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AGRONOMY AND SOILS

Response of Yield, Yield Components, and Fiber Properties of Egyptian Cotton (*Gossypium barbadense* L.) to Nitrogen Fertilization and Foliar-applied Potassium and Mepiquat Chloride

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ABSTRACT

Research to delineate nitrogen, potassium, and mepiquat chloride (MC) effects on cotton performance has been primarily conducted with upland cotton (*Gossypium hirsutum* L.). A field study was conducted at the Agricultural Research Center, Giza, Egypt, to evaluate N, K, and MC effects on yield, yield components, and fiber properties of Egyptian cotton (*Gossypium barbadense* L). The experimental treatments were N rates of 95 or 143 kg ha^{-1}, foliar K at 0.0, 319, 638, or 957 g ha^{-1} applied 70 and 95 days after planting, and MC applied 75 days after planting at 0.0 or 48 g ha^{-1}, and 90 days after planting at 0.0 and 24 g ha^{-1}. Number of opened bolls per plant, boll weight, seed index, lint index, seed cotton yield per plant, and seed cotton and lint yield per hectare increased with the higher N rate and with foliar application of K and MC. There were no interactions among N, K, and MC on yield, and applications increased average lint yield 125 kg ha^{-1}. Effect on earliness of harvest was inconsistent, and harvest maturity increased from 69% to 72% with application of K and MC in the second season. Nitrogen, K, and MC effects on fiber properties were small and inconsistent. The combination of the three inputs increased length 0.3 mm, micronaire 0.1 units, and strength 0.39 cN tex^{-1} (0.4 g tex^{-1}). Under the conditions of this study, applying N at 143 kg ha^{-1} combined with foliar application of K at 319 g ha^{-1} and MC at 48 + 24 g ha^{-1} improved growth and yield of Egyptian cotton.

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Soil fertility and crop management are the two most important factors of modern agricultural activity. 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 a cotton crop. It is well known from numerous fertilizer experiments that the yield of agricultural crops has been strongly dependent on the supply of mineral nutrients, such as N, which has been used in crop cultivation to exploit the full genetic potential of the plant (Khan, 1996). Mineral nutrient supply affects leaf area and the rate of photosynthesis, and therefore the ability of the plant to deliver photosynthates to the 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). With a dynamic crop like cotton, excesses of N delay maturity, promote vegetative tendencies, and usually result in lower yields (McConnell et al., 1996). Errors made in N management can impact the crop through either deficiencies or excesses. If a deficiency of N develops in a cotton crop, it is not particularly difficult to diagnose and correct. Excess N fertility levels, which can damage final crop productivity, are more difficult to detect and to correct.

The importance of K fertilization in Egyptian agriculture has become more apparent since the completion of the High Dam, which resulted in the deposition of the suspended Nile silt upstream from the formed lake. This Nile silt was a source K-bearing minerals that enriched the soils during the seasonal floods (Abd et al., 1997). Continuous crop removal without replenishment of these nutrients can lead to an irreparable damage to soil fertility. Potassium affects respiration, photosynthesis, chlorophyll development, water content of leaves, carbon dioxide (CO_2) assimilation, and carbon movement (Sangakkara et al., 2000). Potassium also has an important role in the translocation of photosynthates from sources to sinks (Cakmak et al., 1994). Potassium deficiencies can limit the accumulation of crop biomass. This has been attributed to a reduction in the partitioning of assimilate to the formation of leaf area and a decrease in the efficient use of intercepted radiation for the production of above-ground biomass (Colomb et al., 1995). Pettigrew (1999) stated that part of the overall effect of K deficiency was reducing the amount of photosynthate available for reproductive sinks, which produced changes in lint yield and fiber quality. In one study, the application of K increased lint index (Pettigrew and Meredith, 1997). Lint index is a major determinant of ginning turnout and lint yields of cotton. One of the essential objectives sought by cotton breeders is to develop new cultivars characterized by higher gin turnout and consequently higher lint yield. Singh and Bains (1968) reported that lint index and seed index could account for about 70% of the total variability in gin turnout. It was apparent that the direct contribution of lint index to gin turnout was more than twofold of that of seed index.

In spite of using high yielding cultivars and the best agronomic practices, the yields of Egyptian cotton have not increased substantially. Excess vegetative growth, poor bud development, flower shedding, and growth imbalance between the source and sink are responsible for the unpredictable behavior of the crop. In recent years, several approaches have been tried to break this yield plateau and among them application of plant growth regulators, particularly mepiquat chloride (MC). The advantage of MC has been that it gives producers the flexibility to modify plant growth to suit current growing conditions in order to maximize benefits (Landivar et al., 1995). MC can be used to manage the vegetative development of cotton plants to offset the effect of excessive irrigation or N by decreasing both overall plant height and length of lateral branches (Boquet and Coco, 1993), and enhance reproductive organs by allowing plants to direct more energy towards reproductive structures (Wang et al., 1995). Nuti et al. (2000) stated that MC is thought to cause 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. Compared with the untreated control, application of MC improved leaf photosynthetic rate and increased lint yield (Zhao and Oosterhuis, 1999).

The objective of this study was to evaluate the effects of N fertilization rate, foliar K application rate, and MC application on growth, yield, yield components, and fiber properties of Egyptian cotton, so that treatments that may improve growth, yield, and quality can be identified.

MATERIALS AND METHODS

Field experiments were conducted at the Agricultural Research Center, Ministry of Agriculture in Giza, Egypt (30^{o} N, 31^{o}: 28'E at an altitude of 19 m), using the cotton cultivar Giza 86 in 1999 and 2000. The soil texture in both seasons was a clay loam. Average mechanical analysis (Kilmer and Alexander, 1940) and chemical characteristics (Chapman and Pratt, 1961) for the soil in both seasons is provided in Table 1.

