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REGULAR ARTICLE

Egyptian cotton (*Gossypium barbadense* L.) yield as affected by nitrogen fertilisation and foliar application of potassium and mepiquat chloride

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ABSTRACT

Much research has been done on maximising boll set to produce maximum lint yields, but there is need to develop sufficient plant structure to support the extra boll load. There is also the necessity to achieve better nutrient balance and high fertiliser-use efficiency, and overcome yield barriers. Plant growth regulators give producers the flexibility to modify plant growth to suit current growing conditions to maximise benefits. A field experiment was conducted at the Agricultural Research Center, Giza, Egypt, during the 1999 and 2000 seasons The aim was to study the effects of nitrogen (N) fertilisation (at 95 or 143 kg N ha^{-1}), foliar application of potassium (at 0.0, 319, 638 or 957 g K ha^{-1}, applied twice: 70 and 95 days after planting) and the plant growth regulator (PGR) mepiquat chloride (MC) (applied twice; 75 days after planting at 0.0 (control) and 48 g active ingredient (*a.i.*) per ha, and 90 days after planting at 0.0 (control) and 24 g *a.i.* per ha) on yield of Egyptian cotton cultivar Giza 86. Seed cotton yield per plant and seed cotton and lint yield per ha were increased at the 143 kg N ha^{-1} rate and with foliar application of 319 g ha^{-1} K and 48 + 24 g *a.i.* ha^{-1} MC. In the absence of N × K, N × MC, K × MC, and N × K × MC interactions, N applied at 143 kg ha^{-1}, K at 319 g ha^{-1} and MC at 48 + 24 g *a.i.* ha^{-1} should be used to improve cotton growth and yield of Giza 86.

Key Words: *field experiment; growth regulator; lint yield; plant yield; seed cotton yield.*

INTRODUCTION

The world's burgeoning population continues to create a wide gap between production and consumption in most field crops. Soil fertility and crop management are two of the most important factors in modern crop production. Research in these areas is driven by the need to intensify production to obtain higher yields. Managing the balance of vegetative and reproductive growth is the essence of managing cotton crop. Fertiliser experiments have indicated that the yield of an agricultural crop strongly depends on the supply of mineral nutrients, such as nitrogen (N), which are needed in crop cultivation for full exploitation of crop genetic potential (Khan, 1996). Mineral nutrient supply strongly affects leaf area and the rate of photosynthesis and, thus, the ability of the plant to direct photosynthates to sink sites. The positive effect of mineral nutrient supply on a number of sink organs results not only from an increase in mineral nutrient supply, but also from an increase in the photosynthate supply to the sink sites or from hormonal effects (Borowski, 2001). Reddy et al. (1996), in a pot experiment under natural environmental conditions with 20-d old cotton plants receiving 0, 0.5, 1.5 or 6 mM NO_3^{-1}, found that net photosynthetic rates, stomatal conductance and transpiration were positively correlated with leaf N concentration. Additionally, excessive rates of N delayed maturity, promoted vegetative growth, and usually lowered yields in cotton (McConnell et al., 1996). Therefore, errors made in N management that can impact the crop can be through either deficiencies or excesses. A N deficiency is not particularly difficult to diagnose and correct. Excess N fertility levels, which can be damaging to final crop productivity and the environment, are more difficult to detect and correct, however.

The importance of potassium (K) fertilisation in Egyptian agriculture has risen since the completion of the High Dam that resulted in the deposition of the suspended Nile silt in the upstream of the formed lake. This Nile silt enriched the Egyptian soils with K during the seasonal floods (Abd El-Hadi et al., 1997). However, continuous cropping without replenishing nutrients can cause an irreparable damage to soil fertility. A K deficiency may affect respiration, photosynthesis, chlorophyll development, and water content of leaves (Sangakkara et al., 2000). Potassium increases the photosynthetic rates of crop leaves and carbon dioxide (CO_2) assimilation, and facilitates carbon movement (Sangakkara et al., 2000). Potassium nutrition has pronounced effects on carbohydrate partitioning by affecting either phloem export of photosynthates (sucrose) or growth rate of sink and/or source organs (Cakmak et al., 1994). Furthermore, K plays an important role in the translocation of photosynthates from source to sink (Cakmak et al., 1994). Potassium deficiencies can limit the accumulation of crop biomass. This has been attributed to (i) a reduction in the partitioning of assimilate to leaf area formation or (ii) a decrease in the efficiency with which the intercepted radiation is used for the production of above ground biomass (Colomb et al., 1995). Elevated carbohydrate concentrations remaining in source tissue, such as leaves, appeared to be part of the overall effect of K deficiency in reducing the amount of photosynthate available for reproductive sinks, thereby causing changes in lint yield and fibre quality in cotton (Pettigrew, 1999)

