Advanced Journal of Seed Science and Technology (AJSST) ISSN 2812-3425 Vol. 7(1), pp. 176-190, January, 2021. Available online at www.advancedscholarsjournals.org © Advanced Scholars Journals

Full length Research paper

Direct and residual effects of mineral nutrients and plant growth retardants on cottonseed yield and its quality

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Accepted 25th January, 2021.

Seed quality is one of the most important factors for stand establishment in cotton (*Gossypium Sp.*), and the use of good quality seeds is therefore essential to obtain an optimum plant population. Conditions prevailing during seed formation can affect the quality of seed produced, and hence crop establishment in the next growing season. These conditions can affect the germination of the seeds and the ability of the seedlings to emerge from soil, these being the most critical stages during the life cycle of cotton plant. Field experiments were conducted to investigate the effect of nitrogen (N), phosphorus (P), potassium (K), foliar application of zinc (Zn) and calcium (Ca), the use of plant growth retardant (PGR) [1, 1-dimethyl piperidinium chloride (MC)], during square initiation and boll setting stage, on growth, seed yield, seed viability, and seedling vigor of cotton.

Keywords Calcium – Phosphorus - Plant Growth Retardants – Potassium - Zinc

INTRODUCTION

Stand establishment of cotton seedlings is one of the most critical stages in cotton production. Cotton-seed quality is affected, to a large extent, by the indeterminate growth habit of the cotton plant, which allows seed to set and develop across an extended period of time. Seed vigor and viability are important components influencing seedling establishment, crop growth, and productivity. Sowing is a critical time in the life cycle of any crop and the seeds are frequently exposed to adverse conditions that may compromise the establishment of seedlings in the field [1]. Stand establishment of cotton seedlings is one of the most critical stages in cotton production. Cotton-seed quality is affected, to a large extent, by the indeterminate growth habit of the cotton plant, which allows seed to set and develop across an extended period of time. Seed vigor and viability are important components influencing seedling establishment, crop growth, and productivity. Any factor (biotic and/or environmental) that negatively affects seed vigor and viability during seed development will have adverse consequences on crop production, especially when seeds are sown under environmentally stressful conditions [2]. Both size and number of seeds, produced by maternal plants, are most likely determined by their nutritional status at the time of flowering and bud initiation. Furthermore, the most important single determinant of mineral nutrient reserves in seeds is the mineral nutrient availability to the maternal plant during reproductive development, with increasing supplies of a particular mineral nutrient enhancing the nutrient concentration in the mature seed [3].

Plant nutrition using a balanced fertilization programmer with both macro- and micro-nutrients has become very important in the production of high quality seed. Many management practices and breeding efforts have allowed plants to partition more carbohydrates into bolls and less into vegetative growth. Mineral nutritional status of plants has a considerable impact on partitioning of carbohydrates and dry matter between shoots and roots. Often, the number of sink organs is the yield component that is affected mostly by mineral nutrients. The positive effect of mineral nutrient supply on the number of sink organs may result not only from an increase in mineral nutrient supply, but also from an increase in photosynthate supply to the sink sites or from hormonal effects [4]. Plant growth retardants (PGR,s) represent diverse chemistries and mode of

action, and provide numerous possibilities for altering crop growth and development, provide farmers with a new management tool for controlling undesirable vegetative growth, and to balance vegetative and reproductive growth as well as to improve yield and its quality

Nitrogen (N)

In cotton culture, N have the most necessity role in production inputs, which controls growth and prevents abscission of squares and bolls, essential for photosynthetic activity [5], and stimulates the mobilization and accumulation of metabolites in newly developed bolls, thus increasing their number and weight. Additionally, with a dynamic crop like cotton, excess N serves to delay maturity, promote vegetative tendencies, and usually results in lower yields [6]. Therefore, errors made in N management that can impact the crop can be through either deficiencies or excesses. With a dynamic crop like cotton, excess N serves to delay maturity, promote vegetative tendencies, and usually results in lower yields [6; 7]. Therefore, errors made in N management that can impact the crop can be through either deficiencies or excesses. If an N deficiency is developing in a cotton crop, it is not particularly difficult to diagnose and correct. Excess N fertility levels, which, can be damaging to final crop productivity, are subtler to detect, and are difficult to correct [8].

Phosphorus (P)

is the second most limiting nutrient in cotton production after nitrogen Response to P fertilizer, however, is often difficult to predict, even with soil test-based applications [9]. The high soil pH (> 7.6) and the high quantities of $CaCO_3$ result in precipitation of P, which reduces the soluble P supply. Its deficiency tends to limit the growth of cotton plants, especially when plants are deprived of phosphorus at early stages than later stages of growth [10]. P is also involved in cell division and development of meristematic tissues [11]. Moreover, on a whole-plant scale, P plays a decisive role in carbon assimilate transport and metabolic regulation [12]. Phosphorus deficiencies lead to a reduction in the rate of leaf expansion and photosynthesis per unit leaf area [13]. The high soil pH (> 7.6) and the high quantities of $CaCO_3$ result in precipitation of P, which reduces the soluble P supply. Sasthri et al. [14] found that application of 2% diammonium phosphate to cotton plants increased seed yield, seed germination, root length, vigor index and dry matter production.

Potassium (K)

The physiological role of K during fruit formation and maturation periods is mainly expressed in carbohydrate metabolism and translocation of metabolites from leaves and other vegetative organs to developing bolls. K increases the photosynthetic rates of crop leaves, CO_2 assimilation and facilitating carbon movement [15]. At least sixty enzymes are known to be activated by this ion. The enzyme pyruvate kinas (more correctly referred to as ATP: pyruvate phosphotransferase), which participates in glycolysis [16]. The high concentration of K^+ is thought to be essential for normal protein synthesis. Potassium role in this process is considered to be the maintenance of a proper association between t RNA molecules and ribosomes during the translation of mRNA [16]. Potassium also acts as an activator for several enzymes involved in carbohydrates metabolism. The requirement of cotton for K increases with the beginning of bud formation stage. A greater accumulation of sugars and starch in leaves under K-deficient conditions adversely affects development of bolls due to deficiency of metabolites. K deficiency during the reproductive period can limit the accumulation of crop biomass [17], markedly changes the structure of fruit-bearing organs, and decreases yield and quality. Pettigrew [18] stated that the elevated carbohydrate concentrations remaining in source tissue, such as leaves, appear to be part of the overall effect of K deficiency in reducing the amount of photosynthate available for reproductive sinks and thereby producing the changes in yield and quality seen in cotton.