Table 1. Mechanical and chemical analysis of soils used in the N, K, and mepiquat chloride rate study

Soil analysis	1999	2000
Clay (%)	43.0	46.5
Silt (%)	28.4	26.4
Fine sand (%)	19.3	20.7
Coarse sand (%)	4.3	1.7
Texture	Clay loam	Clay loam
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

Each experiment included 16 treatment combinations of N, K, and MC. Two N rates (95 and 143 kg ha^{-1}) were applied as ammonium nitrate in two equal doses at 6 and 8 wk after planting. Each application in the form of pinches beside each hill was followed immediately by irrigation. Four K rates (0, 319, 638, and 957 g ha^{-1}) were applied as potassium sulfate (K_2SO_4) in a foliar sprays at 70 and 95 days after planting (DAP) during the square initiation and boll development stage. It was assumed that soil S was adequate for cotton production, and the cotton would not respond to the S in the foliar-applied potassium sulfate. Mepiquat chloride was either not applied or foliar-applied at 75 DAP at 48 g ha^{-1} and at 90 DAP at 24 g ha^{-1}. Potassium and MC were applied to the leaves with uniform coverage in a solution volume of 960 L ha^{-1} using a knapsack sprayer. The pressure was 0.4 kg/cm^2 that resulted in a nozzle output of 1.43 L/min. The applications were carried out between 0900 and 1100 h.

Experiments were planted 3 Apr. 1999 and 20 Apr. 2000 in a randomized complete block design with four replications. The plot size was 1.95 m x 4 m and contained three ridges (beds). Hills were spaced 25 cm apart on one side of the ridge, with seedlings thinned to two plants per hill at 6 wk after planting. This provided a plant density of 123,000 plants ha^{-1}. Total irrigation during the growing season (surface irrigation) was about 6,000 m^3 ha^{-1}. Irrigation was first applied 3 wk after planting and again 3 wk later. Thereafter, the plots were irrigated every 2 wk until the end of the season (11 Oct. 1999 and 17 Oct. 2000) for a total of nine irrigations. On the basis of soil test results, P fertilizer was applied at 24 kg ha^{-1} P as calcium super phosphate during land preparation. The recommended fertilizer K rate for semi-fertile soil was applied at 47 kg ha^{-1} as potassium sulfate before the first irrigation. Fertilization (P and K) and pest and weed management was carried out according to local practices performed at the experiment station.

In both years, 10 plants were randomly chosen from the center ridge of each plot to determine number of open bolls per plant, boll weight (grams of seed cotton per boll), and seed cotton yield per plant in grams. Earliness was calculated as the percentage of first harvest. First hand picking took place on 20 and 26 September and final picking on 11 and 17 October in 1999 and 2000, respectively. Total seed cotton yield of each plot (including 10 plant subsamples) was ginned to determine seed cotton and lint yield (kg ha^{-1}), lint percentage, seed index (g 100 seed^{-1}) and lint index (g lint 100 seed^{-1}). Fiber tests were conducted at a relative humidity of 65 ± 2% and a temperature of 20 ± 1 °C to determine fiber length in terms of 2.5 and 50% span length (mm) and uniformity ratio as measured by a digital fibrograph (ASTM, 1998a). Micronaire reading, including combined measure of fiber fineness and maturity, was measured by a micronaire instrument (ASTM, 1998b), and flat bundle strength was measured by stelometer at 1/8 inch gauge length (ASTM, 1998c).

Results were analyzed as a factorial experiment in a randomized complete block design as a combined statistical analysis for the two years following the procedure outlined by Snedecor and Cochran (1980). The least significant difference (P = 0.05) was used to verify the significance of differences among treatment means and the interactions to determine the effects of N, K, and MC.

RESULTS AND DISCUSSION

Results from the combined analysis of variance for yield components, yield, earliness, and fiber properties are presented in Tables 2 through 4. Significant effects for years were observed for yield components, yield, earliness, and all fiber properties except for boll weight.

Table 2. Mean squares from analysis of variance for yield components of cotton treated with N, K, and mepiquat chloride

Source	Df	Yield component[z]				
		Open bolls plant^{-1}	Boll weight (g)	Lint (%)	Seed index (g)	Lint index (g)
Year	1	13.92*	0.0488	26.3720*	1.652*	3.8199*
Replicate	6	3.21*	0.0212	0.4241*	0.131*	0.0018
N	1	34.25*	0.2757*	0.8224*	1.684*	0.2348*
K	3	18.83*	0.1815*	0.3634	0.619*	0.0811*
MC	1	7.66*	0.1384*	0.0838	0.512*	0.1036*
N x K	3	0.21	0.0007	0.0003	0.077	0.0209*
N x MC	1	0.25	0.0035	0.0007	0.007	0.0026
K x MC	3	0.61	0.0041	0.0004	0.004	0.0008
N x K x MC	3	0.06	0.0021	0.0016	0.019	0.0048
Treatments x Year	15	0.36	0.0008	0.0045	0.009	0.0031
Error	0	1.03	0.0151	0.1426	0.053	0.0051

[z]Values followed by * are significant (P = 0.05).

Table 3. Mean squares from analysis of variance for cotton yield and yield earliness treated with N, K, and mepiquat chloride

Source	df	Yield and earliness[z]			
		Seed cotton plant^{-1} (g)	Seed cotton ha^{-1} (kg)	Lint ha^{-1} (kg)	Earliness (%)
Year	1	14.36	135377	16753	1075.32*
Replicate	6	40.27*	404860*	50458*	4.48
N	1	147.21*	1415571*	500163*	41.86*
K	3	456.74*	4325402*	294768*	84.17*
MC	1	261.15*	2504938*	145492*	76.86*
N x K	3	132.53*	1223591*	299	0.45
N x MC	1	0.18	1463	332918*	3.19
K x MC	3	3.47	31779	3935	1.18
N x K x MC	3	4.19	36432	4633	0.37
Treatments x Year	15	0.18	1879	209	0.92
Error	90	2.50	24240	3071	9.27

[z]Values followed by * are significant ($P = 0.05$).