Despite the use of high yielding cultivars and best agronomic practices, including proper fertility, yield levels could not be increased substantially. Excess vegetative growth, poor bud development, shedding of fruiting forms, and growth imbalance between the source and sink are responsible for the unpredictable behaviour of the crop. Several approaches have been tried to break yield plateau and among them was application of plant growth regulators (PGRs); particularly mepiquat chloride (MC; 1,1-dimethylpiperidinium chloride; also known as 'Pix') has received greater attention than the other PGRs in recent years. The advantage of PGRs is that they allow producers the flexibility to modify plant growth to maximise profits (Landivar et al., 1995). Thus, MC as a PGR can be used to manage the vegetative development of cotton plants to offset the effect of excessive surface irrigation as well as of high rates of N fertilisation by decreasing both overall plant height and length of lateral branches (Boquet and Coco, 1993). This allows plants to direct more energy to reproductive organs (Wang et al., 1995). According to Nuti et al. (2000), who applied MC to control vegetative growth in cotton, MC caused a shift in partitioning of photo-assimilates from vegetative to reproductive growth. Redistribution of assimilates between vegetative and reproductive growth may be one means by which yields can be increased.

The objective of this study was to evaluate the effects of N fertilisation rate, foliar K application, and MC application on cotton yield. The study was designed to identify the best combination of production treatments to improve yield.

MATERIALS AND METHODS

A field experiment was conducted at the Agricultural Research Center, Ministry of Agriculture in Giza (30ºN, 31º: 28′E and 19 m altitude), Egypt using cotton cultivar 'Giza 86' in 1999 and 2000. The soil type in both seasons was a clay loam. Textural properties (Kilmer and Alexander, 1940) and chemical characteristics (Chapman and Pratt, 1961) of the soil in both seasons are given in Table 1. Each experiment included 16 treatment combinations. Two N rates (95 and 143 kg of N ha^{-1}) applied as ammonium nitrate with lime (NH_4NO_3 + $CaCO_3$, 33.5% N) at two equal doses, 6 and 8 weeks after planting (each application was followed immediately by irrigation): four rates of potassium sulfate (K_2SO_4, '40% K') (0, 319, 638 and 957 g K ha^{-1}) applied as foliar spray, 70 and 95 days after planting (during square initiation and boll development stage; the solution volume applied was 960 L ha^{-1}): two rates of the MC were used as foliar application (75 days after planting at 0 (control) and 48 g *a.i.* ha^{-1}, and 90 days after planting at 0 (control) and 24 g *a.i.* ha^{-1}), where the solution volume applied was also 960 L ha^{-1}. The K and MC were applied to leaves uniformly using a knapsack sprayer at 0.4 kg cm^{-2} pressure, which resulted in an output of 1.43 L per min. The application was carried out between 09.00 and 11.00 h. A summary of the various treatments is given in Table 2.

Table 1. Textural and chemical properties of soil samples in 1999 and 2000.

