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Effect of Nano and Mineral Selenium Application on Chemical, Yield and Technological Properties of Cotton Under Water Deficit Condition

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Abstract

Water deficit conditions restrict cotton growth and productivity by disrupting plants biochemical and physiological process. Selenium (Se) improves plant physiological and antioxidant properties under stress conditions. The current study was carried out in 2020 and 2021 seasons at Mallawi station, Cotton Research Institute, Agricultural Research Centre, Minya, Egypt. The experiment design was split-plot with three replications, which main plots were devoted to irrigation intervals treatments of normal irrigation (NI) and irrigation water deficit (IWD), while the sub-plots were randomly of spraying Se in mineral and nano-forms (mSe and nSe) at 50 and 100 ppm concentration at twice squaring and flowering stages to evaluate the effect of mSe and nSe on leaves chemical constituent, growth, yield, fiber and yarn properties of Giza 95 cotton cultivar. The results stated that IWD conditions reduced significantly pigments, yield, fiber and yarn properties, whereas increased significantly enzymes activity and osmoprotecant compounds compares to NI conditions. Foliar application of Se enhanced significantly all chemical constituent, growth, yield, fiber and yarn properties, which nSe (50 ppm) recorded the highest results then nSe (100 ppm) and mSe (100 ppm) compared to untreated plants. The interaction between two factors affected significantly in almost studied parameters, which the maximum values gave by spraying nSe (50 ppm) then nSe (100 ppm) comparing with control under NI and IWD conditions in both seasons. Finally, selenium nano particles were more effective in all studied parameters especially under IWD conditions to amelioration the adverse effects of stress conditions.

Keywords: Cotton, Irrigation water deficit, Selenium, chemical constituent, yield components, fiber and yarn properties.

1. Introduction

Irrigation water deficit (IWD) effects in different physiological and metabolic processes of plant that due to reduce plant growth, productivity and yield quality, almost 45% of agricultural lands under constantly drought conditions [1 and 2]. Long-term exposure cotton plants to drought conditions led to inhibition of photosynthesis, stomata closure, accumulation osmoprotectant compounds such as soluble sugars, free amino acids, total phenols and increase the activation of antioxidant system including catalase (CAT) and peroxidase (POD) for reducing the generation of reactive oxygen species (ROS) [3 and 4]. Exposing cotton plant to drought stress during flowering, boll formation and fiber elongation stages that due to harmful effects such as decreasing plant growth, number of fruiting branches/plant, boll distribution, development number of bolls yield and fiber quality properties [5 and 6]. In addition to, the endogenous of anti-drought compounds not enough for plant resist to long-term under drought conditions, so that used exogenous to improve plant resist water deficit conditions worthily.

Egyptian cotton is an important fiber crop in the textile industry, which is known as extra-long staple fibers comparing with the other cotton of all over the world. Egyptian cotton is the best world's cotton that due to have some great characteristics such as fiber length, which it able to make the best of yarns with the good strength of the yarn. The fiber strength makes fabric and yarn more solid and stress resistant [7]. Cotton fiber quality properties such as fiber length, micronair value and fiber strength affected significantly by stress conditions, which cotton plants exposed to drought stress reduced fiber revalue especially through fiber maturation stage that due to decreased fiber size, fiber immaturity, fiber length and fiber strength [8, 9, 10 and 11]. However, Book et al. [12] inducted that drought stress increased cotton fiber strength. Also, Dagdelen et al. [13] and Snowden et al. [14] found that the micronair reading decreased under short-term of drought stress

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conditions and increased under long-term of drought conditions.

Nano-fertilizer enter directly the stomata of plant leaves and transport to different organs, which its dimensions is (1-100 nm) that less than plants cell wall pores size so it cross easily [15 and 16].

Selenium (Se) is an important micronutrient for physiological and antioxidants processes, which it absorbed and makes the same capacity pathway of sulfur in plant, so it found in selenium amino acids like selenomethionine and selenocysteine [17]. Besides that, Se used as bio-fertilizer with bio-fortifications functions for plant tolerance under abiotic conditions, which Se preserved turgor, decreased the osmotic potential, advanced the accumulation of osmoprotectant compounds and antioxidant enzymes [18, 19 and 20], enhanced carotenoids and proline contents [21], modified the uptake of essential elements, keep ions balance, cells structural [22] and reduced membrane damage and ROS generations [23] that with low concentrations of Se, while high concentrations have harmful effects on plants under both normal and stress conditions [24 and 25]. Se foliar application is more effective than soil addition, safe and economic for plant [26]. Nano-selenium (nSe) application alleviated the negative effects of drought stress on plant via enhancing photosynthetic pigments, antioxidant activity, growth and yield characters [27].