Table 4. Mean squares from analysis of variance for fiber properties of cotton treated with N, K, and mepiquat chloride

Source	df	Fiber property[z]				
		2.5% span length (mm)	50% span length (mm)	Uniformity ratio (%)	Micronaire	Strength (cN tex^{-1})
Year	1	5.080100*	3.156*	4.129*	0.138*	13.319*
Replicate	6	0.072787	0.024	0.084	0.020	1.168*
N	1	1.828906*	0.705*	0.277	0.125*	1.604*
K	3	0.618906	0.291	0.219	0.090*	3.047*
MC	1	0.839271*	0.295	0.089	0.063*	2.109*
N x K	3	0.000001	0.018	0.166	0.011	0.005
N x MC	1	0.017135	0.032	0.202	0.002	0.012
K x MC	3	0.027552	0.017	0.059	0.005	0.025
N x K x MC	3	0.033837	0.033	0.115	0.004	0.087
Treatments x Year	15	0.025747	0.012	0.097	0.006	0.041
Error	90	0.287175	0.144	0.233	0.023	0.388

[z]Values followed by * are significant ($P = 0.05$).

Effects of interactions among treatments. There were no significant interactions among N, K, MC with respect to quantitative and qualitative characters under investigation, except for the interaction between N rate and MC for lint index (Table 5). Application of the high N rate combined with MC application increased lint index over the high N rate or MC alone. With the exception of lint percentage, which tended to decrease, favorable effects on cotton productivity and quality accompanied the application of N, K, and MC. The effects of N, K, and MC were additive or perhaps synergistic. These results are similar to those of Boman and Westerman (1994), who did not observed any significant N by MC interactions for growth, yield, or fiber properties of upland cotton 'Paymaster 404'

Table 5. Effect of interactions between N rate and foliar application of mepiquat chloride on lint index averaged across two years

N (kg ha^{-1})	Mepiquat chloride (g ha^{-1})	
	0	48+24
95	5.51 c	5.54 bc
143	5.57 b	5.65 a

Means followed by the same letter are not significantly different according to LSD ($P = 0.05$).

when treated with N at 0, 56, 112 or 224 kg ha^{-1} and sprayed at early flowering with MC at 0, 10, or 20 g ha^{-1}.

Number of open bolls per plant. Averaged across years, the number of open bolls per plant was significantly greater at 143 kg ha^{-1} N than with 95 kg ha^{-1} N (Table 6). This could be attributed to the fact that N is an important nutrient for new growth (Borowski, 2001) and preventing abscission of squares and bolls. Nitrogen deficiency has been observed to decreased the auxin content and markedly increased the content of inhibitors in the leaves and stems (Anisimov and Bulatova, 1982). The number of bolls observed in this study agrees with those obtained by Ali and El-Sayed (2001) when N was applied at 95 to 190 kg ha^{-1}, and Ram et al. (2001) when N was applied up to 100 kg ha^{-1}.

Foliar application of 319 g ha^{-1} K significantly increased the number of open bolls per plant compared with the untreated control (Table 6). Applications at 638 g ha^{-1} and 957 g ha^{-1} did not provide an additional increase in boll number. The role of K in plants suggests that it affects abscission and yield. Guinn (1985) indicated that nutritional stress increases boll shedding (an important aspect of cutout) through an increase in ethylene production; however, K fertilizer had been reported to reduce boll shedding (Zeng, 1996). Results for boll numbers to K application in this study were similar to those obtained by Gormus (2002).

Application of MC significantly increased the number of open bolls per plant over the untreated control in both years. These results agree with those previously reported by Mekki (1999), Biles and Cothren (2001), and Ram et al. (2001). Increases in bolls per plant may be due to increased photosynthetic activity of leaves following MC application (Wu et al., 1985). Increased photosynthesis increases flowering and boll retention (Kler et al., 1989). Khan (1996) stated that plant growth regulators could be used for maintaining internal hormonal balance and an efficient sink source relationship that enhances crop productivity. Others, however, have not found an increase in boll numbers associated with MC application (Lamas and Staut, 1999).

Boll weight. Boll weight increased as N rate increased from 95 to 143 kg ha^{-1} (Table 6). Similar results were obtained by Karthikeyan and Jayakumar (2001) and Ram et al. (2001). The increase in boll weight may be due to N-induced increase in mineral uptake (Breitenbeck and Boquet, 1993) and to photosynthate assimilation and accumulation in sinks. Nitrogen fertilizer increased leaf photosynthetic rates by 11% to 29%, when plants were given up to 157

Table 6. Effect of N rate and foliar application of K and mepiquat chloride on cotton yield components averaged across two years

Treatments	Yield component^z				
	Open bolls plant^{-1}	Boll weight (g)	Lint (%)	Seed index (g)	Lint index (g)
N rate (kg ha^{1})					
95	11.85	2.49	35.4	10.09	5.52
143	12.88	2.58	35.2	10.32	5.61
LSD ($P = 0.05$)	0.36	0.04	0.1	0.08	0.03
K rate (g ha^{-1})					
0	11.69	2.44	35.4	10.03	5.49
319	12.36	2.54	35.3	10.19	5.56
638	12.63	2.57	35.3	10.27	5.60
957	12.80	2.59	35.3	10.32	5.62
LSD ($P = 0.05$)	0.50	0.06	NS	0.11	0.04
MC rate (g ha^{-1})					
0	11.98	2.49	35.4	10.13	5.54
48 + 24	12.75	2.57	35.3	10.27	5.59
LSD ($P = 0.05$)	0.36	0.04	NS	0.08	0.03

kg ha^{-1} N (Cadena and Cothren, 1995). This might account for a higher accumulation of metabolites, which directly impacted boll weight.

