Effect of Phosphorus Fertilization and Foliar Application of Chelated Zinc and Calcium on Quantitative and Qualitative Properties of Egyptian Cotton (*Gossypium barbadense* L. Var. Giza 75)

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Field experiments in two successive seasons, at the Agricultural Research Center (ARC), Giza, Egypt, were conducted to study the effects of phosphorus fertilization (addition at rates of 44 or 74 kg of P_2O_5/ha) and foliar application of zinc (applied at 0.0 or 40 ppm of Zn at two times: 75 and 90 days after planting) and calcium (applied at 0.0, 20, 40, or 60 ppm of Ca at two times: 80 and 95 days after planting) on growth, mineral uptake, yield components, yield, and fiber properties of the Egyptian cotton cultivar Giza 75. Dry matter yield of cotton plants (shoots), 105 days after sowing, phosphorus, calcium, and zinc uptake/plant, number of opened bolls/plant, boll weight, seed index, lint index, seed cotton yield/plant, seed cotton and lint yield/ha, and earliness of harvest increased with increasing phosphorus rate and application of Zn and Ca. Treatments generally had no significant effect on lint percentage and fiber properties, except in season I, when Micronaire reading and flat bundle strength increased by addition of high phosphorus rate and 2.5 and 50.0% span length increased by application of Ca at 40 and 60 ppm compared to control.

Keywords: *Phosphorus; zinc; calcium; cotton yield; fiber properties*

INTRODUCTION

Plant nutrition using balanced macro- and micronutrient doses is considered a major problem, especially with a large variation in soil fertility composition and different macro- and micronutrient needs for every crop. Many of our management practices and breeding efforts in cotton have been aimed at partitioning more carbohydrate into bolls than into vegetative plant parts. These management practices attempt to overcome several deficiencies by optimizing growth conditions. Phosphorus is one of the essential macronutrients for Egyptian cotton (Abd El Hadi et al., 1987). In large parts of the world, crop production under natural conditions is limited by phosphorus availability. Phosphorus has many essential roles in plants. It is a component of plant cell materials that control the life cycle of plant cells (Guinn, 1984). Phosphorus is an integral component of a number of important compounds present in plant cells, including the sugar phosphates used in respiration, photosynthetic processes, and nucleic acids, phospholipids, and other plant phosphocompounds (Taiz and Zeiger, 1991). Supplemented energy for different plant processes is trapped through photosynthesis in the form of adenosine triphosphate (ATP) and nicotinamide adenine dinucleotide phosphate (NADP). The optimum conditions of phosphorus nutrition increased the capacity of phloem to attract assimilates. This is ascribed to the intensification of different biosynthetic processes, especially the formation of cell membrane substances. The increased metabolic activity of stem tissues induces the translocation rate of assimilates from photosynthetic organs (Kosheleva et al., 1984). Zinc deficiency is observed in cotton growing on high-pH soils, particularly where the topsoil has been removed to alter the field slope for irrigation, exposing the Zn-deficient subsoil. In addition, Zn deficiencies have occurred where high rates of phosphorus are applied. High rates of phosphorus in the plant interfere with the utilization of zinc (Oosterhuis et al., 1991). Zinc deficiency may increase square and boll abscission because Zn is required for auxin [indole-3-acetic acid (IAA)] biosynthesis (which is the major hormone that inhibits abscission) and photosynthesis. Furthermore, the important role of photosynthesis in maintaining boll growth and preventing abscission may provide another explanation for the effects of Zn deficiency on boll setting. Zinc is also a component of carbonic anhydrase, an enzyme that plays an important role in photosynthesis (Ohki, 1976). Calcium also plays an important role in plant growth as a major component of the middle lamella (calcium pectate). This explains the possible role of calcium deficiency in abscission (Addicott and Lyon, 1973). Calcium deficiency may also decrease the basipetal transport of auxin (De la Fuente and Leopold, 1973). This investigation measured the effects of phosphorus fertilization rates and foliar application of Zn and Ca at different concentrations in chelated form, during square initiation and boll formation stage of Egyptian cotton grown on alluvial soil for impacts on growth, yield, and fiber quality properties.