Calcium (Ca)

Ca is essential in cell nucleus matrix. It activates enzymes, particularly those that are membrane-bound [19]. Calcium is important in membrane permeability, maintenance of cell integrity, and in ion uptake. Calcium deficiency may also decrease the basipetal transport of auxin [20]. Addicot and Lyon [21] listed Ca deficiency as one of the causes of abscission and suggested this plus the role of Ca in the middle lamella (Ca pectates) as the possible reason. It is thought that Ca is important in the formation of cell membranes and lipid structures. Ma and Sun [22], suggested that Ca might be involved in light signal transduction chain for phototropism. Ca also plays an important role in plant growth as a major component of the middle lamella (calcium pectate). A likely reason was that Ca deficiency affected translocation of carbohydrates, causing accumulation in the leaves and a decline in stems and roots.

Zinc (Zn)

Although only small amounts of Zn are removed from the field by a cotton crop (0.5 ounces per bale), Zn is critical for several key enzymes in the plant [23]. Zinc influences electron transfer reactions, including those of the Kreb cycle, and thereby affecting the plant's energy production. Zinc binds tightly to Zn-containing essential metabolites in vegetative tissues, e.g., Zn-activated enzymes such as carbonic anhydrase [2]. Zn deficiency has been shown to affect growing sink organs; it

adversely affects the development and viability of pollen grains [24]. Zinc deficiency occurs on high-pH soils, particularly where topsoil has been removed in preparing fields for irrigation and thereby exposing the Zn-deficient subsoil. Also, Zn deficiencies have occurred where high rates of P are applied. The high P rates in the plant interfere with the utilization of Zn [25].

Plant growth retardants (PGR's)

PGR represent diverse chemistries and mode of action, and provide numerous possibilities for altering crop growth and development [26]. PGR [1, 1-dimethyl piperidinium chloride (MC). provide farmers with a new management tool for controlling undesirable vegetative growth. An objective for using PGR in cotton is to balance vegetative and reproductive growth as well as to improve yield and its quality [27]. Visual growth-regulating activity of MC [28; 29], being expressed as reduced plant height and width (shortened stem and branch internodes and leaf petioles), influence leaf chlorophyll concentration, structure and CO_2 assimilation, and thicker leaves.

In Egypt, soil fertilization is the primary limiting factor affecting growth and production under intensive land use for two or more crops per year. Furthermore, recently released varieties have high yielding ability, which largely depends on ensuring the plant's essential nutritional requirements (e.g., N, P, K, Ca; Zn). Considerable interest also exists in using PGR for cotton production because of their potential for altering crop growth and seed development [26]. All environmental factors and their interactions that influence plant growth can potentially influence the complicated and dynamic processes that control their seed initiation, development, and seed nutrient reserves. These factors can modify the ultimate vigor and viability of seeds [30]. The objectives of this study were to evaluate the effects of N and P, and K fertilization and foliar application of chelated Ca and Zn nutrients, and the PGR (MC) during square initiation and boll setting stage and to identify the best combination of these production treatments in order to improve seed yield, seed weight, and seed quality (as measured by seed viability, seedling vigor and cool germination test) of Egyptian cotton (*G. barbadense*).

METHODS AND MEASUREMENTS

Field experiments were conducted at the Agricultural Research Center (ARC), in Giza (30°N, 31°: 28'E and 19 m altitude). The soil type was a clay loam with an alluvial substratum. Average textural properties [31] and chemical properties [32] of soil in both seasons are reported in Table 1.

Table 1. Physical and chemical properties of the soil used in I and II seasons.

Season	I	II
Soil texture		
Clay (%)	43.0	46.5
Silt (%)	28.4	26.4
Fine sand (%)	19.3	20.7
Coarse sand (%)	4.3	1.7
Soil texture	Clay	Loam
Chemical analysis		
Organic matter (%)	1.8	1.9
Calcium carbonate (%)	3.0	2.7
Total soluble salts (%)	0.13	0.13
pH (1:2.5)	8.1	8.1
Total nitrogen (%)[a]	0.12	0.12
Available nitrogen (mg kg^{-1} soil)[b] (1% K_2SO_4, extract)	50.0	57.5
Available phosphorus (mg kg^{-1} soil) ($NaHCO_3$ 0.5 N, extract)	15.7	14.2
Available potassium (mg kg^{-1} soil) (NH_4OAC 1N, extract)	370.0	385.0
Total Sulphur (mg kg^{-1} soil)	21.3	21.2
Calcium (meq/100g) (with Virsen, extract)	0.2	0.2

[a]Total nitrogen, i.e. organic N + inorganic N

[b]Available nitrogen, i.e. NH_4^+ & NO_3^-

The Physical analysis (soil fraction) added to the organic matter, calcium carbonate and total soluble salts to a sum of about 100% [33].

Range and mean values of the climatic factors recorded during the growing seasons are presented in Table 2. These data were obtained from the Agricultural Meteorological Station of the, ARC, Giza, Egypt. No rainfall occurred during the two growing seasons [33]. The experiments were arranged as a randomized complete block design in a factorial arrangement. The plot size was 1.95m. (3 ridges, its ridge was 65 cm. width) × 4m. (length), including three ridges (beds). Hills were spaced 25 cm apart on one side of the ridge (16 hills per ridge), and seedlings were thinned to two plants hill^{-1} 6 weeks after sowing (AS), providing plant density of 123,000 plants ha^{-1}. Total irrigation amount during the growing season (surface irrigation) was about 6,000 m^3 ha^{-1}. The first irrigation was applied 3 weeks AS, and the second one was 3 weeks later. Thereafter, the plots were irrigated every 2 weeks until the end of the season, thus providing a total of nine irrigations. In every experiment, fertilization along with pest and weed management was applied as needed during the growing season, according to local practices performed at the experimental station.

