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RESEARCH ARTICLE

Effect of zinc foliar application on productivity and quality characteristics of several cotton varieties

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Abstract

Zinc deficiency is a common issue in cotton cultivation that can significantly impact yield and quality, especially when the soil zinc content is unavailable due to a problem related to nutrient competition. A field experiment was conducted during the summer season of 2023, on a farmers' field in Al-Anbar province, Iraq, to investigate the effect of zinc spraying on cotton yield and its components, as well as quality characteristics, for several cotton varieties. The experiment utilised a split-plot design that was arranged within a randomised complete block design (RCBD) with three replications. The main plots occupied by four zinc concentrations, which were 0, 75, 150 and 225 mg L^{-1}, while the sub-plot contained four cotton varieties: Spearo888, Cocker 310, Pak-cot and Candia. The results showed that the Spearo 888 cotton variety had the highest average in terms of plant height, reaching 156.72 cm, while the Pak-Cot variety had the highest average for traits: branch per $plant^{-1}$ (12.61), number of total and opened bolls per $plant^{-1}$ (26.57 and 19.04), boll weight (3.97 g) and total seed cotton yield (2.95 t ha^{-1}). The studied traits improved progressively with increasing zinc concentration, with the highest concentration yielding the best results. The integration of zinc with the varieties led to the best results. The cotton fibre characteristics were not significantly affected by zinc concentrations; rather, variety had the greatest influence, indicating that these characteristics are more influenced by gene action than by environmental conditions.

Keywords: cotton variety; foliar application; productivity; zinc spray

Introduction

Cotton plant (*Gossypium hirsutum* L.), which belongs to the Malvaceae family, is considered one of the most important fibres and industrial crops in the world, as it is used as a raw material in many industries such as spinning and textile production. Cotton fibres constitute 85–90 % of the worlds' fibre production. The fibres represent about 35 % of the weight of the cotton boll. As well as, the seeds are a valuable industrial source of important oils, which typically constitute 18–26 % of their total weight. In addition, the by-product of cotton, viz. cottonseed meal, is used in feed fodders, as it contains a high percentage of protein ranging from 32–36 % (1). Cotton production is a major source of income for producing countries, generating economic activity that extends far beyond the farm to include jobs in gins, spinning mills and textile factories. In terms of cotton production, Iraq still suffers from a shortage and its local production represents only a small percentage of the actual demand, due to the high cost of production, inflation of imports and lack of suitable varieties (2).

Cotton varieties differ in their behaviour towards environmental conditions and production is greatly affected by the availability of growth requirements, most importantly, nutrients. So, selecting a suitable variety that is characterised by high productivity and adaptation to environmental conditions is considered one of the important goals for developing and improving cotton productivity per unit area. Most growth and yield components traits that are related directly to yield, such as plant height and the number of fruiting branches, are affected significantly by variety differences (3). In a similar study, it was also observed that varieties varied significantly in the number of opened bolls, boll weight and seed cotton yield. In contrast, the existence of significant differences between cotton varieties in qualitative characteristics was also confirmed (4). Zinc plays an important role in nitrogen metabolism and protein synthesis. It is also involved in the formation of chlorophyll and carbohydrates (5). Foliar zinc application twice, i.e., (0 and 58 g ha^{-1}) after sowing increased seed cotton yield, number of bolls, 100 seed weight and fibre yield (6). The application of zinc has been shown to significantly influence various growth and yield traits in cotton. Zinc positively affected plant height, the number of sympodial branches, boll number and both plant and fibre uniformity ratios (7, 8). Research has demonstrated that zinc played an important role in enhancing vegetative growth, yield components and fibre quality in cotton (9, 10). This study aimed to determine the effect of zinc concentrations on yield and its components for several varieties of cotton.

