaf chemical contents did not respond to the interaction between potassium fertilization and irrigation number. The highest values of leaf chemical contents were obtained for plants fertilized with 96 kg K/ha plus foliar application of 2% nano chitosan-NPK solution twice and irrigated 9 irrigations. Whereas, the plants fertilized with 96 kg K/ha and watered 6 irrigations possessed the lowest values.

Table 7. leaf chemical constituents as affected by chemical and nano-particles potassium fertilization and irrigation number.

Treatments		N (%)		P (%)		K (%)		Chlorophyll a (mg/g f.wt)		Chlorophyll b (mg/g f.wt)		Carotenoids (mg/g f.wt)	
Number of irrigation (A)	K-fertilization (B)	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
9 irrigations (I_1)	K_1*	2.21	2.18	0.41	0.46	2.55	2.49	3.07	3.00	2.21	2.19	0.56	0.57
	K_2	2.56	2.52	0.42	0.46	3.01	2.97	3.28	3.26	2.68	2.66	0.68	0.69
	K_3	2.73	2.69	0.42	0.45	3.28	3.20	3.31	3.28	2.75	2.74	0.71	0.71
	K_4	2.38	2.35	0.41	0.45	2.77	2.68	3.35	3.32	2.91	2.90	0.77	0.78
	K5	2.49	2.46	0.41	0.46	2.85	2.77	3.47	3.44	2.96	2.97	0.81	0.83
Mean		2.47	2.44	0.41	0.46	2.98	2.82	3.30	3.25	2.70	2.69	0.71	0.70
6 irrigations (I_2)	K_1	2.01	2.00	0.32	0.35	2.33	2.28	2.86	2.84	2.02	2.00	0.50	0.52
	K_2	2.34	2.31	0.33	0.36	2.89	2.80	3.26	3.23	2.67	2.65	0.67	0.68
	K_3	2.55	2.52	0.33	0.35	2.97	2.91	3.30	3.27	2.73	2.72	0.70	0.72
	K_4	2.20	2.16	0.32	0.35	2.54	2.47	3.33	3.31	2.89	2.87	0.75	0.76
	K_5	2.28	2.22	0.33	0.35	2.67	2.60	3.48	3.45	2.95	2.93	0.80	0.81
Mean		2.28	2.24	0.33	0.35	2.68	2.61	3.25	3.22	2.65	2.63	0.68	0.70
Mean of K	K_1	2.11	2.09	0.37	0.41	2.44	2.39	2.97	2.92	2.12	2.10	0.53	0.55
	K_2	2.45	2.42	0.38	0.41	2.95	2.89	3.27	3.25	2.68	2.66	0.68	0.69
	K_3	2.64	2.61	0.38	0.40	3.13	3.06	3.31	3.28	2.74	2.73	0.71	0.72
	K_4	2.29	2.26	0.37	0.40	2.66	2.58	3.34	3.32	2.90	2.89	0.76	0.77
	K_5	2.39	2.36	0.37	0.41	2.76	2.69	3.48	3.45	2.96	2.95	0.81	0.82
L.S.D at 0.05	A	0.07	0.06	0.05	0.05	0.09	0.08	0.11	0.10	0.07	0.06	0.03	0.04
	B	0.08	0.07	Ns	Ns	0.09	0.07	0.09	0.09	0.07	0.05	0.02	0.03
	AB	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns

*K_1= 96 kg K/ha. K_2= 96 kg K/ha + foliar application of 2% potassium sulphate twice. K_3= 96 kg K/ha + foliar application of 2% nano chitosan-NPK twice. K_4= foliar application of 2% potassium sulphate four times. K_5= foliar application of 2% nano chitosan-NPK four times.

3.4. Water relations:

3.4.1 Irrigation water applied (IWA, m^3/ha):

The water applied for cotton plants as affected by two irrigation treatments are given in Table 8. The data reveal that the total amount of applied water for both irrigation treatments were 12387.90 and 8634.64 m^3/ha for the first season and 12644.94 and 8794.10 m^3/ha for the second one. It is obvious to notice that the applied water was decreased by about 30.3 and 30.5% when decreased the irrigation number from 9 to 6 in both growing seasons, respectively.

Table 8. Application water (m^3/ha) and number of irrigations under irrigation treatments.

Irrigation events	Irrigation number			
	9 irrigations		6 irrigations	
	2019	2020	2019	2020
Planting irrigation	1676	1697	1685	1690
fixing irrigation	1300	1309	1302	1314
Third irrigation	1373	1409	1380	1419
Fourth irrigation	1404	1440	1409	1445
Fifth irrigation	1469	1476	1464	1480
Sixth irrigation	1409	1435	1419	1447
Seventh irrigation	1388	1414	-	-
Eight irrigation	1309	1357	-	-
Ninth irrigation	1062	1109	-	-
Total	**12388**	**12645**	**8635**	**8794**
Number of irrigations	**9**	**9**	**6**	**6**

3.4.2 Water consumptive use (CU, m^3/ha):

The data of the seasonal water consumptive use as affected by potassium and irrigation treatments are given in Table 9. As for the main effect of potassium treatments, the obtained results indicated that mixed 96 kg K/ha with foliar application of nano chitosan-NPK or K_2SO_4 solution twice gave the highest values of CU (8437 and 8363 in first season and 8449 and 8373 m^3/ha in the second one, respectively). Whereas, cotton plants fertilized with 48 kg K/ha exhibited the lowest ones (8066 and 8083 m^3/ha in both seasons, respectively.