Table 2. Range and mean values of the weather variables recorded during the growing seasons (April-October).

Weather variables	Season I		Season II		Overall date (Two seasons)	
	Rang	Mean	Range	Mean	Range	Mean
Max Temp [°C]	20.8-44.0	32.6	24.6-43.4	32.7	20.8-44.0	32.6
Min Temp [°C]	10.4-24.5	19.4	12.0-24.3	19.3	10.4-24.5	19.3
Max-Min Temp [°C]	4.7-23.6	13.2	8.5-26.8	13.4	4.7-26.8	13.3
Sunshine [h d^{-1}]	0.3-12.9	11.1	1.9-13.1	11.2	0.3-13.1	11.1
Max Hum [%]	48-96	79.5	46-94	74.7	46-96	77.2
Min Hum [%]	6-48	30.1	8-50	33.0	6-50	31.5
Wind speed [m s^{-1}]	0.9-11.1	5.2	1.3-11.1	5.0	0.9-11.1	5.1

[33]

Experiments

A. Effect of P, Zn and Ca on Cotton Seed Yield, Viability and Seedling Vigor

Materials

A field experiment was conducted at the ARC in Giza, Egypt, using the cotton cultivar Giza 75 in the two seasons I and II. The experiment included 16 treatments, combinations of:

1- Two P rates (44 or 74 kg ha^{-1}P_2O_5), were applied (banded into soil) as calcium super phosphate (15% P_2O_5) three weeks AS, just before the first irrigation. General Farmer practice of applying 44 kg ha^{-1} P_2O_5 was used as the control treatment.

2- Two Zn rates (0 as control or 40 ppm Zn) were applied as the chelated form. Each rate was foliar-sprayed twice, at 75 and 90 DAS. Volume of solution applied was 960 l ha^{-1} (actual Zn applied in each spray was 0 or 38.4 g ha^{-1}),

3- Four Ca rates (0 as control, 20, 40 or 60 ppm Ca) were applied as the chelated form. Each rate was foliar-sprayed twice, at 80 and 95 DAS. Volume of solution applied was 960 l ha^{-1} (actual Ca applied in each spray was 0, 19.2, 38.4 or 57.6 g ha^{-1}) [34].

B. Effect of N, K and PGR's on Cotton Growth, Seed Yield, Seed Viability and Seedling Vigor

Materials

A field experiment was conducted at the ARC in Giza, Egypt using the cotton cultivar Giza 86 in the two seasons I and II. The factors studied were N fertilization, foliar application of potassium, and the PGR MC. Two N rates, 95.2 and 142.8 kg N ha^{-1}, were applied as ammonium nitrate at two equal doses, six and eight weeks AS. Each application in the form of side dressing beside each hill was followed immediately by irrigation. Four K rates (0, 0.38, 0.77, 1.15 kg ha^{-1} K_2O) were applied in a volume 960 l ha^{-1}as K sulfate (K_2SO_4, '48% K_2O') twice during the reproductive phase. The first application occurre 70 DAS during square initiation and the second at 95 DAS during boll development. The foliar PGR MC was applied twice during reproductive phase, both times delivered in of 960 l H_2O ha^{-1}. The first application (0.048 kg a.i. ha^{-1}) occurre 75 DAS and the second (0.024 kg a.i. ha^{-1}) 90 DAS. Control plots received no MC. The K_2O and MC were both applied to the leaves with uniform coverage using a knapsack sprayer [33].

Measurements

At harvest, bolls of 10 randomly chosen plants from each plot were harvested (handpicking) and laboratory-ginned to determine seed yield in g per plant. Total seed cotton yield of each plot (including the 10-plant

sub-sample) was lab-ginned to determine seed yield in kg ha^{-1}. A random sample of 100 g of seeds from each plot was taken to determine seed weight (weight of 100 seed in g) and to evaluate seed quality in terms for seed viability, cool germination test performance, and seedling vigor [33].

Seed viability

Germination was evaluated using the International Rules of Seed Testing [35] in the Seed Research Unit, Central Administration of Seed, ARC, Giza, Egypt. Aluminum dishes 17 cm in diameter and 3 cm deep were used, and the sand substratum was sieved/washed/sterilized and kept moistened to 50% of water-holding capacity. Fifty seeds were planted in each dish in sand depressions made with a standard puncher and then covered with a top layer of 2 cm of loose moist sand. Each of the four replicates of each treatment included two dishes for each replicate. Dishes were then incubated at 30 ± 1°C for 12 days. The following parameters were measured:

a. First germination count (germination velocity): percentage of seeds that sprouted after four days of incubation.

b. Second germination count: percentage of seeds that sprouted after eight days of incubation. This count was used to calculate germination rate index.

c. Total germination capacity (final count): total percentage of normal seedlings after 12 days of incubation.

d. Germination rate index (GRI): was calculated according to Bartlett [36] as follows:

$$GRI = \frac{a + (a+b) + (a+b+c)}{n(a+b+c)},$$

Where n = 3 is the number of times counts were taken [33].

Cool germination test performance

In this test, the germination chamber was maintained at a constant temperature of 18 ± 1°C with sufficient humidity to prevent drying of the paper towel substratum [37]. Two hundred seeds (four replicates of 50 seeds each) were tested per field treatment. Four paper towels represented each of the four replicates of each treatment. In each of the four replicates, the 50 seeds were randomly placed on moist towels, as usually practiced in the standard germination test. Two towels were placed over the seeds before rolling. The towels were moistened, but not so wet that by pressing, a film of water formed around the finger. Rolled towel tests were then set upright in wire mesh baskets in the germinator. Additional moisture was not needed during the test period. Two counts of germination were made for germination on the fourth and seventh day under test conditions [33].