Boll weight was significantly increased by application of 319 g ha^{-1} K relative to the control. Application of higher K rates up to 957 g ha^{-1} did not increase boll weight further. Since the soil in the experimental area was classified as having medium K fertility (Table 1) and received a fertilizer K application, large responses to the foliar K applications were not expected. These results for boll weight agree with those obtained by Gormus (2002). 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), so K deficiency reduces the amount of photosynthate available for reproductive sinks, which affects boll weight.

Application of MC significantly increased boll weight. These results are similar to Mekki (1999) and Ram et al. (2001). This could be attributed to increase in photosynthetic pigments (Wu et al., 1985), which stimulate photosynthetic activity and subsequently dry matter accumulation. These in turn increase formation of fully matured bolls and their weight. Schott and Rittig (1982) found that treating cotton plants with MC expanded the xylem of cotton stems, and this increase in transport ability may account for heavier bolls produced. Three to four applications of MC (at 12 to 45 g ha^{-1}) at peak square, initial flowering, peak flower, and the boll setting stages helped form a suitable plant type for high photosynthetic activity to improve the nutritional regimes of squares and bolls (Wu et al., 1994).

Lint percentage. As N rate increased, lint percentage was significantly reduced by 0.16% (Table 6). Phipps et al. (1996) found that lint percentage was minimally or not significantly affected with increasing application rate of N from 45 to 134 kg ha^{-1} on 'DPL 50', and Hussain et al. (2000) reported that N application did not affect gin turnout.

Foliar-applied K or MC did not affect lint percentage compared with the untreated control. Gormus (2002) reported inconsistent results for lint percentage following soil applications of K at 66, 132 and 198 kg ha^{-1}. In the first year, soil-applied K at 66 kg ha^{-1} gave the same lint turnout as the untreated control, while applications of 132 and 198 kg ha^{-1} K increased lint turnouts. In the second year, lint turnout was not affected by any of the K treatments. Hayes et al. (1995) did not observe any significant response of lint percentage to MC, but Mekki (1999) observed that ginning percentage was reduced by MC treatment.

Seed index. Seed index significantly increased with an increase in N from 95 to 143 kg ha^{-1} (Table 6). Similar findings were obtained by Ali and El-Sayed (2001). The increase in seed index may be due to enhanced photosynthetic activity, as N is an essential component of chlorophyll (Bondada and Oosterhuis, 2000).

Application of K at all three rates significantly increased seed index compared with the untreated cotton. The difference between the high rate (957 g ha^{-1} K) and low rate (319 g ha^{-1} K) was also significant. Ghourab et al. (2000) reported that application of K fertilizer resulted in an increase in seed index. An increase in seed index might be due to the effect of K on mobilization of photosynthates, which would directly influence boll weight and increase seed index (Cakmak et al., 1994). Zhao et al. (2001) indicated that K deficiency during squaring reduced leaf area and dry matter accumulation, and affected assimilate partitioning among plant tissues.

Application of MC significantly increased seed index compared with the untreated control. It has been reported that bolls on cotton treated with MC have larger photosynthetically supplied sinks for carbohydrates and other metabolites than untreated bolls (Zhao and Oosterhuis, 1999). Similar results to the this study were obtained by Hayes et al. (1995) and Mekki (1999), which demonstrates a consistent effect across environments of MC on seed index.

Lint index. Nitrogen at 143 kg ha^{-1} and application of MC significantly increased the lint index over the control (Table 6). These results agreed with those previously reported by Sawan et al. (1997). Foliar application of K also increased the lint index compared with the untreated control in both years. Maximum response of lint index to K occurred with application of 319 to 638 g ha^{-1}. The difference between the highest K rate (957 g ha^{-1}) and medium K rate (638 g ha^{-1}) was not significant.

Yield. Seed cotton yield per plant and seed cotton and lint yield per hectare significantly increased with increase in the N rate from 95 to 143 kg ha^{-1} (Table 7). The lint yield response to N rate was 2.6 kg for each kg of applied N. Similar results were obtained by Karthikeyan and Jayakumar (2001) and Ram et al. (2001). Yield increases in this study were from increased boll numbers and boll weight. This was attributed to the fact that N was an important nutrient in controlling new growth (Perumai, 1999; Borowski, 2001) and nutrient uptake, and in preventing abscission of squares and bolls. Nitrogen is also essential for photosynthetic activity (Bondada and Oosterhuis, 2000). Integration of growth and development mediated by N led to a favorable canopy environment for productivity (square formation and seed cotton yield) (Perumai, 1999). Zhao and Oosterhuis (2000) indicated that low N supply at the reproductive stage decreased cotton leaf area, leaf net photosynthetic rate, and chlorophyll content. They also indicated that fruit abscission increased and lint yield decreased in N deficient plants. Yield decreases, sometimes reported as a result of N application above an optimum level (Howard et al., 2001), were not observed in this study.