The aim of the present study to investigate and evaluate the effect of mineral and nano selenium (mSe and nSe) foliar application under different irrigation intervals of normal irrigation (NI) and irrigation water deficit (IWD) on chemical constituents, growth traits, yield component, fiber and yarn properties of Giza 95 cotton cultivar in 2020 and 2021 seasons.

2. Material and method

2.1. Experimental design and treatments

The experiment was conducted in two seasons 2020 and 2021 at Mallawi Research Station of Plant Physiology Department, Cotton Research Institute, Agricultural Research Center, Minya, Egypt. A split plot design with three replications was adopted, the main plots were randomly assigned to irrigation intervals including NI and IWD then the sub-plots were randomly assigned for seven treatments as follows: untreated plants (control), mSe 50 ppm and 100 ppm, nSe 50 ppm and 100 ppm to study the effect of foliar application of mSe and nSe of cotton plants on leaves chemical constituents, growth traits, yield component, fiber and yarn properties under NI and IWD conditions. Seeds of cultivar Giza 95 were sown in clay loam soils on 24th of April in 2020 season and on the 28th April in 2021 season. The experimental plot consisted of 7 rows, 3.5 m long and 0.6 m width (plot area = 14.70 m^2). Plots divided to two groups the first one irrigated every two weeks (NI) and the second one irrigated every four weeks (IWD). Plants were sprayed with mSe and nSe twice at squaring and flowering stages in both NI and IWD conditions, beside the untreated plots (NI and IWD treatments).

All experimental plots received irrigation, pesticide and fertilizer as recommended by the Egyptian Ministry of Agriculture for cotton cultivation. The soil analysis was conducted according to Rebecca [28], which soil chemical properties of the experimental field are showed in table (1).

Table (1). Chemical properties of experimental soil during 2020 and 2021 seasons.

	2020	2021		2020	2021
pH	8.09	8.14	**Soluble anions (meq/l)**		
E.C. (dsm^{-1})	1.32	1.36	**CO_3^{2-}**	--	--
Available minerals (mg/Kg soil)			**HCO_3^-**	1.24	1.00
N	55.73	57.42	**Cl^-**	2.27	2.00
P	12.65	15.89	**SO_4^{2-}**	0.73	0.60
K	504.28	537.53	**Soluble cations (meq/l)**		
Cu	9.35	9.68	**Ca^{2+}**	1.68	1.53
Fe	37.62	38.25	**Mg^{2+}**	0.69	0.62
Mn	9.48	10.06	**Na^+**	1.45	1.21
Zn	13.85	15.17	**K^+**	0.34	0.26

2.2. Chemical analysis

Leaves samples were taken randomly after the second spraying plants with mSe and nSe at flowering stage to determine the chemical analysis as follows:

2.2.1. Total chlorophyll content was determined by the method of Arnon [29] and Robbeten [30] assayed carotenoids contents.

2.2.2. Total soluble sugars content was determined in ethanol extract by the method of phenol-sulfuric acid according to Cerning [31].

2.2.3. Total free amino acids content was determined in ethanol extract according to Rosen [32] by ninhydrin method.

2.2.4. Total phenols were assayed in ethanol using method of Folin-Ciocalteau according toSimons and Ross [33].

2.2.5. Free proline content was assayed according to method of Bates *et al.* [34] as μmoles of proline/g of fresh weight.

2.2.6. Total antioxidant capacity was determined in ethanol extract by method of phosphomolybdenum as described by Kumara and Karunakaran [35].

2.2.7. Antioxidant enzymes extraction was prepared for assay enzymes activities according to Choudhury and Panda [36].

2.2.8. Assay of CAT activity was measured according to the method of Sinha [37].

2.2.9. Assay of POD activity was measured according to the method of Herzog and Fah [38].

2.3. Growth traits, yield and its components

Growth and yield samples were taken from three plots at harvest stage. Growth traits including plant height (cm), number of fruiting branches/plant. Yield and its components such as number of opened boll/plant, boll weight (g), lint %, seed index (g) and yield k/f were recorded.

2.4. Fiber and yarn quality properties

Giza 95 as long staple cotton cultivar was used for this study. All samples were spun into 40s carded yarns and 3.6 twist multiplier using ring spinning at the spinning mill, cotton spinning research department, Cotton Research Institute, Agriculture Research Center, Giza.