Seedling vigor

Aluminum dishes, similar to those described regarding the seed viability test, were used to evaluate seedling vigor. Two dishes represented each of the four replicates of each treatment; in each dish, 50 seeds were planted. Ten seedlings were randomly taken from each dish after eight days of incubation at 30 ± 1°C to measure the following seedling vigor characters: (1) length (in cm) of hypocotyl, radicle and entire seedling; and (2) fresh and dry weights (g) of 10 seedlings. The 10 seedlings were weighed immediately to record fresh weight, and then oven-dried for 72 hours at 85°C to determine dry weight [33].

Statistical analysis

Data for the studied characters observed were analyzed as a factorial experiment arranged in a randomized complete block design, and combined statistical analysis for the two years had been done, according to Snedecor and Cochran [38]. The Least Significant Difference (L.S.D.) test (*t*-test) at the 0.05 significance level was used to examine differences among treatment means [33].

ANALYZED DATA FOR MEASUREMENTS

Experiments

A. Effect of P, Zn and Ca on Cotton Seed Yield, Viability and Seedling Vigor

Seed yield

Seed yield $plant^{-1}$ and $plot^{-1}$, significantly increased when P was applied at the highest rate with the application of high P-rate in both years (Table 3) [34]. Phosphorus as a constituent of cell nuclei is essential for cell division and development of meristematic tissue, and hence it should have a stimulating effect on the plants, increasing the number of flowers and bolls per plant. Further, P has a well-known impact in photosynthesis as well as synthesis of nucleic acids, proteins, lipids and other essential compounds [39], all of which are major factors affecting boll weight and consequently cottonseed. These results are confirmed by those of Abdel-Malak et al. [40], Ibrahim et al. [41], and Saleem et al [42]. Application of Zn significantly increased Seed yield $plant^{-1}$ and $plot^{-1}$, as compared with the untreated control. This may be due to its favorable effect on photosynthetic activity, which improves mobilization of photosynthates and directly influences of boll weight [16]. Also, Zn enhances the activity of tryptophan synthesis, which is involved in the synthesis of the growth control compound IAA, the major hormone that inhibits abscission of squares and

Table 3. Effect of P-rate and foliar application of Zn and Ca on seed yield plant^{-1} and seed yield plot^{-1}, and seed weight.

Treatment	Cotton seed yield (g plant^{-1})		Cotton seed yield (kg plot^{-1})		Seed weight (g 100 seed^{-1})	
	I	II	I	II	I	II
P_2O_5 rate (kg ha^{-1})						
44 (control)	17.04	17.93	1.302	1.345	10.06	10.32
74	18.80**	20.03**	1.439**	1.505**	10.26**	10.54**
LSD (0.05)	0.451	0.697	0.0385	0.0511	0.091	0.075
(0.01)	0.603	0.931	0.0515	0.0683	0.121	0.101
Zn rate (ppm)						
0 (control)	17.30	18.10	1.322	1.358	10.11	10.36
40	18.54**	19.87**	1.419**	1.492**	10.21*	10.50**
LSD (0.05)	0.451	0.697	0.0385	0.0511	0.091	0.075
(0.01)	0.603	0.931	0.0515	0.0683	n.s.	0.101
Ca rate (ppm)						
0 (control)	16.61	17.79	1.270	1.333	10.03	10.30
20	17.96**	18.92*	1.368**	1.419*	10.18*	10.43*
40	18.46**	19.43**	1.411**	1.460**	10.21*	10.47**
60	18.65**	19.80**	1.432**	1.488**	10.22*	10.51**
LSD (0.05)	0.638	0.986	0.0545	0.0723	0.129	0.107
(0.01)	0.853	1.317	0.0728	0.0966	n.s.	0.143

n.s.: Not significant; * Significant at 5% level; and ** Significant at 1% level [34]

bolls. The application of Zn increased the number of retained bolls plant^{-1}. Similar results were obtained by Alikhanova and Tursunov [43] by application of Zn at 2.5-7.5 kg ha^{-1}, by Sawan et al. [44] when cotton was sprayed with Zn at 12.5 ppm and by Gomaa [45] when cotton was sprayed with 0.952 kg Zn SO_4 ha^{-1}. Results are confirmed by those of Zeng [46] and Ibrahim et al. [41]. The three concentrations of Ca applied significantly exceeded the control (Table 3) [34]. In general, the highest Ca concentration (60 ppm) was better than the other two). The role of Ca in increasing seed yield can possibly be ascribed to its involvement in the process of photosynthesis and the translocation of carbohydrates to young bolls. Calcium deficiency depressed the rate of photosynthesis (rate of CO_2 fixation). Guinn [39] stated that Ca deficiency would cause carbohydrates to accumulate in leaves and not in young bolls. The results obtained agree with those reported by Shui and Meng [47] and Wright et al. [48].

Seed weight

Application of P at the high rate of 74 kg ha^{-1} P_2O_5 and Zn at the concentration of 40 ppm, both significantly increased seed weight relative to the control in the two seasons (Table 3) [34]. A possible explanation for increased seed weight due to the application of P at the higher rate is that this nutrient activated biological reactions in the cotton plants, particularly CO_2 fixation and the synthesis of sugar, amino acids, protein, lipids and other organic compounds. It also increased the translocation of assimilates from photosynthetic organs to the sink [49]. Similar results were obtained by El-Debaby et al. [50]. Application of Zn significantly increased seed index, compared to the control. This may be due to its favorable effect on photosynthetic activity. Zinc improves mobilization of photosynthates and directly influences boll weight that coincide directly with increased seed index. These results are confirmed by those obtained by Ibrahim et al. [41]. Calcium applied at all rates significantly increased seed index over the control. The highest rate of Ca (60 ppm) showed the highest numerical value of seed index. Similar results were obtained by Ibrahim et al. [41].