Materials and Methods

Field operations

A field experiment was conducted during the summer season of 2023 in Al-Anbar province, which is located at a latitude of 33 N and a longitude of 43 E, to determine the response of several varieties of cotton to foliar application of zinc with different concentrations and also their effect on some yield traits and fibre quality. The experiment was employed in a split-plot design with three replications as in RCBD. The main plots included four zinc concentrations, which were 0, 75, 150 and 225 mg L^{-1}, while the sub-plots included four cotton varieties: Spearo888, Cocker 310, Pak-cot and Candia. The experimental plot was prepared by ploughing, smoothing and levelling and was divided into experimental units (a Total of 48 experimental units, with 16 experimental units per replication) with an area of each unit of 3 × 2.5 m. Each experimental unit contained 4 rows with a distance of 65 cm between each row and 25 cm between each plant. Diammounium phosphate (DAP) fertiliser (46 % P) was applied at a rate of 100 kg ha^{-1} in one dose during planting and nitrogen fertiliser was applied at a rate of 80 kg nitrogen (N) ha^{-1} in the form of urea (46 % N) in two doses viz. the first application with a half dose was done during planting and the second dose was done after a month from the first dose (11, 12). The cotton seed varieties were bedded on 1st may, 2023, putting 3–4 seeds in each hole with a depth of 2–3 cm. After planting, the field was immediately irrigated. Agricultural operations such as irrigation, weeding, thinning and pest control were performed as needed. Thinning was done to leave only one plant per hole. Zinc was applied 60 days after planting. The first cotton picking was carried out on September 3, 2022. The second cotton picking was carried out on November 15, 2023, after the bolls had fully matured and naturally opened.

Studied traits

When cotton plants reached the physiological maturity stage, the following traits were measured: plant height, number of fruiting branches per plant, number of bolls per plant, total number of healthy and open bolls, number of open bolls per plant, boll weight and seed cotton yield. In terms of fibre cotton characteristics, cotton fibre technology traits, the traits were taken as below: After the harvesting process (the first and second harvests) was completed, the two harvests were mixed. The ginning process was then performed (separating the fibre from the seeds). A sample of cotton fibre from each treatment (300 g) was taken to assess some of its quality characteristics using the seed cotton ginning machine and perspiration fastness tester (Fig. 1–2) in the laboratories of the General Company for Textile and Leather Industries - Cotton Factory, Quality Control Department - Physical Laboratory-Al-Kadhimiya, Baghdad, Iraq. The following quality characteristics were measured.

Upper half mean (UHM mm)

It is the average length of the total filament lengths suitable for spinning. It was measured using a fibre length distribution tester.

Strength

It is defined as the resistance of the material to various cutting forces, including both regular and sudden tensile forces. It also expresses the strength of the fibres in terms of their basic ability to resist tearing. It was measured using a Perseille device at a distance of 1/8 inch between the jaws and gives the resistance of a strand of fibres to cutting and is expressed in grams (g) of Tex^{-1}.

Statistical analysis

The data of the studied traits were statistically assessed using the SASS computer program Version 9.0 and the results were compared using the least significant difference (LSD) at the 95 % confidence level.

Results and Discussions

Plant height

The results showed significant differences between cotton varieties and zinc concentrations and the interaction between them in plant height (Table 1). Spearo888 plants recorded the highest mean of 156.72 cm, while the Candia variety gave the lowest mean of 149.37 cm. Perhaps the reason for this increase is due to the genetic variation between varieties in terms of internode lengths, which distinguishes each variety from the other, in addition to the fact that the plants of the Spearo888 variety took the longest period to reach the flowering stage. This allows for stem elongation compared to other early varieties. Research indicates that the varieties differ significantly in plant height due to genetic variation (13, 14).

The cotton plants that were sprayed with a concentration of 225 mg L^{-1} gave the highest average plant height of 172.51 cm compared to the control plants, 153.24 cm. The reason for this increase may be that zinc works to form and protect the tryptophan amino acid, which is used to produce the IAA hormone, which is directly related to the elongation of stem cells. Also, zinc is very important in cell division and the formation of meristematic cells. Results have demonstrated that plant height increased with increased zinc concentrations (8, 9, 15). The results suggest that there is a significant interaction between cotton varieties and zinc concentrations in the plant height, as the Spearo888 variety that was sprayed with a concentration of 225 mg L^{-1} gave the highest interaction value of 175.36 cm compared to the control treatment with the Candia variety, which gave the lowest interaction value of 132.61 cm.

Number of fruiting branches per plant

The results indicated significant differences between cotton varieties and zinc concentrations and the interaction between them on the number of fruiting branches per plant (Table 2). As the Pak-Cot variety gave the highest average of 12.61 branch $plant^{-1}$ compared to the variety Candia, which gave the lowest average of 10.71 branch $plant^{-1}$. The reason for this superiority may be due to the genetic nature of the variety and its response to environmental conditions. Research has demonstrated that the varieties differ in the number of fruiting branches in cotton plants (16, 17).