Fiber tests were examined in fiber research department, Cotton Research Institute, Agriculture Research Center, Giza. High Volume Instrument (HVI) according to ASTM (D:4605-1986) [39] was used to measure fiber length, short fiber index, fiber uniformity, micronaire value, maturity ratio, reflectance (Rd%), yellowness degree (+b), fiber strength (g/tex) and fiber elongation (%). Single yarn strength (cN/tex) and yarn elongation (%) were tested in Cairo secondary school for spinning and weaving. Before testing, all samples were conditioned for 24 hours under the standard atmospheric conditions (21 ± 2˚C temperature, 65 ± 2% relative humidity).

2.5. Statistical Analysis

The variables analyzed by ANOVA using M Stat-C statistical package [40]. Mean comparisons were done using method of least significant differences (L.S.D) at 5% level ($P \leq 0.05$) of probability for comparing differences between the means [42].

3. Result and discussion

3.1. Cotton leaves chemical constituents

The obtained results in Table (2) revealed that the irrigation intervals (NI and IWD), selenium foliar application (mSe and nSe) and their interaction effect on cotton leaves chemical constituents of total chlorophyll, carotenoids, soluble sugars, free amino acid, proline, phenols contents, antioxidant capacity and enzymes activities of catalase and peroxidase.

Considering the irrigation intervals (NI and IWD) treatments, the data mentioned that IWD treatment reduced significantly the cotton leaves contents of total chlorophyll by 38.37%, carotenoids by 45.13%, while increased significantly the leaves contents of total soluble sugars by 15.01%, total free amino acids by 93.38%, free proline by 710.14%, total phenols by 37.61%, total antioxidant capacity by 61.41% and the activity of CAT by 66.18% and POD 59.95%, respectively, compared to NI treatments.

The decrease of cotton leaves pigment contents under IWD treatment might be related to the reduction of plant leaves numbers and increasing ROS generation that due to decrease in photosynthesis rate and chlorophyll content [23 and 25]. On the other hand, leaves contents of total soluble sugars increased as a result to its serious role as osmoprotectant in cotton plant under stress conditions. Moreover, free amino acids accumulated specially proline in high concentrations, which it acted as ROS detoxification and source of energy and nitrogen for plant under stress [4]. Likewise, the increasing of total phenols and antioxidant capacity under stress which it acts as photosynthesis protection, ROS scavenger and increasing the enzymes activity of CAT and POX as strategy to reduce stress harmful effects on plants. These results are in line with Saleem *et al.* [6] and Shallen *et al.* {15] who, obtained that cotton plant under stress increased total phenols, soluble sugars and total antioxidant compounds to improve plant tolerance. Also, Sattar *et al.* [20] noted that CAT and POX activates increased to reduce ROS production under drought stress on plants.

As for foliar application of selenium (mSe and nSe), the results clearly noticed that spraying selenium in mineral (mSe) and nano (nSe) forms increased significantly all leaves chemical constituents of total chlorophyll, carotenoids, soluble sugars, free amino acid, free proline, phenols contents, antioxidant capacity and enzymes activities of CAT and POD comparing with untreated cotton plants under both NI and IWD treatments. The best means recorded by spraying nSe with 50 ppm concentration, then nSe with 100 ppm and mSe 100 ppm concentration compared to control (untreated plants) under both NI and IWD conditions.

Foliar application of nSe (50 ppm) gave the best results of all chemical constituents of total chlorophyll by 29.79%, carotenoids by 31.01%, soluble sugars by 30.92%, free amino acid by 38.19%, free proline by 23.73%, total phenols by 25.18%, antioxidant capacity by 55.21%, CAT activity by 70.94% and POD activity by 67.93%, respectively, compared to untreated cotton plants.

Table (2). Effect of nano and mineral selenium under normal irrigation, irrigation water deficit treatments and the their interaction on total chlorophyll, carotenoids, total soluble sugars, total amino acid, proline, total phenols, contents, total antioxidant capacity, catalase and peroxidase activity in cotton leaves.