Seed viability, seedling vigor and cool germination test

Seed viability, seedling vigor and cool germination test performance were generally significantly increased by addition of P at high rate and by application of Zn at 40 ppm and Ca at different concentrations in both years. (Tables 4; 5) [34]. This may be attributed to the fact that P is required for production of high quality seed, since it occurs in coenzymes involved in energy transfer reactions. Energy is tapped in photosynthesis in the form of adenosine triphosphate (ATP) and nicotinamide adenine dinucleotide phosphate (NADP). This energy is then used in photosynthetic fixation of CO_2 and in the synthesis of lipids and other essential organic compounds [51]. Also, this could be attributed to the increase of total photo assimilates (e.g. lipids) and the translocated assimilates to the sink as a result of applying zinc. The highest Ca-concentration (60 ppm)

significantly increased total germination count. Ochiai [52] notes that Ca^{2+} can bridge phosphate and carboxylate groups of phospholipids and proteins; that it increases hydrophobicity of membranes; that it generally increases membrane stability and reduces water permeability. Certain hydrolase's acting on macromolecular substrates (e.g. some @-amylases, phospholipase, and nucleases) requires Ca^{2+} for activity. Although Ca^{2+} probably has a structural role rather than catalytic (binds at sites other than catalytic, changing enzyme conformation), it is also possible that macromolecular substrates such as starch might require Ca^{2+} for bridge complexes [53]. Phosphorus-rates or application of Zn or Ca at different concentrations had no significant effect in either year on germination rate index .

Table 4. Effect of P-rate and foliar application of Zn and Ca on seed viability and cool germination test performance.

Treatment	First germination count (%)		Second germination count (%)		Total germination count (%)		Germination rate index (GRI unit)		Cool germination test performance (%) 4-day count		7-day count	
	I	II	I	II	I	II	I	II	I	II	I	II
P_2O_5 rate (kg ha^{-1})												
44 (Control)	73.19	75.44	79.25	82.31	80.62	83.69	0.656	0.655	33.06	34.00	68.19	70.06
74	76.38**	78.94**	84.00**	85.62**	85.38**	86.88**	0.654	0.656	35.81**	37.88**	71.56**	73.12**
	1.703	1.588	1.719	1.579	1.675	1.504	n.s.	n.s.	1.555	1.548	1.837	1.626
LSD (0.05)	2.275	2.121	2.297	2.109	2.238	2.009	n.s.	n.s.	2.077	2.068	2.454	2.171
(0.01)												
Zn rate (ppm)												
0 (Control)	73.75	76.12	80.50	82.75	81.94	84.19	0.655	0.655	33.56	34.88	68.81	70.44
40	75.81*	78.25**	82.75*	85.19**	84.06*	86.38**	0.655	0.656	35.31*	37.00**	70.94*	72.75**
LSD (0.05)	1.703	1.588	1.719	1.579	1.675	1.504	n.s.	n.s.	1.555	1.548	1.837	1.626
(0.01)	n.s.	2.121	n.s.	2.109	n.s.	2.009	n.s.	n.s.	n.s.	2.068	n.s.	2.171
Ca rate (ppm)												
0 (Control)	72.12	74.25	78.88	81.62	80.25	82.75	0.655	0.655	32.62	33.75	67.50	69.12
20	74.75*	77.38**	81.50*	83.88*	82.62*	85.38*	0.656	0.656	34.25	36.38*	70.20*	71.50*
40	75.88**	78.25**	82.75**	84.62**	83.75**	85.88**	0.656	0.656	35.12	36.62*	70.75*	72.62**
60	76.38**	78.88**	83.38**	85.75**	85.38**	87.12**	0.654	0.656	35.75*	37.00*	71.12*	73.12**
LSD (0.05)	2.409	2.246	2.432	2.233	2.369	2.127	n.s.	n.s.	2.199	2.190	2.598	2.299
(0.01)	3.218	2.999	3.248	2.983	3.165	2.841	n.s.	n.s.	n.s.	n.s.	n.s.	3.071

n.s.: Not significant; * Significant at 5% level; and ** Significant at 1% level [34]

B. Effect of N, K and PGR on Cotton Growth, Seed Yield, Seed Viability and Seedling Vigor

Plant growth and mineral contents

From Table 6, it follows that there were significant effects under the high N-rate regime (142.8 kg ha-1 N) on growth and nutrient content of cotton plants (105 DAS) compared with the lower rate (95.2 kg ha-1 N) [33]. These findings coincide with the fact that N is an essential nutrient in building a plant dry matter as well as many energy- rich compounds (ATP), which regulate photosynthesis. Under N deficiency, a considerably larger proportion of dry matter (photosynthates) is partitioned to roots than shoots, leading to reduced shoot/root dry weight ratios [54]. Shrivastava et al. [55] found that an increase in N level (from 0 up to 120 kg N ha-1) application caused an increased uptake of N, P and K. Perumai [56] stated that when cotton was given 0-120 kg N ha-1, an increase in an N level (from 0 up to 120 kg ha-1 N) significantly increased above ground biomass production. Bronson et al. [9] found that petiole NO3-N readings were positively related to N rate when applied up to 112 kg N ha-1. According to the N-status in our experimental soil (Table 1), it was classified as medium fertile for N. The K applied at all the three K concentrations (0.38, 0.77, 1.15 kg of K2O ha-1) significantly enhanced growth, N and K uptake of cotton plants as compared to control (0 kg ha-1 K2O). In this connection, Fan et al. [57] found that K content in petioles and total dry matter production in cotton increased by application of K. Gormus [58] indicated that the 0 kg ha-1 K2O plots (untreated control) had lower leaf K concentrations compared with the plots with 80, 160 and 240 kg ha-1 K2O. According to the K-status in our experimental soil (Table 1), it classified as medium fertile for K. MC significantly increased dry matter yield and N and K uptake of cotton plants compared with plots not treated with MC. Hodges et al. [59] stated that application of MC increased canopy

Table 5. Effect of P-rate and foliar application of Zn and Ca on seedling vigor.