	1999	2000
Textural properties		
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	Clay loam
Chemical properties		
Organic matter (%)	1.8	1.9
Calcium carbonate (%)	3.0	2.7
Total soluble salts (%)	0.1	0.1
pH (1:2.5)	8.1	8.1
Total nitrogen (%)	0.1	0.1
Available nitrogen (mg kg^{-1} soil)	50.0	57.5
Available phosphorus (mg kg^{-1} soil)	15.7	14.2
Available potassium (mg kg^{-1} soil)	370.0	385.0
Total sulphur (mg kg^{-1} soil)	21.3	21.2
Calcium (meq $100g^{-1}$)	0.2	0.2

A randomized complete-block design with four replications was used. Seeds were planted April 3, 1999 and April 20, 2000. The plot size was 1.95 m × 4 m, including three ridges (beds). Hills were spaced 25 cm apart on one side of the ridge. Six weeks after planting, seedlings were thinned to two plants per hill. This provided a plant density of 123,000 plants per ha after thinning. Total irrigation applied during the growing season (surface irrigation) was about 6,000 cubic meter per ha. The first irrigation was applied three weeks after planting, followed by the second one three weeks later. Thereafter, the plots were irrigated every two weeks until the end of the season (October 11, 1999 and October 17, 2000, respectively). On the basis of soil tests, phosphorus (P) fertiliser was applied at a rate of 24 kg P ha^{-1} as calcium super-phosphate during land preparation. The K fertiliser was applied at a rate of 47 kg K ha^{-1} as potassium sulfate before the first irrigation - the recommended level for a semi-fertile soil. The pest and weed management was carried out during the growing season, according to practices used at the experimental station.

Table 2. A summary of treatments.

Treatments			Treatment No.	Treatments			Treatment No.
N rate (kg ha^{-1})	K rate (g ha^{-1})	MC rate (g ha^{-1})		N rate (kg ha^{-1})	K rate (g ha^{-1})	MC rate (g ha^{-1})	
95	0	0	1	143	0	0	9
		48 + 24	2			48 + 24	10
	319	0	3		319	0	11
		48 + 24	4			48 + 24	12
	638	0	5		638	0	13
		48 + 24	6			48 + 24	14
	957	0	7		957	0	15
		48 + 24	8			48 + 24	16

In both seasons, 10 plants were randomly chosen from the centre ridge of each plot to determine the seed cotton yield in g per plant. First handpicking was made on 20 and 26 September in 1999 and 2000, respectively and the final handpicking occurred on 11 and 17 October in 1999 and 2000, respectively. Total seed cotton bulk of each plot was used to determine the seed cotton yield (kg ha^{-1}) and was ginned to determine the lint yield (kg ha^{-1}).

Data for the studied characters were analysed as a factorial experiment arranged in a randomised complete block design. A combined analysis of variance was conducted for the two seasons according to Snedecor and Cochran (1980). The Least Significant Difference (LSD) test at the 5% level of significance was used to examine differences among treatment means and the interactions, if significant, to determine the optimum factorial combination of N, K and MC.

RESULTS AND DISCUSSION

Analysis of variance for seed cotton yields per plant and per ha as well as lint yield per ha (Table 3) revealed that years, replications within years, and treatments (main effects) were significant sources of variation. Treatment × year interaction was not significant (Table 3). Thus, only the main effects of N, K, and MC are discussed further. Seed cotton yield per plant and seed cotton and lint yield per ha increased significantly (by as much as 12.8, 12.8, and 12.3 %, respectively) with an increase in N rate from 95 to 143 kg ha^{-1} (Table 4). The yield increases resulted from increased boll numbers and boll weight. This was likely achieved via reduced shedding of squares and bolls and enhanced photosynthetic activity, which in turn resulted in an increase in boll weight (Bondada and Oosterhuis, 2000). Perumai (1999) reported that N-mediated integration of growth and development led to a favorable canopy environment for higher productivity (square formation and seed cotton yield). Zhao and Oosterhuis (2000) indicated that low N supply at the reproductive stage decreased leaf area, leaf net photosynthetic rate and chlorophyll content. They also indicated that fruit abscission of N-deficient plants increased and lint yield decreased. Prakash et al. (2001) also reported similar results.

Table 3. Mean squares from analysis of variance for yield in cotton.