MATERIALS AND METHODS

Two field experiments were conducted at the Agricultural Research Center, Ministry of Agriculture, Giza, Egypt, on cotton cultivar Giza 75 (*Gossypium barbadense* L.) in two successive seasons, seasons I and II. Soil in both seasons was a clay loam. Average mechanical analysis (Kilmer and Alex-

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S0021-8561(95)00816-8 CCC: $14.00

Table 1. Mechanical and Chemical Analyses of Soil Samples

	season I	season II
mechanical analysis		
clay (%)	45.27	39.00
silt (%)	27.21	27.49
fine sand (%)	18.49	26.60
coarse sand (%)	4.12	2.32
texture	clay loam	clay loam
chemical analysis		
organic matter (%)	1.81	1.58
calcium carbonate (%)	2.97	2.90
total soluble salts (%)	0.13	0.11
pH (1:2.5)	8.04	8.10
total nitrogen (%)	0.12	0.08
available nitrogen (mg/kg of soil)	34.00	57.00
available phosphorus (mg/kg of soil)	14.00	19.00
available potassium (mg/kg of soil)	300.00	310.00
available zinc (mg/kg of soil)	1.36	1.30
calcium (mequiv/100 g)	0.20	0.20

ander, 1940) and chemical characteristic examination (Chapman and Pratt, 1961) of the soil in both seasons are illustrated in Table 1. Each experiment included 16 treatments of the following combinations: (1) Two phosphorus rates (44 or 74 kg of P_2O_5/ha) were applied as calcium superphosphate (15% P_2O_5) before the first irrigation (3 weeks after planting). The farmer practice of applying 44 kg of P_2O_5/ha was used as a control. (2) Two zinc rates (0.0 or 40.0 ppm of Zn) as chelated form [ethylenediaminetetraacetic acid (EDTA)] were used. Each Zn rate was foliar sprayed two times, 75 and 90 days after planting (during square initiation and bolling stage) at a volume solution of 960 L/ha. (3) Four calcium rates (0.0,20, 40, or 60 ppm of Ca) were also applied as chelated form. Each calcium application was foliar spayed two times, 80 and 95 days after planting, at a volume solution of 960 L/ha. A randomized complete block design with four replications was used. Treatments can be summarized as follows (P rate is in kg of P_2O_5/ha; Zn and Ca rates are in ppm):

	treatment no.															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
P rate	44	44	44	44	44	44	44	44	74	74	74	74	74	74	74	74
Zn rate	0	0	0	0	40	40	40	40	0	0	0	0	40	40	40	40
Ca rate	0	20	40	60	0	20	40	60	0	20	40	60	0	20	40	60

Seeds were planted on March 19 and 23, in seasons I and II, respectively, in plots 1.8 m × 4 m, including three ridges. Cultural practices were those used for cotton on the research station. Ten days after the last spray of calcium in season II (105 days after planting), five plant samples (shoots) were randomly chosen from the first and third ridges, transferred to the laboratory, and oven-dried at 70 °C for 24 h to determine the dry matter yield (grams per plant). Total phosphorus, calcium, and zinc were determined by using the dry-ash method (Chapman and Pratt, 1961). Micronutrients were determined by atomic absorption spectrophotometry. Ten plants were randomly chosen from the center ridge of each plot to determine the number of opened bolls per plant, boll weight (grams of seed cotton per boll), and seed cotton yield in grams per plant. Earliness, as percentage of total yield harvested in the first picking, was calculated as follows: seed cotton yield in the first picking was divided by the total seed cotton yield and multiplied by 100. First hand-pickings took place on September 25 and 29 and final pickings on October 11 and 15 in seasons I and II, respectively. Total seed cotton yield of each plot (including 10 plant subsamples) was ginned to determine seed cotton and lint yield (kilograms per hectare), lint percentage (lint percent of seed cotton), seed index (grams per 100 seeds), and lint index (grams of lint per 100 seeds). Fiber tests were made 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 (millimeters), and uniformity ratio was measured by a digital fibrograph. Micronaire reading including combined measure of fiber fineness and maturity was measured by a Micronaire instrument. Flat bundle strength (expressed by grams per tex) was determined by a stelometer tester at $^1/_8$ in. gauge length [according to the method of the American Society for Testing Materials (ASTM), 1979]. Results were analyzed as a factorial experiment (Snedecor and Cochran, 1980).