Table 1. Effect of foliar zinc application on the plant height (cm) of three cotton varieties

Zinc concentration mg L^{-1}	Cotton varieties				Mean
	Spearo888	Cocker 310	Pak-Cot	Candia	
0	145.60	142.30	137.91	132.61	139.62
75	149.43	145.60	151.82	145.70	148.51
150	156.53	154.61	15161	148.61	153.01
225	175.36	173.27	169.71	170.80	172.51
Mean	156.72	153.91	152.75	149.37	
	L.S.D = 0.05	Varieties = 0.511	Zinc = 0.706	Interaction = 1.059	

Table 2. Effect of foliar zinc application on the fruiting branches per plant (branch plant $^{-1}$) of three cotton varieties

Zinc concentration mg L^{-1}	Cotton varieties				Mean
	Spearo888	Cocker 310	Pak-Cot	Candia	
0	10.97	8.83	10.32	9.17	9.81
75	10.77	11.57	11.83	10.97	11.28
150	13.70	12.83	12.50	11.07	12.52
225	14.31	13.43	15.83	11.63	13.79
Mean	12.43	11.66	12.61	10.71	
L.S.D = 0.05	Varieties = 0.453	Zinc = 0.530	Interaction = 0.893		

Fig. 1. Seed cotton ginning machine.

Fig. 2. Perspiration fastness tester.

The results indicate an increase in the number of fruiting branches in cotton plants with an increase in zinc concentrations. The cotton plants that were sprayed with a concentration of 225 mg L^{-1} excelled with the highest average of 13.79 branch $plant^{-1}$, with an increase rate of 40 % compared to the control plants of 9.81 branch $plant^{-1}$. This superiority in the number of branches may be due to the role of zinc in increasing the lateral branches in the plant. Research has demonstrated that treating cotton with zinc played a positive role in most of the yield characteristics, including the number of fruiting branches (15, 18). Regarding the interaction between cotton varieties and zinc concentrations in the number of fruiting branches, the results showed a significant response between these factors in terms of this trait The Pak-cot variety which was sprayed with a concentration of 225 mg L^{-1} gave the highest interaction value of 15.83 branch per plant, while the plants of Candia variety with control treatment gave the lowest value of interaction 9.17 branch $plant^{-1}$.

Number of bolls per plant

The result indicated significant differences between varieties and concentrations of Zinc and their interaction in the number of bolls per plant (Table 3). The Pak-Cot variety presented the highest average of the number of bolls 26.57 bolls $plant^{-1}$, while plants of the Candia variety gave the lowest average of 23.68 bolls $plant^{-1}$. The reason for this superiority may be due to the genetic variation for each variety and their response to the surrounding environmental conditions and the genetic factor for each variety controlled the number of bolls per plant. Research indicates that varieties differ in the number of bolls in the plant (11, 19).

The results presented a significant difference between the concentrations of zinc in the total number of bolls per plant, where cotton plants that were sprayed with a concentration of 225 mg L^{-1} achieved the highest average for the number of bolls (28.15 bolls $plant^{-1}$), while the control treatment gave the lowest average for the trait 21.26 bolls $plant^{-1}$. The results indicate that high concentrations of zinc had a superiority in yield and its components (9, 10). The interaction between variety and concentrations of zinc had a significant effect on the number of bolls per plant. Plants of the Cocker 310 variety, which were sprayed with a concentration of 225 mg L^{-1}, achieved the highest value of 30.51 bolls $plant^{-1}$, which was not significantly different from the Pak-Cot variety at the same concentration, which produced 28.84 bolls $plant^{-1}$. However, the Candia variety showed the lowest value of 20.01 bolls $plant^{-1}$.

Number of open bolls per plant

The results indicated a significant effect of cotton varieties, zinc concentrations and their interaction on the number of opened bolls per plant; the interaction between the study factors had no significant effect on this trait (Table 4). The plants of the Pak-cot variety revealed the highest average of 19.04 bolls $plant^{-1}$ and did not differ significantly from the Cocker 310 variety, which gave 18.43 bolls $plant^{-1}$, compared to the Candia variety plants that gave the lowest average of opened bolls, 16.46 bolls $plant^{-1}$. The reason for this increase may be due to the nature of the growth and shape of the Coker 310 plant viz. the general shape of this genetic structure to catch the sunlight and temperature that help the boll open and which are considered the two basic factors for the completion of growth and the opening of the boll, in addition to the genetic composition of the variety plants in response to environmental conditions (temperature and light), which helps in opening a larger number of bolls in the plant. Research has demonstrated that genotypes differ in the number of opened bolls in plants, which is reflected in their response to the environmental conditions of the agricultural area (14, 20, 21). The results indicated that cotton plants sprayed with a concentration of 225 mg L^{-1} presented the highest average of opened bolls in plants, 18.82 bolls $plant^{-1}$ and did not differ significantly from plants sprayed with a concentration of 150 mg L^{-1}, which gave 18.44 bolls $plant^{-1}$. While the control treatment gave the lowest average of 16.60 bolls $plant^{-1}$. Research indicates that plants sprayed with high concentrations of zinc may outperform with higher average yield components (14, 17).