Potassium applied at all three rates (319, 638, and 957 g ha^{-1} K) significantly increased seed cotton yield per plant and seed cotton and lint yield per hectare compare with no K. There were no differences in yield among the three K rates. Yield increases could be attributed to the effect of K on new growth and nutrient uptake (Fan et al., 1999), which caused favorable effects on the number of opened bolls per plant and boll weight, leading to higher cotton yield. Zeng (1996) indicated that K fertilizer reduced boll shedding. Potassium deficiencies can also limit the accumulation of crop biomass (Colomb et al., 1995). Potassium also has an important role in the translocation of photosynthates from sources to sinks (Cakmak et al., 1994). In one study, lower cotton yield was attributed in part to a reduction in boll mass that was mostly ascribed to K deficiency (Pettigrew et al., 1996). Li et al. (1999) reported that cellulose synthesis and dry matter accumulation were increased by K application, which indicates that K deficiency during the reproductive period changes the structure of fruit-bearing organs and decreases yield and its quality. Results obtained in this study are similar to those of Ghourab et al. (2000) and Gormus (2002) but were in contrast with those of Minton and Ebelhar (1991).

Mepiquat chloride significantly increased seed cotton yield per plant, seed cotton and lint yield per hectare by 9.5, 9.6, and 9.3%, respectively, compared with the untreated control (Table 7). These results may be attributed to the beneficial effects that MC might have on boll retention and boll weight, leading to yield enhancement. Biles and Cothren (2001) have attributed this yield effect to changes in maturity and fruiting distribution because of MC application. MC is thought to cause a shift in partitioning of photo-assimilates from vegetative to reproductive growth

Table 7. Effect of N rate and foliar application of K and mepiquat chloride on cotton yield and yield earliness averaged across two years

Treatments	Yield and earliness			
	Seed cotton plant^{-1} (g)	Seed cotton ha^{-1} (kg)	Lint ha^{-1} (kg)	Earliness (%)
N rate (kg ha^{1})				
95	**29.6**	**2882**	**1020**	**71.2**
143	**33.4**	**3250**	**1145**	**70.1**
LSD (*P* = 0.05)	**1.8**	**129**	**45**	**1.1**
K rate (g ha^{-1})				
0	**28.6**	**2793**	**988**	**68.7**
319	**31.5**	**3069**	**1083**	**70.2**
638	**32.5**	**3163**	**1115**	**71.3**
957	**33.3**	**3241**	**1143**	**72.4**
LSD (*P* = 0.05)	**2.8**	**182**	**64**	**1.5**
MC rate (g ha^{-1})				
0	**30.0**	**2926**	**1035**	**69.9**
48 + 24	**32.9**	**3206**	**1131**	**71.5**
LSD (*P* = 0.05)	**1.8**	**129**	**45**	**1.1**

(Nuti et al., 2000). Redistribution of assimilates between vegetative and reproductive growth may be one means by which yields can be increased. Application of MC improved leaf photosynthetic rate and increased lint yield compared with an untreated control (Zhao and Oosterhuis, 1999). Yield results from this study agree with those obtained by Karthikeyan and Jayakumar (2001) and Ram et al. (2001), but others, including Jones et al. (2000), have reported that MC application did not increase yields.

Yield earliness. Earliness of yield significantly decreased with increasing N rate (Table 7), which is similar to the results obtained by Ali and El-Sayed (2001). In contrast, yield earliness increased with application of 638 and 957 g ha^{-1} K compared with the untreated control. Similar results were reported by Gormus (2002). Howard et al. (2000) also indicated that foliar K (4.1 kg ha^{-1} K buffered to pH 4) increased first harvest.

Earliness was significantly enhanced by MC application. Increased earliness may be related to MC effect on biomass partitioning (inhibiting growth of branches and stems, expanding leaves, and extending stem internodes and petioles), which led to the development of a more compact canopy structure (Fernandez et al. (1991). This provides an improved microclimate, especially better light conditions, that results in earlier maturity. Cotton treated with MC in 1, 2, or 3 splits at the beginning of budding, the beginning of flowering, and maximum flowering reduced plant height and improved earliness (Mert and Caliskan, 1998). Yield earliness increased with multiple applications. Cotton plants treated with MC reached physiological maturity before control plants or the target development curve (Oosterhuis et al., 2000).

Fiber properties. The mean values of 2.5 and 50.0% span length, micronaire, and strength (flat bundle) were significantly increased by the use of the higher N rate, but the effects were too small to affect use quality or to be economically important. Nitrogen rate had no effect on fiber uniformity (Table 8). Similar results to this study were obtained by Hussain et al. (2000). Fiber quality was not affected by N applied at 45 to 135 kg ha^{-1} (Phipps et al., 1996).

Application of K significantly increased 2.5% span length, micronaire, and strength. The increases were small and would not be considered economically important improvements. Other researchers (Gormus, 2002; Pettigrew, 1999; Li et al., 1999) have reported similar effects of K on fiber properties. Oosterhuis (1994) found that fiber quality was improved by foliar-applied KNO_3, with the increase occurring primarily in uniformity and strength. Micronaire also increased in some years. The application of KNO_3 either as foliar

Table 8. Effect of N rate and foliar application of K and mepiquat chloride on cotton fiber properties averaged across two years

Treatments	Fiber property				
	2.5% span length (mm)	50% span length (mm)	Uniformity ratio (%)	Micronaire	Flat bundle strength (cN tex^{-1})
N rate (kg ha^{1})					
95	**32.5**	**16.2**	**49.7**	**3.76**	**31.0**
143	**32.7**	**16.3**	**49.8**	**3.83**	**31.2**
LSD (*P* = 0.05)	**0.2**	**0.1**	**NS**	**0.05**	**0.2**
K rate (g ha^{-1})					
0	**32.4**	**16.1**	**49.7**	**3.73**	**30.7**
319	**32.6**	**16.2**	**49.8**	**3.79**	**31.1**
638	**32.7**	**16.3**	**49.8**	**3.83**	**31.2**
957	**32.7**	**16.3**	**49.8**	**3.83**	**31.3**
LSD (*P* = 0.05)	**0.3**	**NS**	**NS**	**0.08**	**0.3**
MC rate (g ha^{-1})					
0	**32.5**	**16.2**	**49.7**	**3.77**	**30.9**
48 + 24	**32.7**	**16.3**	**49.8**	**3.82**	**31.2**
LSD (*P* = 0.05)	**NS**	**NS**	**NS**	**0.05**	**0.2**

treatment alone or in combination with supplemental soil KCl improved uniformity and strength. Nascimento and Athayde (1999) found that K improved micronaire and uniformity, but Minton and Ebelhar (1991) indicated that fiber length was not affected by different levels of K. Gormus (2002) reported lack of response of micronaire to different K levels and times of application.