RESULTS AND DISCUSSION

Plant Growth and Mineral Content. During the two growing seasons no interactions were found between phosphorus rate, application of Zn, and different Ca concentrations on quantitative and qualitative characters under investigation. Dry matter yields of cotton plants (shoots) at 105 days after sowing, as well as phosphorus, calcium, and zinc content were determined to study the effect of phosphorus rate and foliar application of zinc and calcium on plant growth and mineral uptake. A higher response was obtained by increasing the phosphorus rate and foliar application of zinc and calcium (Table 2). Malik et al. (1992) indicated that the manurial value of phosphorus was higher on medium fertility soil, as indicated by a higher pH resulting from phosphorus fixation. Foliar application of zinc improved dry matter yield and phosphorus and zinc uptake. This stimulation is due to a decrease in zinc concentration in the soil (Table 1). Because the pH value of the soil site was >6, zinc almost certainly would give a profitable response (Benton et al., 1991). The importance of phosphorus and zinc nutrition for Egyptian cotton was also confirmed by Mahmoud et al. (1985), who found a significant relationship between zinc uptake and phosphorus uptake by plants. This reflects the positive relationship that exists between the two elements in the nutrition of cotton plants. Data also reveal that the uptake of calcium by cotton plants increased significantly with the application of phosphorus, zinc, and calcium treatments, individually.

Yield Components. *Number of Opened Bolls per Plant.* Number of opened bolls per plant significantly increased as phosphorus rate was increased in both seasons (Table 3). Phosphorus is essential for cell division and for development of meristematic tissue, causing a stimulating effect on the number of flower buds and bolls per plant (Russell, 1973). These results agreed with those obtained by Malik et al. (1990) when 25−100 kg of P_2O_5/ha was applied and with those of Gomaa (1991) when cotton was given 59.5 or 119 kg of P_2O_5/ha. Application of Zn significantly increased the number of opened bolls per plant over the untreated control in the two seasons. The synthesis of IAA, the major hormone that inhibits abscission of squares and bolls, from tryptophan requires zinc (Takaki and Kushizaki, 1970). These results confirm those of Shrivastava and Singh (1988), who applied zinc sulfate at 50 kg/ha, and Gomaa (1991), who sprayed cotton with 0.952 kg of $ZnSO_4$/ha. Calcium concentrations increased the number of opened bolls per plant in both seasons, as compared with control. This increase was significant for all Ca concentrations in season I and for Ca at 40 and 60 ppm in season II experiments. Spraying plants with Ca at 60 ppm produced the highest number of opened bolls per plant. According to Addicott and Lyon (1973), Ca may inhibit square and boll abscission. The increase in the number of bolls per plant due to calcium addition was also observed by Sawan (1985), who applied calcium 70, 85, and 100 days at 50 ppm, and Shui and Meng (1990), who applied 3731 −14925 kg of lime/ha.

Table 2. Effect of P Rate and Foliar Application of Zn and Ca on Dry Matter Yield and Uptake of P_2O_5, Zn, and Ca by Cotton Plants (Season II, Sampled 105 Days after Planting)[a]

		P_2O_5		Zn		Ca	
treatment	dry matter yield (g/plant)	concn/dm (%)	P_2O_5 uptake (μg/plant)	concn/dm (ppm)	Zn uptake (μg/plant)	concn/dm (%)	Ca uptake (μg/plant)
P_2O_5							
44 kg/ha	33.40	0.1948	65.24	42.56	1420.8	0.9578	318.9
74 kg/ha	36.84**	0.2263**	83.32**	43.53	1609.2**	0.9900*	365.8**
lsd 0.05	1.267	0.00822	3.830	NS	100.26	0.03096	17.91
lsd 0.01	1.693	0.01098	5.115	NS	133.91	NS	23.92
Zn							
0 ppm, control	34.19	0.2071	71.11	40.56	1384.8	0.9602	327.5
40 ppm	36.06**	0.2140	77.45**	45.53**	1645.7**	0.9875	357.2**
lsd 0.05	1.267	NS	3.830	2.506	100.26	NS	17.91
lsd 0.01	1.693	NS	5.115	3.347	133.91	NS	23.92
Ca							
0 ppm, control	32.62	0.2040	66.80	42.31	1383.8	0.8836	287.8
20 ppm	34.53*	0.2086	72.17	42.50	1464.5	0.9654**	334.3**
40 ppm	36.29**	0.2144	78.13**	43.75	1592.4**	1.0142**	364.0**
60 ppm	37.05**	0.2152	80.02**	43.63	1620.3**	1.0322**	383.4**
lsd 0.05	1.792	NS	5.416	NS	141.79	0.04379	25.33
lsd 0.01	2.394	NS	7.234	NS	189.38	0.05849	33.84

[a] *, significant at 5% level; **, significant at 1% level; and NS, not significant.