Treatment	Hypocotyl length (cm)		Radicle length (cm)		Seedling length (cm)		Seedling fresh weight (g 10 seedling^{-1})		Seedling dry Weight (g 10seedling^{1})	
	I	II	I	II	I	II	I	II	I	II
P_2O_5 rate (kg ha^{1})										
44 (Control)	7.53	7.59	15.72	15.86	23.25	23.45	6.99	7.30	0.596	0.601
74	7.80**	7.92**	16.30**	16.55**	24.10**	24.47**	7.23**	7.52**	0.620**	0.625**
LSD (0.05)	0.182	0.149	0.325	0.344	0.487	0.468	0.135	0.163	0.0133	0.0112
(0.01)	0.243	0.199	0.434	0.459	0.651	0.625	0.181	0.217	0.0178	0.0149
Zn rate (g ha^{-1})										
0.0 (Control)	7.57	7.64	15.79	15.95	23.36	23.59	7.02	7.33	0.600	0.605
40	7.76*	7.86**	16.22*	16.46**	23.98*	24.32**	7.20*	7.50*	0.615*	0.622**
LSD (0.05)	0.182	0.149	0.325	0.344	0.487	0.468	0.135	0.163	0.0133	0.0112
(0.01)	n.s.	0.199	n.s.	0.459	n.s.	0.625	n.s.	n.s.	n.s.	0.0149
Ca rate (ppm)										
0 (Control)	7.44	7.53	15.53	15.70	22.98	23.23	6.95	7.16	0.592	0.597
20	7.69	7.77*	16.08*	16.26*	23.77*	24.03*	7.12	7.40*	0.609	0.614*
40	7.74*	7.81*	16.16*	16.38*	23.90*	24.19*	7.16*	7.52**	0.612*	0.618*
60	7.78*	7.89**	16.26*	*16.49**	24.04*	*24.38**	7.22*	7.58**	0.618*	0.624**
LSD (0.05)	0.257	0.210	0.459	0.486	0.689	0.662	0.191	0.230	0.0189	0.0158
(0.01)	n.s.	0.281	n.s.	0.649	n.s.	0.884	n.s.	0.308	n.s.	0.0211

n.s.: Not significant; * Significant at 5% level; and ** Significant at 1% level [34].

grass photosynthesis of cotton within 48 h, suggesting a direct effect of MC on photosynthesis. Zhao and Oosterhuis [60] stated that MC application improved leaf photosynthetic rate compared with the untreated control.

Seed yield

An increase in N dose from 95.2 to 142.8 kg ha-1 N increased seed yield per plant and per ha (by 13.08 and 13.03%) (Table 7) [33]. There is an optimal relationship between the nitrogen content in the plant and CO2 assimilation, where decreases in CO2 fixation are well documented for N-deficient plants. Nitrogen deficiency is associated with elevated levels of ethylene (which increase boll shedding), suggesting ethylene production in response to N-deficiency stress [61]. N is also an essential nutrient in creating plant dry matter, as well as many energy-rich compounds which regulate photosynthesis and plant production [6278], thus influencing boll development, increasing the number of bolls plant-1 and boll weight. Similar findings were obtained by McConnell and Mozaffari [63] when N fertilizer was applied at 120 kg ha-1, and Saleem et al. [64] when N fertilizer was applied at 120 kg ha-1. Also, similar results were obtained by Sarwar Cheema et al. [65]. On the other hand Boquet [66] reported that increasing N from 90 to 157 kg ha-1 did not result in increased cotton yield in irrigated or rain-fed cotton. All the three K concentrations (0.38, 0.77, 1.15 kg ha-1 K2O) significantly increased seed yield per plant (by 10.28-16.45%) and per ha (by 10.02-16.26%) compared to the untreated control. This could be attributed to the fact that K significantly enhanced growth and N and K uptake of the plants (Table 6) [33]. These increases could be due to the favorable effects of this nutrient on yield components such as number of opened bolls plant-1, boll weight, or both, leading to higher cotton yield. Zeng [46] indicated that K fertilizer affects abscission and reduced boll shedding and it certainly affects yield. Pettigrew [18] stated that, the elevated carbohydrate concentrations remaining in

Table 6. Mean effects of N-rate and foliar application of potassium and the plant growth MC on dry matter yield and uptake of N and K by cotton plants (season II, sampled 105 days after planting).

Treatments	Dry matter yield (g plant^{-1})	N Conc./d.m. (%)	uptake (mg plant^{-1})	K Conc./d.m. (%)	uptake (mg plant^{-1})
N rate (kg ha^{-1})					
95.2	39.8^{b}	3.12^{b}	1242.7^{b}	2.10^{b}	836.4^{b}
142.8	47.9^{a}	3.26^{a}	1560.6^{a}	2.46^{a}	1177.6^{a}
L.S.D. 0.05	3.4	0.11	77.2	0.14	46.7
K_2O rate (kg ha^{-1})					
0	38.2^{b}	3.08^{b}	1177.2^{c}	2.04^{b}	779.7^{d}
0.38	43.0^{b}	3.16^{b}	1358.2^{b}	2.26^{a}	971.4^{c}
0.77	45.3^{a}	3.22^{b}	1457.7^{ab}	2.38^{a}	1077.4^{b}
1.152	48.9^{a}	3.30^{a}	1615.0^{a}	2.44^{a}	1194.1^{a}
L.S.D. 0.05	4.8	0.16	109.5	0.20	68.9
MC rate (kg ha^{-1})					
0	40.2^{b}	3.09^{b}	1241.9^{b}	2.18^{b}	876.1^{b}
0.048 + 0.024	47.5^{a}	3.29^{a}	1563.4^{a}	2.38^{a}	1131.0^{a}
L.S.D. 0.05	3.4	0.11	77.2	0.14	46.7

Values followed by the same letter are not significantly different from each other at 0.05 levels [33].