Micronaire and strength increased with the application of MC compared with no MC. Mepiquat chloride had no affect on the other fiber properties. Livingston et al. (1992) increased fiber strength by 1.5 to 2.8 g tex^{-1} with MC. Boman and Westerman (1994), however, stated that application of MC increased fiber strength in only one of three years (by 3.8%). Others (Mert and Caliskan, 1998; Karthikeyan and Jayakumar, 2001) have reported that MC did not significantly affect fiber qualities, but micronaire increased with MC application (Mekki, 1999) The small effects of N, K, and MC on fiber properties in this study, and the inconsistent effects in other studies, indicate that these three variables should be expected to have inconsistent and small effects that are not likely to be of economic importance.

CONCLUSIONS

The maximum yield in this study was obtained from a combination of N, K, and MC applications. Only two N rates were used, so it is not possible to pinpoint the precise optimal N rate, which could be lower or higher than 143 kg ha^{-1} evaluated in this study. There was a 12% yield increase from increasing the N rate from 95 to 143 kg ha^{-1}, which indicates that the optimal rate was between 95 and 143 kg ha^{-1}. The optimal rate of foliar-applied K was two applications of 319 g ha^{-1} applied 70 and 95 DAP. Two applications of MC (48 g ha^{-1} 70 DAP + 24 g ha^{-1} 90 DAP) increased lint yield by 100 kg ha^{-1}. The nutrient and MC applications had significant but small effects on fiber properties that were not economically important. Responses of Egyptian cotton to N, K, and MC did not differ substantially from reported responses of upland cotton.

The soil fertility in this study was sufficient to supply the cotton crop during the early growth stages, but was not sufficient to supply all needed N and K during the extended flowering and boll filling stages when nutrient supplies were lower and plant demand is higher. In comparison with the usual cultural practices adopted by Egyptian cotton producers, the combination of N, K, and MC treatments could improve cotton productivity and perhaps fiber quality. Additional research is needed with N, K, and MC rates and timing to establish the optimal strategies for these production inputs.

REFERENCES

Abd, E., A.H., M.S. Khadr, and M.H. Taha. 1997. Effect of fertilization under the intensive cropping system in Egyptian agriculture. p. 147-154. *In* Proc. FAO-IRCRN (Inter-Regional Cooperative Research Network on Cotton) Joint Meeting of the Working Groups on Cotton Nutrition and Growth Regulators, Cairo, Egypt. 20-23 Mar. 1995. FAO, Rome, Italy.

Ali, S.A., and A.E. El-Sayed. 2001. Effect of sowing dates and nitrogen levels on growth, earliness and yield of Egyptian cotton cultivar Giza 88. Egypt. J. Agric. Res. 79: 221-232.

American Society for Testing Materials (ASTM). 1998a. Standard test method for length and length uniformity of cotton fibers by fibrograph measurement (D1447-89). p. 391-395. *In* Annual Book of ASTM Standards, Vol. 07.01. ASTM; West Conshohocken, PA.

American Society for Testing Materials (ASTM). 1998b. Standard test method micronaire reading of cotton fibers (D1448-97). p. 396-398. *In* Annual Book of ASTM Standards, Vol. 07.01. ASTM; West Conshohocken, PA.

American Society for Testing Materials (ASTM). 1998c. Standard test method for breaking strength and elongation of cotton fibers (flat bundle method) (D1445-95). p. 383-390. *In* Annual Book of ASTM Standards, Vol. 07.01. ASTM; West Conshohocken, PA.

Anisimov, A.A., and T.A. Bulatova. 1982. The content of auxins and growth inhibitors in plants under various mineral conditions. Fiziol. Rast. (Russian) 29: 908-914.

Biles, S.P., and J.T. Cothren. 2001. Flowering and yield response of cotton to application of mepiquat chloride and PGR-IV. Crop Sci. 41: 1834-1837.

Boman, R.K., and R.L. Westerman. 1994. Nitrogen and mepiquat chloride effects on the production of nonrank, irrigated, short-season cotton. J. Prod. Agric. 7: 70-75.

Bondada, B.R., and D.M. Oosterhuis. 2000. Yield response of cotton to foliar nitrogen as influenced by sink strength, petiole and soil nitrogen. p. 672-675. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN

Boquet, D.J., and A.B. Coco. 1993. Cotton yield and growth interactions among cultivars, row spacing and soil types under two levels of Pix. p. 1370-1372. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 10-14 Jan. 1993. Natl. Cotton Counc. Am., Memphis, TN.

Borowski, E. 2001. The effect of nitrogenous compounds on the growth, photosynthesis and phosphorus uptake of sunflowers. Annales Universitatis Mariae Curie-Sklodowska. Sectio EEE, Horticultura 9: 23-31.

Breitenbeck, G.A., and D.J. Boquet. 1993. Effects of N fertilization on nutrient uptake by cotton. p. 1298-1300. *In* Proc. Beltwide Cotton Conf., New Orleans, LA.10-14 Jan. 1993. Natl. Cotton Counc. Am., Memphis, TN.