Irrigation intervals (A)	Selenium forms and concentrationppm (B)	Total chlorophyll (mg/g FW)	Carotenoids (mg/g FW)	Total soluble sugars (mg/g FW)	Total amino acids (mg/g FW)	Free proline (µmol/g FW)	Total phenols (mg/g FW)	Total antioxidant capacity ($O.D_{695nm}$)	Catalase activity (U/g protein)	Peroxidase activity (U/g protein)
Normal irrigation	Control	6.95	0.597	23.62	11.21	1.42	16.39	0.438	0.069	0.285
	mSe 50	8.15	0.705	28.89	13.57	1.97	18.55	0.477	0.134	0.388
	mSe100	8.48	0.822	30.09	14.89	2.29	18.39	0.619	0.162	0.500
	nSe 50	9.59	0.863	31.75	18.86	2.57	19.06	0.834	0.175	0.425
	nSe 100	8.66	0.814	30.82	16.32	2.14	18.67	0.744	0.153	0.513
Mean		**8.36**	**0.760**	**29.03**	**14.97**	**2.07**	**18.21**	**0.622**	**0.139**	**0.422**
Irrigation water deficit	Control	3.79	0.351	26.96	22.67	14.34	19.68	0.750	0.166	0.451
	mSe 50	5.05	0.412	31.94	26.31	16.56	25.27	0.981	0.203	0.655
	mSe100	5.66	0.439	34.29	30.28	17.02	24.83	1.086	0.258	0.743
	nSe 50	5.85	0.457	38.36	34.99	18.58	29.07	1.104	0.279	0.802
	nSe 100	5.28	0.428	35.41	30.51	17.37	26.48	1.099	0.247	0.722
Mean		**5.12**	**0.417**	**33.39**	**28.95**	**16.77**	**25.06**	**1.004**	**0.231**	**0.675**
General mean of selenium forms and concentrations (B)	Control	5.37	0.474	25.29	16.94	7.88	18.03	0.594	0.117	0.368
	mSe 50	6.60	0.558	30.41	19.94	9.26	21.91	0.729	0.168	0.521
	mSe100	7.07	0.631	32.19	22.58	9.65	21.61	0.853	0.210	0.622
	nSe 50	7.72	0.660	35.05	26.92	10.57	24.06	0.969	0.227	0.613
	nSe 100	6.97	0.621	33.11	23.41	9.75	22.57	0.922	0.200	0.618
LSD at 0.05 of	$A_{(t\ test)}$	**	**	**	**	**	**	**	**	**
	B	0.077	0.035	0.474	0.378	0.252	0.247	0.024	0.006	0.006
	A x B	0.109	0.050	0.671	0.534	0.356	0.349	0.034	0.009	0.008

The positive effects of Se application might be due to that Se regulated biochemical and physiological processes of plant by increasing pigment, soluble sugars, amino acids contents and activities of antioxidant system especially under IWD condition to increase plant tolerance. Se applications at low concentrations improved and protected photosynthesis from ROS damage and increased pigment contents [19]. Likewise, Se increased soluble sugars accumulation as osmoprotectant and shared in starch degradation by activation amylase enzyme under drought stress in plant [18]. Moreover, Se application improved soluble protein content and activated nitrate reductase that led to upset amino acids metabolism and increased its contents, especially proline that act as osmotic adjustment in plant under IWD conditions [24]. Additionally, Se increased total phenols and antioxidant enzymes activities like CAT and POD to detoxification ROS and enhanced plant resistant under stress. These results in agreement with Sattar *et al.* [20] who, demonstrated that Se application activated enzymes such as CAT, POD and antioxidant compounds to reduce oxidative stress. Similar, Ali *et al.* [25] and Zahedi *et al.* [27] found that Se application increased water ration, pigments, amino acids, proline, phenols, soluble sugars contents and antioxidant activity on plant under drought stress.

With regard to the interaction between irrigation intervals (NI and IWD) treatments and selenium foliar application (mSe and nSe), the finding in Table (2) stated that the increasing in all leaves chemical constituents (total chlorophyll, carotenoids, total soluble sugars, total free amino acids, free proline, total phenols, total antioxidant capacity and the activity of CAT and POD) due to spraying Se in both forms (mSe and nSe). The highest values of leaves chemical constituents were observed by spraying cotton plant via nSe with 50 ppm concentration then nSe with 100 ppm and mSe with 100 ppm concentration under two irrigation intervals treatments (NI and IWD). On the other hand, the untreated cotton plants confirmed that the lowest values of all leave chemical constituents in both NI and IWD conditions. In this concern, Nawaz *et al.* [18], Sattar *et al.* [20] and Zahedi *et al.* [27], who demonstrated that foliar application with Se improved pigments contents and osmolyte compounds (total soluble sugars, amino acids, proline and total phenols) as compared with both the control plants and drought stressed in plants.

3.2. Growth traits, yield and yield component

The data in Table (3) illustrated that the irrigation intervals (NI and IWD) treatments, foliar application of selenium (mSe and nSe) and their interaction effect on growth traits (plant height and number of fruiting branches/plant) and yield and its components (number of opened bolls/plant, boll weight, seed index, lint% and seed cotton yield) in 2020 and 2021 seasons.