The superiority caused by combined soil and foliar application of potassium may be due to these treatments encourage root and shoot growth than other treatments as mentioned before, hence absorbed greater amounts of water. These results are in line with those obtained by Farrag et al (2015) and Abd El-Gayed and Bashandy (2018).

Considering irrigation treatment, the data show that in comparison with full irrigation, irrigated cotton plants 6 irrigations resulted in decrement of seasonal consumptive use by about 19.6% for both growing seasons. In this concern, Ewis et al (2015) reported that the increment in CU under full irrigation may be attributed to the abundance of soil moisture in soil, beside the plant tends to grow without water stress in the last stage of growth. Furthermore, Abd El-Latif et al (2016) stated that the seasonal consumptive use by plants depended on occurrence of soil moisture in the root zone and the stage of plant growth. These results are in harmony with those obtained by Zhang et al (2016) and Zonta et al (2016).

As for the interaction, the data reveal that seasonal consumptive use unaffected by the interaction between potassium and irrigation treatments. In general, the plants fertilized with 48 kg K/ha and watered 6 irrigations recorded the lowest amount of CU in both seasons. On the other hand, the plants supplied with 96 kg K/ha + foliar application of 2% nano chitosan-NPK or K_2SO_4 solution twice and irrigated 9 irrigations gave the greatest seasonal consumptive use.

3.4.3. Water use efficiency (WUE) and Water productivity (WP):

Data of WUE and WP as affected by potassium fertilization and irrigation number are given in Table 9. As for the main effect of potassium, the data show that, at the same irrigation number both WUE and WP had similar trends as for seed cotton yield, where the highest values for these two relations were obtained under the treatment of combined 96 kg K/ha with foliar application of 2% nano chitosan-NPK solution twice (0,44 and 0.36 in the first season and 0.46 and 0.37 kg/m^3 in the second one, respectively), the positive effect of this potassium treatment on WUE and WP is mainly due to its effect on seed cotton yield as discussed before. Similar results were obtained by Abd El-Gayed and Bashandy (2018) and Li et al (2020).

Table 9. Water consumptive use, water use efficiency and water utilization efficiency as affected by chemical and nano-particles potassium fertilization and irrigation number.

Treatments		Applied water (m^3/ha)		Water consumptive use (CU, m^3/ha)		Water use efficiency (WUE, kg/m^3)		Water utilization efficiency (WP, kg/m^3)	
Number of irrigation (A)	K-fertilization (B)	2019	2020	2019	2020	2019	2020	2019	2020
9 irrigations (I_1)	K_1*			9011	9030	0.32	0.33	0.23	0.24
	K_2			9263	9275	0.36	0.38	0.27	0.28
	K_3			9296	9311	0.39	0.41	0.29	0.31
	K_4			9065	9077	0.34	0.36	0.25	0.26
	K5			9065	9189	0.35	0.37	0.26	0.27
Mean		12388	12645	9139	9177	0.35	0.37	0.26	0.27
6 irrigations (I_2)	K_1			7119	7135	0.27	0.29	0.22	0.23
	K_2			7461	7468	0.45	0.47	0.39	0.40
	K_3			7576	7585	0.48	0.50	0.42	0.43
	K_4			7290	7307	0.34	0.34	0.29	0.28
	K_5			7290	7383	0.35	0.35	0.30	0.30
Mean		8635	8794	7347	7376	0.38	0.39	0.32	0.33
Mean of K	K_1			8066	8082	0.30	0.31	0.23	0.24
	K_2			8363	8373	0.41	0.43	0.33	0.34
	K_3			8437	9449	0.44	0.46	0.36	0.37
	K_4			8178	8192	0.34	0.34	0.27	0.27
	K_5			8178	8287	0.35	0.36	0.28	0.29
L.S.D at 0.05	A			184	194	0.02	0.03	0.02	0.03
	B			171	182	0.03	0.03	0.02	0.04
	AB			Ns	Ns	Ns	Ns	Ns	Ns

*K_1= 96 kg K/ha. K_2= 96 kg K/ha + foliar application of 2% potassium sulphate twice. K_3= 96 kg K/ha + foliar application of 2% nano chitosan-NPK twice. K_4= foliar application of 2% potassium sulphate four times. K_5= foliar application of 2% nano chitosan-NPK four times.