Cadena, J., and J.T. Cothren. 1995. Yield response of cotton to nitrogen, irrigation, and PGR-IV regimes. p. 1142-1150. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 1995. Natl. Cotton Counc. Am., Memphis, TN.

Cakmak, I., C. Hengeler, and H. Marschner. 1994. Partitioning of shoot and root dry matter and carbohydrates in bean plants suffering from phosphorus, potassium and magnesium deficiency. J. Exp. Bot. 45: 1245-1250.

Chapman, H.D., and P.F. Pratt. 1961. Methods of Analysis for Soils, Plants and Waters. Univ. of California, Div. of Agric. Science.

Colomb, B., A. Bouniols, and C. Delpech. 1995. Effect of various phosphorus availabilities on radiation-use efficiency in sunflower biomass until anthesis. J. Plant Nutr. 18: 1649-1658.

Fan, S., X. Yuzhang, and Z. Chaojun. 1999. Effects of nitrogen, phosphorus and potassium on the development of cotton bolls in summer. Acta Gossypii Sinica 11: 24-30.

Fernandez, C.J., J.T. Cothren, and K.J. Mcinnes. 1991. Partitioning of biomass in well-watered and water-stressed cotton plants treated with mepiquat chloride. Crop Sci. 31: 1224-1228.

Ghourab, M.H.H., O.M.M. Wassel, and N.A.A. Raya. 2000. Response of cotton plants to foliar application of (Pottasin-P)™ under two levels of nitrogen fertilizer. Egypt. J. Agric. Res. 78: 781-793.

Gormus, O. 2002. Effects of rate and time of potassium application on cotton yield and quality in Turkey. J. Agron. Crop Sci. 188: 382-388.

Guinn, G. 1985. Fruiting of cotton. III. Nutritional stress and cutout. Crop Sci. 25: 981-985.

Hayes, R.W., J.N. Jenkins, and J.C. McCarty, Jr. 1995. Effects of Pix at low rate multiple application reproductive and vegetative structures in cotton. p. 577. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 1995. Natl. Cotton Counc. Am., Memphis, TN.

Howard, D.D., M.E. Essington, C.O. Gwathmey, and W.M. Percell. 2000. Buffering of foliar potassium and boron solutions for no-tillage cotton production. J. Cotton Sci. 4: 237-244 [Online]. Available at http://www.cotton.org/journal/2000-04/4/237.cfm.

Howard, D.D., C.O. Gwathmey, M.E. Essington, R.K. Roberts, and M.D. Mullen. 2001. Nitrogen fertilization of no-till cotton on loess-derived soils. Agron. J. 93:157-163.

Hussain, S.Z., S. Faird, M. Anwar, M.I. Gill, and M.D. Baugh. 2000. Effect of plant density and nitrogen on the yield of seed cotton-variety CIM-443. Sarhad J. Agric. 16: 143-147.

Jones, M.A., C.E. Snipes, and G.R. Tupper. 2000. Management systems for transgenic cotton in ultra-narrow rows. p. 714-716. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

Karthikeyan, P.K., and R. Jayakumar. 2001. Nitrogen and chlormequat chloride on cotton cultivar. p. 806-807. *In* W.J. Horst et al. (ed.) Plant nutrition: food security and sustainability of agro-ecosystems through basic and applied research. Intl. Plant Nutr. Colloq., 14th, Hannover, Germany. 27 July - 3 Aug. 2001. Kluwer Academic Publishers, Dordrecht, Netherlands.

Khan, N.A. 1996. Response of mustard to ethrel spray and basal and foliar application of nitrogen. J. Agron. Crop Sci. 175: 331-334.

Kilmer, V.J., and L.T. Alexander. 1940. Methods of making mechanical analysis of soils. Soil Sci. 68:15.

Kler, D.S., D. Raj, and G.S. Dhillon. 1989. Modification of micro-environment with cotton canopy for reduced abscission and increased seed yield. Environ. Ecol. 7: 800-802.

Lamas, F.M., and L.A. Staut. 1999. Doses of nitrogen and mepiquat chlorate for cotton in a direct planting system. p. 87-89. *In* Annual Brasilian Congress of Cotton, 2nd, Ribeirao Preto, SP, Brasil. 5-10 Sept. 1999. Brasilian Agricultural Research Corporation, Brasilia, Brasil.

Landivar, J.A., D. Locke, Z. Cespedes, and D. Moseley. 1995. The effect of estimated plant concentration of Pix on leaf area expansion and main stem elongation rate. p. 1335-1338. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 1995. Natl. Cotton Counc. Am., Memphis, TN.

Li, F.S., Y.Z. Xu, and C. Zhang. 1999. Effects of nitrogen, Phosphorus and potassium on the development of cotton bolls in summer. Acta Gossypii Sinica 11: 24-30.

Livingston, S.D., D.J. Anderson, L.B. Wilde, Jr., and J.A. Hickey. 1992. Use of foliar applications of Pix, PRG IV, and PCHA in low rate multiple applications for cotton improvement under irrigated and dryland conditions. p. 1055-1056. *In* Proc. Beltwide Cotton Conf., Nashville, TN. 6-10 Jan. 1992. Natl. Cotton Counc. Am., Memphis, TN.

McConnell, J.S., W.H. Baker, and B.S. Frizzell. 1996. Distribution of residual nitrate-N in long term fertilization studies of an alfisol cropped for cotton. J. Environ. Qual. 25: 1389-1394.

Mekki, B.B. 1999. Effect of mepiquat chloride on growth, yield and fiber properties of some Egyptian cotton cultivars. Arab Univ. J. Agric. Sci. 7: 455-466.

Mert, M., and M.E. Caliskan. 1998. The effect of mepiquat chloride (PIX) on yield, yield components and fiber characteristics of cotton. Turkish J. Field Crops 3: 68-72.