With regard the main effect of irrigation intervals (NI and IWD) treatments, the results in Table (3) stated that IWD condition due to drought stress on cotton plants, had harmful effects on growth traits, yield and yield components comparing with NI conditions in both seasons. IWD treatment reduced significantly cotton growth traits of plant height (92.34 and 94.48 cm) and number of fruiting branches/plant (9.77 and 12.34) in both seasons, respectively. Likewise, IWD conditions reduced significantly yield and its components of number of opened bolls/plant (11.8 and 14.6), boll weight (2.37 and 2.42 g), seed index (10.47 and 10.69 g) and seed cotton yield (6.23 and 7.5 k/f), while lint % decreased significantly (41.12 and 41.22 %) compared to NI condition in both seasons, respectively.

The reduction in growth traits, yield and yield components of cotton under IWD conditions might be attributed to the stress conditions that decreased photosynthesis rate and damaged photochemical proteins then limited growth, yield and quality. These results are agreement with Sattar *et al.* [20], Ali *et al.* [25] and Ibrahim [4]. In this connect, Rady *et al.* [23] found that IWD conditions due to reduce plant growth and yield, which IWD stress continued for prolonged or increased in cruelty that caused irreversible harmful effects led to plant death.

The data in Table (3) revealed that selenium foliar application (mSe and nSe) had positive effects on cotton plant growth traits (plant height and number of fruiting branches/plant) and yield and its components (number of opened bolls/plant, boll weight, seed index, lint % and seed cotton yield) under both irrigation intervals (NI and IWD) treatments in 2020 and 2021 seasons. Spraying nSe with 50 ppm concentration gave the highest significantly means then nSe with 100 ppm and mSe with 100 ppm concentration comparing with untreated cotton plants under both NI and IWD conditions in both seasons.

Exogenously application of nSe with 50 ppm concentration recorded the maximum significantly results on growth traits, yield and yield components of plant height by 7.38 and 2.74%, number of fruiting branches/plant by 25.24 and 15.86%, number of opened bolls/plant by 19.6 and 12.31%, boll weight by 7.11 and 4.41%, seed index by 13.36 and 12.5% and seed cotton yield by 26.71 and 18.12% compared to untreated cotton plant in both seasons, respectively.

The benefit effects of selenium application (mSe and nSe) on growth traits, yield and yield components is mainly due to Se effect on improving cotton plant growth, leaves chemical constituents, photosynthesis rate, increase osmoprotectant compounds and total antioxidant system, and also directly to improve number of fruiting branches/plant, number of open boll/plant and boll weight under irrigation normal and IWD conditions. These results are harmony with the results of Nawaz *et al.* [18], who proved that wheat plants growth was improved by Se applications under drought stress. Besides that, Saleem *et al.* [24] noticed that spearing Se at 150 mg/l improved yield components on cotton plant under stress conditions. These results are in line with Shedeed *et al.* [19], Sattar *et al.*, [20], Ali *et al.* [25] and Rady *et al.* [23] on plants.

As for the interaction between irrigation intervals (NI and IWD) treatments and spraying selenium (mSe and nSe), the data in Table (3) showed that growth traits, yield and yield components statistically affected by the interaction between the two studied factors in 2020 and 2021 seasons.

Table (3). Effect of nano and mineral selenium under normal irrigation, irrigation water deficit treatments and the interaction between them on growth traits, yield and its components of cotton plant during 2020 and 2021 seasons