Boll weight

The results indicated significant differences between the varieties and the concentrations of zinc and the interaction between them in the boll weight (Table 5). The plants of the Pak-Cot variety exhibited the highest average of 3.97 g, while the plants of the Spearo888 variety gave the lowest average of 3.70 g. This is due to genetic variation between varieties and to the increased number of seeds in the boll, which in turn leads to an increase in the weight of the boll. Research indicates that significant differences between varieties in boll weight were found (19, 22). Likewise, the results indicate an increase in boll weight with an increase in zinc concentrations, as the cotton plants that were sprayed with a concentration of 225 mg L^{-1} gave

Table 3. Effect of foliar zinc application on the bolls per plant (bolls $plant^{-1}$) of three cotton varieties

Zinc concentration mg L^{-1}	Cotton varieties				Mean
	Spearo888	Cocker 310	Pak-Cot	Candia	
0	22.34	20.31	22.39	20.01	21.26
75	22.58	22.47	27.09	23.46	23.90
150	25.13	28.51	27.99	24.86	26.62
225	26.83	30.51	28.84	26.42	28.15
Mean	24.22	25.38	26.57	23.68	
L.S.D = 0.05	Varieties = 0.851	Zinc = 2.365	Interaction = 2.590		

Table 4. Effect of foliar zinc application on open bolls per plant (bolls $plant^{-1}$) of three cotton varieties

Zinc concentration mg L^{-1}	Cotton varieties				Mean
	Spearo888	Cocker 310	Pak-Cot	Candia	
0	17.32	17.37	17.30	14.41	16.60
75	17.94	18.47	18.70	16.47	17.89
150	18.07	19.05	20.06	16.60	18.44
225	17.97	18.85	20.12	18.36	18.82
Mean	17.82	18.43	19.04	16.46	
L.S.D = 0.05	Varieties = 0.113	Zinc = 0.094	Interaction = 0.210		

Table 5. Effect of foliar zinc application on the boll weight (g) of three cotton varieties

Zinc concentration mg L^{-1}	Cotton varieties				Mean
	Spearo888	Cocker 310	Pak-Cot	Candia	
0	3.19	3.52	3.78	3.58	3.51
75	3.67	3.54	3.90	3.73	3.71
150	3.69	3.94	3.99	3.98	3.90
225	4.17	4.35	4.22	3.92	4.16
Mean	3.70	3.83	3.97	3.80	

L.S.D = 0.05 Varieties = 0.113 Zinc = 0.094 Interaction = 0.210

the highest average of 4.16 g, increasing by 18 % compared to the control plants that gave the lowest average of 3.51 g. The role of zinc is to increase the number of seeds in the boll and thus increase the weight of the boll. The research indicates that an increase in yield components with increasing zinc concentrations. The interaction between the varieties and the concentrations of zinc was significant for the characteristic of the boll weight, as the plants of the variety Cocker 310, which were sprayed with a concentration of 225 mg L^{-1}, achieved the highest value of interaction of 4.35 g, which was significantly different from the plants of the two varieties Pak-Cot and Spearo888, which were sprayed with the same concentration, as it gave 4.22 and 4.17 g respectively, while the plants of the Spearo888 variety, when treated with control gave the lowest value of interaction of 3.19 g.

Seed cotton yield

The results indicated significant differences between varieties, zinc concentrations and their interaction on the total seed cotton yield, as shown in Table 6. The variety Pak-Cot was characterised by the highest average of 2.95 t $ha^{-1,}$ which did not differ from the variety Cocker 310, compared to the Candia variety, which gave the lowest average of 2.48 t ha^{-1}. This increase in the total seed cotton yield for Pak-Cot is due to its superiority in the number of opened bolls per plant and boll weight (Table 4, 5). Research indicates that the significant differences between cotton varieties in terms of the total yield as a result of the optimal utilisation of available growth factors by the superior variety (4, 18).