Minton, E.B., and M.W. Ebelhar. 1991. Potassium and aldicarb-disulfoton effects on verticillium wilt, yield, and quality of cotton. Crop Sci. 31:209-212.

Nascimento, J., A. Do, and M.L.F. Athayde. 1999. Effects of lime and of potassium fertilizer on technological properties of cotton fibres. p. 423-426. *In* Annual Brasilian Congress of Cotton, 2nd, Ribeirao Preto, SP, Brasil. 5-10 Sept. 1999. Brasilian Agricultural Research Corporation, Brasilia, Brasil.

Nuti, R.C., T.K. Witten, P.H. Jost, and J.T. Cothren. 2000. Comparisons of Pix Plus and additional foliar *Bacillus cereus* in cotton. p. 684-687. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

Oosterhuis, D.M. 1994. Potassium nutrition of cotton in the USA, with particular reference to foliar fertilization. Challenging the Future: p. 133-146. *In* G. A. Constable and N. W. Forrester (ed.) Proc. World Cotton Res. Conf., 1st, Melbourne, Australia. 14-17 Feb. 1994. CSIRO, Melbourne, Australia.

Oosterhuis, D.M., D.L. Coker, and S.K. Gomez. 2000. Characterization of the fruiting growth curve used in crop monitoring. Spec. Rep. 198. Arkansas Exp. Stn., Fayetteville, AR.

Perumai, N.K. 1999. Effect of different nitrogen levels on morpho-physiological characters and yield in rainfed cotton. Indian J. Plant Physiol. 4: 65-67.

Pettigrew, W.T. 1999. Potassium deficiency increases specific leaf weights of leaf glucose levels in field-grown cotton. Agron. J. 91: 962-968.

Pettigrew, W.T., J.J. Heitholt, and W.R. Meredith, Jr.1996. Genotypic interactions with potassium and nitrogen in cotton of varied maturity. Agron. J. 88:89-93.

Pettigrew, W.T., and W.R. Meredith, Jr. 1997. Dry matter production, nutrient uptake, and growth of cotton as affected by potassium fertilization. J. Plant Nutr. 20:531-548.

Phipps, B.J., W.E. Stevens, J.B. Mobley, and J.N. Ward. 1996. Effect of nitrogen level and mepiquat chloride (Pix) upon maturity. p. 1211-1212. *In* Proc. Beltwide Cotton Conf., Nashville, TN. 9-12 Jan. 1996. Natl. Cotton Counc. Am., Memphis, TN.

Ram, P., M. Prasad, and D.K. Pachauri. 2001. Effect of nitrogen, chlormequat chloride and FYM on growth, yield and quality of cotton (*Gossypium hirsutum* L.). Ann. Agric. Res. 107-110.

Sangakkara, U.R., M. Frehner, and J. Nosberger. 2000. Effect of soil moisture and potassium fertilizer on shoot water potential, photosynthesis and partitioning of carbon in mungbean and cowpea. Crop Sci. 185: 201-207.

Sawan, Z.M., M.H. Mahmoud, and O.A. Momtaz. 1997. Influence of nitrogen fertilization and foliar application of plant growth retardants and zinc on quantitative and qualitative properties of Egyptian cotton (*Gossypium barbadense* L. var. Giza 75). J. Agric. Food Chem. 45: 3331-3336.

Schott, P.E., and F.R. Rittig. 1982. New Findings on The Biological Activity of Mepiquat Chloride. p. 415-424. *In* J.S. McLaren, (ed.) Chemical Manipulation of Crop Growth and Development. Butterworth Scientific; London, U.K.

Singh, R. B., and S. S. Bains. 1968. Variability and correlation studies on ginning outturn and its components in certain varieties of Upland cotton (*Gossypium hirsutum* L.). Indian J. Agric. Sci. 88: 391-404

Snedecor, G.W., and W.G. Cochran. 1980. Statistical Methods. 7th ed. Iowa State University Press, Ames, Iowa.

Wang, Z., Y. Yanping, and S. Xuezhen. 1995. The effect of DPC (N,N-dimethyl piperidinium chloride) on the $^{14}CO_2$-assimilation and partitioning of ^{14}C assimilates within the cotton plants interplanted in a wheat stand. Photosynthetica 31: 197-202.

Wu, L.Y., Z.H. Chen, Y.N. Yuan, and M.Y. Hu. 1985. A comparison of phsyiological effects of DPC and CCC on cotton plants. Plant Physiol. Commun. 5: 17-19.

Wu, Z.L., Q.B. Pan, Y.H. Gao, J.Y. Wang, and J. Wang. 1994. Technical researches on the all round chemical regulation of cotton plants. China Cottons 21: 10-11.

Zeng, Q. 1996. Experimental study on the efficiency of K fertilizer applied to cotton in areas with cinnamon soil or aquic soil. China Cottons 23: 12.

Zhao, D., D.M. Oosterhuis, and C.W. Bednarz. 2001. Influence of potassium deficiency on Photosynthesis, chlorophyll content, and chloroplast ultrastructure of cotton plants. Photosynthetica 39: 103-109.

Zhao, D., and D.M. Oosterhuis. 1999. Physiological, growth and yield responses of cotton to Mepplus and mepiquat chloride. p. 599-602. *In* Proc. Beltwide Cotton Conf., Orlando, FL. 3-7 Jan. 1999. Natl. Cotton Counc. Am., Memphis, TN.

Zhao, D., and D.M. Oosterhuis. 2000. Nitrogen application effect on leaf photosynthesis, nonstructural carbohydrate concentrations and yield of field-grown cotton. Spec. Rep. 198. Arkansas Agric. Exp. Stn., Fayetteville, AR.