Irrigation intervals (A)	Selenium forms and concentrations ppm (B)	Growth traits				Yield and yield components									
		Plant high (cm)		No. of fruiting branches/plant		No. of open bolls/plant		Boll weight (g)		Seed index (g)		Lint %		Seed cotton yield (k/f)	
		2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Normal irrigation	Control	108.52	115.48	11.54	13.74	13.25	15.82	2.45	2.61	10.25	10.47	40.57	40.64	7.25	8.87
	mSe 50	112.93	116.54	12.71	14.35	14.52	16.51	2.61	2.64	10.84	10.92	40.49	40.55	8.65	9.28
	mSe 100	113.86	117.16	13.43	14.96	15.00	16.76	2.63	2.68	11.00	11.15	40.39	40.49	8.80	9.61
	nSe 50	116.24	118.32	14.62	15.82	16.46	17.49	2.70	2.73	11.56	11.63	40.23	40.36	10.1	10.34
	nSe 100	114.37	117.85	13.85	15.17	15.83	17.05	2.67	2.71	11.28	11.48	40.31	40.43	9.80	9.97
Mean		**113.18**	**117.07**	**13.23**	**14.80**	**15.01**	**16.72**	**2.61**	**2.67**	**10.98**	**11.13**	**40.39**	**40.49**	**8.92**	**9.61**
Irrigation water definite	Control	88.74	92.94	8.66	11.34	10.84	13.42	2.33	2.38	9.66	9.85	41.27	41.35	5.85	6.69
	mSe50	91.25	93.65	9.45	11.82	11.62	14.25	2.35	2.40	10.03	10.49	41.16	41.24	6.25	7.32
	mSe 100	92.93	94.74	9.87	12.36	11.93	14.87	2.38	2.42	10.74	10.86	41.14	41.22	6.25	7.59
	nSe 50	95.58	95.83	10.68	13.25	12.35	15.36	2.43	2.47	11.00	11.24	40.92	41.11	6.50	8.04
	nSe 100	93.26	95.26	10.19	12.94	12.26	15.10	2.40	2.44	10.92	11.05	41.13	41.18	6.30	7.88
Mean		**92.35**	**94.48**	**9.77**	**12.34**	**11.80**	**14.60**	**2.37**	**2.42**	**10.47**	**10.69**	**41.12**	**41.22**	**6.23**	**7.50**
General mean of Selenium forms and concentrations (B)	Control	98.63	104.21	10.10	12.54	12.04	14.62	2.39	2.49	9.95	10.16	40.92	40.99	6.55	7.78
	mSe 50	102.09	105.09	11.08	13.08	13.07	15.38	2.48	2.52	10.43	10.70	40.82	40.89	7.45	8.30
	mSe 100	103.39	105.95	11.65	13.66	13.46	15.81	2.50	2.55	10.87	11.00	40.76	40.85	7.52	8.60
	nSe 50	105.91	107.07	12.65	14.53	14.40	16.42	2.56	2.60	11.28	11.43	40.57	40.73	8.30	9.19
	nSe 100	103.81	106.55	12.02	14.05	14.04	16.07	2.53	2.57	11.10	11.26	40.72	40.80	8.05	8.92
LSD 0.05	$A_{(t\ test)}$	**	**	**	**	**	**	**	**	**	**	**	**	**	**
	B	0.375	0.070	0.043	0.058	0.283	0.079	0.032	0.014	0.147	0.036	0.061	0.069	0.410	0.081
	A x B	0.530	0.099	0.061	0.082	0.400	0.112	0.045	0.019	0.208	0.052	N.S	N.S	0.580	0.115

Selenium foliar application especially in nanoparticles form decreased the harmful effects of IWD stress and improving growth and yield components under both irrigation intervals treatments compared to untreated cotton plants in both seasons. Spraying nSe with 50 ppm concentration recorded the best significantly means then nSe and 100 mSe concentration on growth and yield components comparing with control. On the other hand, the untreated cotton plants exhibited the lowest values on growth and yield components in 2020 and 2021 seasons. These results are agreement with Nawaz *et al.* [18] and Sattar *et al.* [20] on and Ali *et al.* [25].

3.3. Fiber and yarn quality properties

Data in Tables (4 and 5) showed that the effect of irrigation intervals (NI and IWD) treatments, selenium foliar application (mSe and nSe) and the interaction between them on fiber quality properties of micronair value, maturity ratio %, upper half mean length (mm), uniformity index (%), short fiber index (%), fiber strength (g/tex), fiber elongation (%), reflecatness degree and yellowness, also and yarn quality properties of yarn strength (cN/tex) and yarn elongation (%) in 2020 and 2021 seasons.

As for irrigation intervals (NI and IWD) treatments, the data in Tables (4 and 5) reported that IWD conditions decreased significantly fiber and yarn quality properties of micronair value (3.76 and 3.8), maturity ratio (0.85 and 0.86 %), upper half mean length (26.95 and 27.1 mm), uniformity index (82.76 and 82.79 %), fiber strength (36.77 and 36.9 g/tex), fiber elongation (6.73 and 6.81 %), reflecatness degree (64.81 and 64.89), yarn strength (16.19 and 16.22 cN/tex) and yarn elongation (5.16 and 5.19 %), whereas short fiber index increased significantly comparing with NI conditions in both studied seasons, respectively.