With respect to irrigation number, the results show that, regardless potassium treatments, WUE and WP increased as irrigation number increased from 6 to 9, which may be due to the increase in water loss through leaching processes. Similar results were obtained by Dagdelen et al (2006) and Li et al (2020) who found that water utilization efficiency increased as the amount of irrigation decreased. As for the interaction between treatments, the results clearly indicate that both WUE and WP did not respond to the interaction between potassium and irrigation treatments. This means the highest values of WUE and WP were recorded under the treatment of 96 kg K/ha as soil application + foliar application of 2% nano chitosan-NPK solution twice and watered 9 irrigations. Whereas, the plants supplied with 48 kg K/ha and irrigated 6 irrigations exhibited the lowest ones.

4. CONCLUSION

From the present study, it could be concluded that irrigation of cotton plants 6 irrigations and fertilization with 96 kg K/ha as soil application + foliar application of 2% nano chitosan-NPK twice can produce seed cotton yield, statistically equal to those irrigated 9 irrigations. Under conditions of arid region in Egypt, to conserve limited water resources, it could be recommended to irrigate cotton plants 6 irrigations which saving about three irrigations (about 3808 m^3/ha) provided that fertilization the soil with potassium and application cotton plants with nano chitosan-NPK.

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الملخص العربي

اثر الاجهاد المائي علي نباتات القطن المسمد بالتسميد البوتاسي والسماد النانو كيتوزان المحمل بالنيتروجين والفوسفور والبوتاسيوم

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أجريت تجربتان حقليتان بالمزرعة البحثية بمحطة البحوث الزراعية بسدس– مركز البحوث الزراعية– مصر فى موسمى النمو ٢٠١٩ و ٢٠٢٠ لدراسة إمكانية زيادة قدرة نبات القطن على تحمل نقص مياه الري بالتسميد البوتاسي والسماد النانوكيتوزان المحمل بالنيتروجين والفوسفور والبوتاسيوم. وقد استخدم تصميم القطع المنشقة في تنفيذ التجارب، حيث وضعت معاملات الري (الري كل ٦ و ٩ ريات) فى القطع الرئيسية، بينما وضعت معاملات البوتاسيوم (بو١= ٩٦ كجم بو /هكتار، بو٢=٩٦ كجم بو/هكتار + الرش مرتين بمحلول كبريتات البوتاسيوم ٢%، بو٣= ٩٦ كجم بو /هكتار + الرش مرتين بمحلول السماد والسماد النانوكيتوزان المحمل بالنيتروجين والفوسفور والبوتاسيوم ٢% ، بو٤= الرش أربع مرات بمحلول كبريتات البوتاسيوم ٢%، بو٥= الرش أربع مرات بمحلول والسماد النانوكيتوزان المحمل بالنيتروجين والفوسفور والبوتاسيوم ٢% في القطع المنشقة، ويمكن تلخيص أهم النتائج فيما يلى:–

– أدت معاملة بو٣ يليها بو٢ إلى الحصول على أفضل قيم لطول النبات، موقع أول فرع ثمرى، عدد الأفرع الثمرية، عدد اللوز المتفتح، وزن اللوزة ووزن المائة حبة، تصافى الحليج ومحصول القطن الزهر، التركيب الكيميائي لورقة القطن (تركيز النيتروجين والبوتاسيوم ما عدا تركيز الفوسفور، والكلوروفيل أ، ب والكاروتينات) وكذلك الاستهلاك المائى الموسمى وكفائة استخدام المياه وكفائة الانتفاع بالمياه.

– أدي رى نبات القطن ٩ ريات الى أفضل قيم لصفات النمو، والمحصول ومكوناته والتركيب الكيميائى لورقة القطن ما عدا تركيز الفوسفور، الكمية الكلية للمياه المضافة، وكمية المياه الموسمية المستخدمة، بينما أثرت بالسلب على كفائة استعمال المياه وكفائة الانتفاع بالمياه.

– انخفضت نسبة التبكير بالتسميد البوتاسي بزيادة مياه الري، ولم تتأثر صفات البتله بمعاملات البوتاسيوم أو الرى.

– توضح نتائج التداخل بين المعاملات على أن تسميد نبات القطن بالمعاملة بو٣ مع الرى كل ٦ ريات أدى الى أعلى انتاجية للقطن مساويا احصائيا لمعاملة الرى الموصي بها (٩ ريات)، وهذا يشير الى امكانية تخفيف الضرر الناتج من نقص مياة الرى لنبات القطن بتسميده بمعدل ٩٦ كجم بو /هكتار + رش محلول والسماد النانوكيتوزان المحمل بالنيتروجين والفوسفور والبوتاسيوم بمعدل ٢% مرتان.

ونظرا لمحدودية مياة الرى واحتمالية نقصانها، وتحت ظروف منطقة مصر الوسطى يمكن التوصية برى نبات القطن كل ٦ ريات مع تسميده بالبوتاسيوم بمعدل ٩٦ كجم بو/هكتار + الرش مرتان بمحلول والسماد النانوكيتوزان المحمل بالنيتروجين والفوسفور والبوتاسيوم بتركيز ٢% للحصول على أعلى انتاجية مساوية لمعاملة ٩ ريات، مما يؤدى الى توفير ثلاث ريات (حوالي ٣٨٤٠ م^3/هكتار).