Cotton plants sprayed with a concentration of 225 mg L^{-1} gave the highest average of the total seed cotton yield, 3.07 t $ha^{-1,}$ with an increase of 36 % compared to the control plants that gave the lowest average, 2.25 t ha^{-1}. The reason for this increase may be due to the superiority of the cotton plants sprayed with a concentration of 225 mg L^{-1} in the total number of open bolls per plant, as well as the boll weight and seed cotton yield per plant (Tables 4, 5), which helped to increase the total seed cotton yield. Research has demonstrated that an increase in the total yield is observed by increasing the zinc concentrations (9, 13, 14). The interaction between the study factors had a significant effect on the total cotton yield. Cocker 310 plants sprayed with a concentration of 150 mg L^{-1} gave the highest value of 3.20 t ha^{-1}, which did not differ significantly from the Lashata plants sprayed with the same concentration (150 mg L^{-1}), which gave the yield of 3.07 t ha^{-1}, while Montana plants with the control treatment gave the lowest yield, 1.96 t ha^{-1}.

Upper half means (UHM)

The results in Table 7 indicated significant differences between cotton varieties in the UHM, while zinc concentrations and the interaction between the two factors did not have a significant effect on this trait. The plants of the variety Cocker 310 showed the highest mean for the trait, reaching 25.49 mm and did not differ significantly from the plants of the varieties Candia and Pak-Cot, which gave 25.31 and 25.26 mm, respectively, while the plants of the variety Spearo888 gave the lowest mean for the trait, reaching 24.98 mm. This superiority may be due to the genetic nature of the variety and its response to environmental conditions. Research has demonstrated that genetic variation plays a crucial role in cotton fibre characteristics (23–25).

Strength (g/tex)

The results indicated a significant effect of cotton varieties on the number of strength (g/tex), while the zinc concentrations and the interaction between the two factors did not have a significant effect on this trait, as seen in Table 8. The plants of the Coker 310 variety revealed the highest average, reaching 21.19 g/tex, with an increase of 10 % compared to the Pak-Cot variety plants that gave the lowest average of 19.15 g/tex. This trait varies from one variety to another and is linked to the genetic adaptation to available growth nutrients as well as the

Table 6. Effect of foliar zinc application on the seed cotton yield (t ha^{-1}) of three cotton varieties

Zinc concentration mg L^{-1}	Cotton varieties				Mean
	Spearo888	Cocker 310	Pak-Cot	Candia	
0	2.14	2.35	2.53	2.01	2.25
75	2.23	2.44	2.91	2.38	2.49
150	2.62	2.98	3.08	2.73	2.85
225	3.01	3.18	3.28	2.82	3.07
Mean	2.50	2.73	2.95	2.48	

L.S.D = 0.05 Varieties = 0.274 Zinc = 0.361 Interaction = 0.723

Table 7. Effect of foliar zinc application on the upper half mean (mm) of three cotton varieties

Zinc concentration mg L^{-1}	Cotton Varieties				Mean
	Spearo888	Cocker 310	Pak-Cot	Candia	
0	24.97	25.15	25.04	25.12	25.17
75	24.46	25.21	25.30	25.32	25.07
150	25.21	25.61	25.38	25.14	25.33
225	25.28	25.62	25.35	25.67	25.53
Mean	24.98	25.49	25.26	25.31	

L.S.D = 0.05 Varieties = 0.35 Zinc = N.S Interaction = N.S

Table 8. Effect of foliar zinc application on the strength (g/tex) of three cotton varieties

Zinc concentration mg L^{-1}	Cotton varieties				Mean
	Spearo888	Cocker 310	Pak-Cot	Candia	
0	20.11	20.62	19.48	19.05	20.06
75	19.58	21.14	20.23	19.09	20.01
150	21.27	21.56	20.27	19.13	20.55
225	20.28	21.45	21.31	19.34	20.59
Mean	20.31	21.19	20.57	19.15	

L.S.D = 0.05 Varieties = 0.714 Zinc = N.S Interaction = N.S

environmental conditions. Research has demonstrated that micronutrients play an important role in biological processes, but not necessarily in the cotton strength staple (25–29).

Conclusion

It concluded that the results showed that spraying zinc at different concentrations improved both the yield and quality traits of various cotton varieties. Applying zinc at a concentration of 225 mg L^{-1} to the Pac-Cot variety led to the highest seed yield and yield components. On the other hand, the Coker 310 variety showed the best quality characteristics. These findings highlight the importance of zinc application and variety selection in improving cotton production. Further studies will be conducted later to highlight the effect of foliar application of micronutrients on cotton yield and quality under the Iraqi irrigated areas.

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Authors' contributions

NAH for the ideas and designed experiments. IMA performed the experiments. AHA drafted the manuscript. AAA conceived and coordinated the overall study. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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