The reduction on fiber and yarn quality properties under IWD conditions might be due to the adverse effect of water stress conditions on bolls and fruiting branches and make many changes in cotton fiber properties. Exposing cotton plants to water stress conditions at flowering and elongation stages lead to harmful effects on plant cell expansion and due to decrease fiber strength and fiber elongation [9]. In this connect, Karademir et al. [10] and Gao et al. [11] stated that drought stress had harmful effects on ginning percentage and cotton fiber quality properties, which decreased fiber strength, fiber length, fiber elongation and fiber fineness, whereas did not effect on fiber uniformity. Also, Zhang et al. [8] found that IWD conditions decreased fiber length by 4.7%, while increased micronaire value by 8.4% comparing with NI conditions. Similary, Book et al. [12] demonstrated that fiber strength increased under IWD conditions. However, Liu et al. [42] reported that fiber strength reduced under IWD conditions. As well as, [43] noted that drought conditions due to reduce fiber strength, micronaire value and fiber length comparing with cotton fiber under normal conditions, whereas fiber index increased from 28.2 to 54.1% under drought conditions. Witt *et al.* [44] noted that fiber length and uniformity index decreased in irrigation levels from high to low. Also, Sahito [5] revealed that drought conditions reduced fiber strength, fiber length and fiber fineness.

With regard the major effect of selenium foliar application (mSe and nSe), the results in Tables (4 and 5) inducted that spraying selenium (mSe and nSe) improved all fiber and yarn quality properties except short fiber index (%) and yellowness reduced significantly compared to untreated plants in 2020 and 2021 seasons. The best means recorded by spraying nSe with 50 ppm concentration the nSe with 100 ppm and mSe with 100 ppm compared to control plants in both NI and IWD conditions in both seasons.

Table (4). Effect of nano and mineral selenium under normal irrigation, irrigation water deficit treatments and the interaction between them on fiber quality properties of cotton plant during 2020 and 2021 seasons

Irrigation intervals (A)	Selenium forms and concentrations ppm (B)	Micronaire value		Maturity ratio %		Upper half mean length (mm)		Uniformity index		Short fiber index %	
		2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Normal irrigation	Control	4.44	4.47	0.94	0.95	30.15	30.73	84.48	84.57	7.86	7.74
	mSe 50	4.53	4.56	0.95	0.96	30.3	30.83	84.75	84.84	7.74	7.64
	mSe100	4.74	4.83	0.96	0.97	30.66	30.93	85.15	85.24	7.55	7.57
	nSe 50	5.30	5.15	0.99	0.99	32.15	32.16	87.44	87.85	6.15	6.13
	nSe 100	4.90	4.94	0.98	0.98	30.94	30.97	85.76	85.86	7.12	7.39
Mean		**4.78**	**4.79**	**0.96**	**0.97**	**30.84**	**31.12**	**85.52**	**85.67**	**7.28**	**7.29**
Irrigation water definite	Control	3.36	3.36	0.76	0.77	26.14	26.59	82.23	82.26	9.74	9.64
	mSe 50	3.55	3.59	0.82	0.83	26.34	26.47	82.45	82.49	9.65	9.54
	mSe 100	3.84	3.89	0.86	0.86	26.86	26.87	82.64	82.67	9.47	9.44
	nSe 50	4.14	4.2	0.92	0.93	28.25	28.34	83.74	83.76	8.86	8.76
	nSe 100	3.93	3.95	0.9	0.9	27.15	27.25	82.75	82.79	9.23	9.14
Mean		**3.76**	**3.80**	**0.85**	**0.86**	**26.95**	**27.10**	**82.76**	**82.79**	**9.39**	**9.30**
General mean of Selenium forr and concentrations (B)	Control	3.90	3.92	0.85	0.86	28.15	28.66	83.36	83.42	8.8	8.69
	mSe50	4.04	4.07	0.89	0.89	28.32	28.65	83.6	83.67	8.7	8.59
	mSe 100	4.29	4.36	0.91	0.92	28.76	28.9	83.9	83.96	8.51	8.5
	nSe 50	4.72	4.68	0.96	0.96	30.2	30.25	85.59	85.8	7.51	7.45
	nSe 100	4.41	4.44	0.94	0.94	29.05	29.11	84.25	84.32	8.18	8.27
LSD 0.05	A $_{(t\ test)}$	**	*	**	**	**	**	**	**	**	**
	B	N.S	N.S	0.038	0.054	N.S	N.S	N.S	0.054	0.232	0.058
	A x B	N.S	N.S	0.054	0.076	N.S	0.299	N.S	N.S	0.328	N.S

Table (5). Effect of nano and mineral selenium under normal irrigation, irrigation water deficit treatments and the interaction between them on fiber and yarn quality properties of cotton plant during 2020 and 2021 seasons