source tissue, such as leaves, appear to be part of the overall effect of K deficiency in reducing the amount of photosynthate available for reproductive sinks and thereby producing changes in boll weight. Cakmak et al. [67] found that, the K nutrition had pronounced effects on carbohydrate partitioning by affecting either the phloem export of photosynthates (sucrose) or growth rate of sink and/or source organs. Results obtained here confirmed those obtained by Aneela et al. [68] when applying 200 kg K2O ha-1, Pervez et al. [69] under 62.5, 125, 250 kg K ha ha-1, and Pettigrew et al. [70] under K fertilizer (112 kg ha-1). MC significantly increased seed yield plant-1 (by 9.68%), and ha-1 (by 9.72%) compared with untreated plants. This could be attributed to the fact that MC significantly controlled new growth and N and K uptake of cotton plants compared to plots not treated with MC (Table 6) [33]. Such increases could be due to the fact that, the application of MC restrict vegetative growth and thus enhance reproductive organs by allowing plants to direct more energy towards the reproductive structure [71]. This means that bolls on treated cotton would have a larger photo synthetically supplied sink of carbohydrates and other metabolites than did those on untreated cotton [72]. Results agreed with those obtained by Prakash et al. [73] when MC was applied at 50 ppm, Mekki [74] when MC was applied at 100 ppm, and Kumar et al. [75]. Also, similar results were obtained by Sarwar Cheema et al. [65].

Seed weight

Seed weight significantly increased with an increase in N from 95.2 to 142.8 kg ha^{-1} (Table 7). This may be due to increased photosynthetic activity, which increases accumulation of metabolites, with direct impact on seed weight (Table 6) [33]. This may be due to increased photosynthetic activity that increases accumulation of metabolites, with direct impact on seed weight. Reddy et al. [5], in a pot experiment under natural environmental conditions, where 20-day old cotton plants received 0, 0.5, 1.5 or 6 mM NO_3, found that, net photosynthetic rates, stomatal conductance and transpiration were positively correlated with leaf N concentration.

Similar findings were reported by Palomo et al. [76], when N was applied at 40-200 kg ha^{-1}, and Ali and El-Sayed [77], when N was applied at 95-190 kg ha^{-1}. The K application, at all the three concentrations, increased seed weight compared with a control. Results from K application were more effective and significant when applied at the high concentration (1.15 kg ha^{-1} K_2O) than those produced from the low concentration (0.38 kg ha^{-1} K_2O).

This may be due to its favorable effects on nutrient uptake, Photosynthetic activity, improving its mobilization (Table 6) [33], which directly influence boll weight and increased seed weight [18]. Ghourab et al. [78] and Ibrahim et al. [41] reported that, the application of K fertilizer MC significantly increased seed weight as compared to untreated control.

Increased seed weight as a result of MC applications may be due to an increase in photosynthetic activity, which stimulates photosynthetic activity, and dry matter accumulation [75; 79], and in turn increases the formation of fully-mature seed and thus increases seed weight. Similar results to the present study were obtained by Ghourab et al. [78] and Lamas [80].

Table 7: Mean effects of N-rate and foliar application of potassium and the plant growth retardant MC on seed yield plant^{-1} and seed yield ha^{-1}, and seed weight.

Treatments	Cotton seed yield (g plant^{-1})	Cotton seed yield (kg ha^{-1})	Seed weight (g 100 seed^{-1})
N rate (kg ha^{-1})			
95.2	19.11^{b}	1862.4^{b}	10.09^{b}
142.8	21.61^{a}	2105.0^{a}	10.32^{a}
L.S.D. 0.05	0.864	78.78	0.075
K_2O rate (kg ha^{-1})			
0	18.48^{b}	1804.3^{c}	10.03^{c}
0.38	20.38^{a}	1985.1^{b}	10.19^{b}
0.77	21.05^{a}	2047.7^{ab}	10.27^{ab}
1.15	21.52^{a}	2097.6^{a}	10.32^{a}
L.S.D. 0.05	1.222	111.42	0.107
MC rate (kg ha^{-1})			
0	19.42^{b}	1891.8^{b}	10.13^{b}
0.048 + 0.024	21.30^{a}	2075.6^{a}	10.27^{a}
L.S.D. 0.05	0.864	78.78	0.075

Values followed by the same letter are not significantly different from each other at 0.05 levels [33]

Seed viability, seedling vigor and cool germination test performance

Seed viability, seedling vigor and cool germination test performance were significantly increased by the high N rate as compared to the low rate and with the application of the three K concentrations and the PGR MC (Tables 8; 9) [33]. Results from K application were more effective and significant when applied at the high concentration (1.15 kg ha^{-1} K_2O) than those produced from the low concentration (0.38 kg ha^{-1} K_2O) concerning its effect on seed viability and hypocotyl and entire seedling length. The Germination rate index was not significantly affected by N rate, three K concentrations and the PGR MC. Effects of adding the high N-

Table 8: Mean effects of N-rate and foliar application of potassium and the plant growth retardant MC on seed viability and cool germination test performance.

Treatments	First germination count (%)	Second germination count (%)	Total germination Capacity (%)	Germination rate index (GRI unit)	Cool germination test performance (%)	
					4-day count	7-day count
N rate (kg ha^{-1})						
95.2	74.56^{b}	81.25^{b}	82.91^{b}	0.655	32.56^{b}	70.03^{b}
142.8	78.13^{a}	84.84^{a}	86.00^{a}	0.656	35.00^{a}	72.50^{a}
L.S.D. 0.05	1.373	1.329	1.206	n.s.	1.077	1.160
K_2O rate (kg ha^{-1})						
0	72.88^{c}	79.81^{c}	81.63^{c}	0.654	31.81^{b}	68.88^{b}
0.38	75.88^{b}	82.69^{b}	84.31^{b}	0.655	33.81^{a}	71.25^{a}
0.77	77.75^{ab}	84.25^{ab}	85.31^{ab}	0.656	34.38^{a}	72.19^{a}
1.15	78.88^{a}	85.44^{a}	86.56^{a}	0.656	35.13^{a}	72.75^{a}
L.S.D. 0.05	1.942	1.879	1.705	n.s.	1.523	1.641
MC rate (kg ha^{-1})						
0	74.84^{b}	81.56^{b}	83.19^{b}	0.655	32.91^{b}	70.28^{b}
0.048 + 0.024	77.84^{a}	84.53^{a}	85.72^{a}	0.656	34.66^{a}	72.25^{a}
L.S.D. 0.05	1.373	1.329	1.206	n.s.	1.077	1.160

Values followed by the same letter are not significantly different from each other at 0.05 levels [33].