Source	d.f.	Seed cotton yield per plant (g)	Seed cotton yield ha^{-1} (kg)	Lint yield ha^{-1} (kg)
Years (Y)	1	147.21**	1415571.4**	332917.8**
Replications within Y	6	40.27*	404859.0*	50458.4*
Treatments (T)	15	75.94**	714189.8**	83868.9**
Nitrogen (N)	1	456.74**	4325402.3**	500162.5**
Potassium (K)	3	132.53**	1223590.9**	145491.8**
Mepiquat chloride (MC)	1	261.15**	2504937.5**	294768.0**
N × K	3	3.47	31778.5	3934.8
N × MC	1	0.17	1463.4	298.6
K × MC	3	4.19	36432.4	4632.6
N × K × MC	3	0.18	1879.3	209.1
T × Y	15	2.50	24239.8	3070.9
Error	90	14.36	135377.4	16752.8

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 4. Effect of N rate and foliar application of potassium and MC on cotton yield.

Treatments	Seed cotton yield (g plant^{-1})	Seed cotton yield (kg ha^{-1})	Lint yield (kg ha^{-1})
N rate (kg ha^{-1})			
95	29.58 b	2882.3 b	1020.0 b
143	33.36 a	3250.0 a	1145.0 a
LSD 0.05	1.33	128.9	45.4
K rate (g ha^{-1})			
0	28.61 b	2792.5 b	988.2 b
319	31.51 a	3068.6 a	1083.4 a
638	32.51 a	3163.0 a	1115.2 a
957	33.25 a	3240.7 a	1143.1 a
LSD 0.05	1.88	182.3	64.1
MC rate (g ha^{-1})			
0	30.04 b	2926.3 b	1034.5 b
48 + 24	32.90 a	3206.1 a	1130.5 a
LSD 0.05	1.33	128.9	45.4

Means followed by the same letter are not significantly different at the 0.05 probability level.

Potassium at all three K rates (319, 638 and 957 g K ha^{-1}) significantly increased seed cotton yield per plant and seed cotton and lint yield per ha, but the lowest K rate of 319 g ha^{-1} was not significantly different from the other two rates (Table 4). This means that the most economical rate was 319 g K ha^{-1}. These yield increases could be attributed to the favourable effects of K on yield components, i.e., number of opened bolls per plant and boll weight (Gormus, 2002). The role of K was to decrease abscission of buds and bolls, and hence increased yield. Zeng (1996) indicated that K fertiliser reduced boll shedding. Potassium deficiencies can limit the accumulation of crop biomass. This is attributed to a reduction in the partitioning of assimilate to the formation of leaf area or to a decreased efficiency of the intercepted radiation used for the production of above-ground biomass (Colomb et al., 1995). This means that K deficiency during the reproductive period markedly changes the structure of fruit-bearing organs and decreases yield and its quality. Yield response to K application agreed with that of Gormus (2002).

Generally, the soil nutrients available during the early growth stages, before applying K fertiliser, could be sufficient to fulfill the needs of plants to a large extent. However, during the extended period of flowering and boll setting (about 60 days), additional K fertiliser might be needed.

Mepiquat chloride significantly increased seed cotton yield per plant as well as seed cotton and lint yield per ha (by 9.5, 9.6, and 9.3%, respectively), compared with the untreated control. These results may be attributed to the effect of MC on boll retention and boll weight. Biles and Cothren (2001) attributed such yield increases caused by MC to changes in maturity and fruiting distribution. Zhao and Oosterhuis (1999) found that compared with the untreated control, MC application improved leaf photosynthetic rate and increased lint yield. These results agree with those of Prakash et al. (2001).

No significant interactions were found between/among the main factors, i.e., N rates and K rates and MC with respect to the traits under investigation. This means that the effects of variables under investigation were additive or perhaps had some synergistic effects. Boman and Westerman (1994) found no significant N × MC rate interactions for yield of cotton cv. Paymaster 404 when it was given 0 to 227 kg N ha^{-1} and sprayed at early flowering with 0, 25 or 50 g MC ha^{-1}

CONCLUSIONS

An N application at the rate of 143 kg ha^{-1} and applications of K (foliar; at the rate of 319 g K ha^{-1}) and MC (at a rate of 48 + 24 g *a.i.* ha^{-1}) should help achieve higher cotton productivity. No significant interactions were found among N rate, K rate, and MC. Since N × K, N × MC, K × MC, and N × K × MC interactions were not significant, N applied at 143 kg ha^{-1}, K at 319 g ha^{-1} and MC at 48 + 24 g *a.i.* ha^{-1} should be used to improve cotton growth and yield of Giza 86.

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