Irrigation intervals (A)	Selenium forms and concentrations ppm (B)	Fiber quality properties: Fiber strength g/tex		Fiber elongation %		Reflecatness degree		Yellowness		Yarn quality properties: Yarn strength (cN/tex)		Yarn elongation%	
		2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Normal irrigation	Control	39.85	39.86	8.34	8.39	67.69	67.70	11.69	11.73	17.54	17.57	6.66	6.74
	mSe 50	39.95	39.63	8.45	8.52	67.74	67.76	11.61	11.66	17.75	17.74	6.88	6.87
	mSe100	40.13	40.16	8.63	8.73	67.83	67.82	11.45	11.54	17.98	17.96	6.95	6.98
	nSe 50	41.75	41.87	9.96	9.97	68.24	68.34	11.26	11.37	20.07	20.17	7.98	7.99
	nSe 100	40.24	40.33	8.75	9.10	67.89	67.94	11.33	11.44	18.16	18.33	6.98	6.98
Mean		**40.38**	**40.37**	**8.83**	**8.94**	**67.88**	**67.91**	**11.47**	**11.55**	**18.30**	**18.35**	**7.09**	**7.11**
Irrigation water definite	Control	36.24	36.28	6.15	6.24	64.34	64.45	12.85	12.91	15.39	15.34	4.25	4.35
	mSe 50	36.44	36.49	6.26	6.35	64.45	64.54	12.73	12.78	15.69	15.77	4.95	4.96
	mSe 100	36.67	36.76	6.64	6.75	64.67	64.74	12.56	12.64	15.97	15.99	5.19	5.27
	nSe 50	37.75	37.77	7.76	7.85	65.76	65.86	12.25	12.31	17.75	17.76	6.13	6.24
	nSe 100	36.73	37.19	6.85	6.84	64.84	64.85	12.43	12.55	16.16	16.22	5.26	5.11
Mean		**36.77**	**36.90**	**6.73**	**6.81**	**64.81**	**64.89**	**12.56**	**12.64**	**16.19**	**16.22**	**5.16**	**5.19**
General mean of Selenium forms and concentrations (B)	Control	38.05	38.07	7.25	7.32	66.02	66.08	12.27	12.32	16.47	16.46	5.46	5.54
	mSe50	38.20	38.06	7.36	7.44	66.10	66.15	12.17	12.22	16.72	16.76	5.92	5.91
	mSe 100	38.40	38.46	7.64	7.74	66.25	66.28	12.00	12.09	16.98	16.97	6.07	6.12
	nSe 50	39.75	39.82	8.86	8.91	67.00	67.10	11.76	11.84	18.91	18.96	7.05	7.11
	nSe 100	38.49	38.76	7.80	7.97	66.37	66.40	11.88	12.00	17.16	17.27	6.12	6.05
LSD 0.05	$A_{(t\ test)}$	**	**	*	**	*	*	N.S	N.S	**	**	*	*
	B	N.S	0.316	0.066	0.222	0.054	0.066	N.S	N.S	N.S	0.068	N.S	0.215
	AB	0.076	0.447	0.093	0.185	N.S	N.S	N.S	N.S	0.076	0.054	N.S	N.S

Foliar application of nSe with 50 ppm concentration enhanced significantly fiber and yarn quality properties of maturity ratio by 12.94 and 11.62%, %, fiber elongation by 22.2 and 21.72 %, reflecatness degree by 1.48 and 1.54 %, However, decreased significantly fiber index by 14.65 and 14.26% compared to untreated plants in both seasons. Uniformity index, fiber strength, yarn strength and yarn elongation increased significantly in only 2021 season. While, yellowness affected insignificantly in both seasons comparing with untreated plants.

The enhancing of cotton fiber quality properties might be related to the positive effects of selenium application (mSe and nSe) on cotton plant growth , leaves chemical constituents and productivity especially under IWD conditions which increasing enzymes activity and alleviating the adverse effects of drought stress conditions on cotton plant. These results are agreement with Saleem *et al.* [6] and Ikram [45].

For the interaction between irrigation intervals (NI and IWD) treatments, selenium foliar application (mSe and nSe), the data in Table (4) revealed that the interaction between two factors affected significantly on all fiber and yarn quality properties in both seasons. The highest values for these parameters were obtained by spraying nSe with 50 ppm concentration under both NI and IWD conditions, while the control plants exhibited the lowest ones in both seasons.

4. Conclusion

IWD conditions (stress conditions) reduced significantly cotton leaves pigments, growth traits, yield components, fiber and yarn properties, while increased significantly osmoprotecant compounds and enzymes activity comparing with NI conditions. Spraying Se in mineral and nano forms enhanced all studies parameters under NI and IWD conditions. Foliar applications of nSe were more effective than mSe applications that due to Se positive effects on plant physiological and antioxidant properties. Moreover, nSe enter directly the stomata of cotton plant leaves and transport to different organs easily than mSe, so that nano-particles maximize the benefits effects of Se on cotton plants especially under water stress conditions.

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