Table 9: Mean effects of N-rate and foliar application of potassium and the plant growth retardant MC on seedling vigor.

Treatments	Hypocotyl length (cm)	Radicle length (cm)	Seedling length (cm)	Seedling fresh weight (g 10 seedling^{-1})	Seedling dry weight (g 10 seedling^{-1})
N rate (kg ha^{-1})					
95.2	7.31^{b}	16.24^{b}	23.56^{b}	6.81^{b}	0.637^{b}
142.8	7.62^{a}	16.69^{a}	24.31^{a}	7.04^{a}	0.655^{a}
L.S.D. 0.05	0.149	0.239	0.377	0.101	0.0085
K_2O rate (kg ha^{-1})					
0	7.18^{c}	15.91^{b}	23.09^{c}	6.71^{b}	0.626^{b}
0.38	7.45^{b}	16.48^{a}	23.93^{b}	6.94^{a}	0.647^{a}
0.77	7.55^{ab}	16.70^{a}	24.24^{ab}	6.99^{a}	0.653^{a}
1.15	7.69^{a}	16.79^{a}	24.48^{a}	7.07^{a}	0.657^{a}
L.S.D. 0.05	0.211	0.338	0.532	0.143	0.0120
MC rate (kg ha^{-1})					
0	7.33^{b}	16.28^{b}	23.61^{b}	6.84^{b}	0.638^{b}
0.048 + 0.024	7.60^{a}	16.66^{a}	24.26^{a}	7.02^{a}	0.654^{a}
L.S.D. 0.05	0.149	0.239	0.377	0.101	0.0085

Values followed by the same letter are not significantly different from each other at 0.05 levels [33].

rate, application of potassium at different concentrations and MC on seed viability, seedling vigor and the cool germination test performance, which are important in stand establishment, may be attributed to the higher synthesis of assimilates (Table 6) in the recovered leaves which were deviated towards bolls [33]. This caused an increase in seed weight associated with its changed composition [2, 51; 81]. These effects are manifested in metabolites formed in plant tissues, which have a direct impact through utilization in growth and development processes. This may be reflected in distinct changes in seed quality and weight. Speed et al. [82] stated that seed density was positively associated with germination capability at 15°C. Gadallah [83] indicated that viability, germination and seedling emergence were directly related to seed density for the *G. barbadense* cultivars. He pointed out that high seed density of all cultivars usually exhibited faster and more uniform rates of radicle emergence than low seed density. Seedlings from heavier seeds had greater accumulation of fresh and dry weight, and quality and vigor indices were also higher than those from light seeds. N is essential for plant protein synthesis including chlorophyll, which is indispensable for photosynthesis and enzymes which act as catalysts in biochemical reactions, and seed reserve proteins [12]. Maiya et al. [8497] indicated that the large- and medium-sized seeds (>4.75 mm) recorded higher field emergence (>65%) and produced vigorous seedlings compared to smaller seeds (<4.75 mm). The shoot and root length of seedlings increased with an increase in seed size. Thus, heavier cottonseed has a higher growth potential than lighter seed. Potassium application has favorable effects as an activator of several enzymes involved in carbohydrate metabolism and on the metabolism of nucleic acids, proteins, vitamins and growth substances [12; 79]. This may be reflected in distinct changes in seed weight and quality. Vasudevan et al. [85] studied the response of sunflower to K, P, and Zn along with recommended doses of N, P and K, and found that those nutrients increased the seed-quality parameters such as higher germination after accelerated ageing, higher speed of germination, higher shoot and root lengths, higher vigor index and seedling-growth rate compared with the control. No information on residual effects of K on cool germination test performance was found in the available literature on cotton plants. Beneficial residual effects of MC on seed viability, seedling vigor and cool germination test performance may be due to their favorable effects on seed weight [75]. Wang et al. [72] stated that the application of MC (at 50 or 100 mg kg^{-1}) to the cotton plants at squaring decreased the partitioning of assimilates to the main stem, the branches and their growing points, and increased partitioning to the reproductive organs and roots. Also, they indicated that, from flower to boll setting, MC application was very effective in promoting the partitioning of assimilates into reproductive organs (seeds). Lamas and Athayde [86] indicated that seedling emergence and seedling dry matter increased with increasing MC rate, when applied at 50, 75, 100 or 125 g ha^{-1}. Significant effects for the main treatments and years were detected, on all studied characters, with one exception for the Germination rate index. Replications within years showed significant effects only on cotton seed yield plant^{-1} and ha^{-1}, seed weight and first germination count. Boman and Westerman [87] found that no

significant N × MC rate interactions on growth and yield of cotton when the plants received 0 to 227 kg ha^{-1} N and were sprayed at early flowering with 0, 25 or 50 g ha^{-1} MC.

CONCLUSION

Under the conditions of this study, it can be concluded that addition of P at 74 kg ha^{-1} P_2O_5 and spraying cotton plants with Zn at 40 ppm and also with Ca at 60 ppm can be recommended to improve cotton seed yield, viability, and seedling vigor [34].

Application of N at the rate of 142.8 kg ha^{-1} and application of K (foliar, at the rate of 1.15 kg ha^{-1} K_2O) and MC (at the rate of 0.048 + 0.024 kg ha^{-1} MC) should help achieve higher cotton seed productivity and quality (seed viability and seedling vigor) in comparison with the usual cultural practices adopted by Egyptian cotton procedures [33].

In comparison with the ordinary cultural practices adopted by Egyptian cotton producers, it is apparent that the applications of such treatments could produce an improvement in cottonseed yield and quality.

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