Table 3. Effect of P Rate and Foliar Application of Zn and Ca on Yield Components of Cotton[a]

	no. of opened bolls/plant		boll wt (g)		lint (%)		seed index (g)		lint index (g)	
treatment	season I	season II	season I	season II	season I	season II	season I	season II	season I	season II
P_2O_5										
44 kg/ha	10.99	11.24	2.732	2.431	34.60	34.46	10.06	10.32	5.322	5.430
74 kg/ha	11.67**	12.08**	2.456**	2.527**	34.44	34.40	10.26**	10.54**	5.396*	5.528**
lsd 0.05	0.384	0.425	0.0347	0.0323	NS	NS	0.091	0.075	0.0604	0.0590
lsd 0.01	0.513	0.567	0.0464	0.0432	NS	NS	0.121	0.101	NS	0.1115
Zn										
0 ppm, control	11.06	11.25	2.392	2.452	34.58	34.45	10.11	10.36	5.346	5.449
40 ppm	11.61**	12.07**	2.436*	2.506**	34.46	34.41	10.21*	10.50**	5.372	5.509*
lsd 0.05	0.384	0.425	0.0347	0.0323	NS	NS	0.091	0.075	NS	0.0590
lsd 0.01	0.513	0.567	NS	0.0432	NS	NS	NS	0.101	NS	NS
Ca										
0 ppm, control	10.68	11.14	2.371	2.430	34.40	34.37	10.03	10.30	5.261	5.394
20 ppm	11.34*	11.64	2.423*	2.479*	34.69*	34.59	10.18*	10.43*	5.409**	5.522*
40 ppm	11.61**	11.83*	2.431*	2.500**	34.58	34.43	10.21*	10.47**	5.406**	5.501*
60 ppm	11.70**	12.02*	2.431*	2.507**	34.41	34.33	10.22*	10.51**	5.361*	5.499*
lsd 0.05	0.544	0.601	0.0491	0.0457	0.236	NS	0.129	0.107	0.0854	0.0834
lsd 0.01	0.727	NS	NS	0.0611	NS	NS	NS	0.143	0.1141	NS

[a] *, significant at 5% level; **, significant at 1% level; and NS, not significant.

Boll Weight. Boll weight was significantly increased by increasing the phosphorus rate in both seasons (Table 3). Similar results were obtained by Malik et al. (1990) and Gomaa (1991). Zinc foliar spray significantly increased boll weight, compared with the untreated control in both seasons. Zinc is a component of carbonic anhydrase enzyme, which plays a role in photosynthesis. Results were similar to those obtained by Sharma et al. (1988) when zinc was applied at 0.5% in two foliar applications at 50 and 65 days after sowing. Increasing the rate of calcium also significantly increased boll weight. Boll weights were greatest from the highest Ca concentration applied (60 ppm). Bottrill et al. (1970) showed that Ca deficiency depressed the rate of photosynthesis (rate of CO_2 fixation). These results agreed with those reported by Shui and Meng (1990) and Waissman Assadian and Fenn (1991) when calcium as calcium chloride was added to urea in different molar ratios.

Lint Percentage. Neither phosphorus rate nor application of Zn caused significant differences in lint percentage in either season (Table 3), although the higher phosphorus rate and application of Zn resulted in a slight reduction in lint percentage. Similar results were obtained by Sabino et al. (1991) for phosphorus and by Shrivastava and Singh (1988) for zinc. Calcium applied at 20 ppm significantly increased lint percentage over control in season I. The other Ca rates had no significant effect on this character in either season. Similar results were obtained by Shui and Meng (1990).

Seed Index. Seed index significantly increased as phosphorus rate increased in both seasons (Table 3). Phosphorus is necessary for the biosynthesis of chlorophyll, as pyridoxal phosphate must be present for its biosynthesis (Ambrose and Easty, 1977). Similar results were obtained by Sabino et al. (1991). Application of Zn significantly increased seed index compared to the control in both seasons. This might be due to its favorable effect on photosynthetic activity, which improves mobilization of photosynthates and directly influences boll weight, factors that coincide with increased seed index. Bottrill et al. (1970) illustrated that Zn deficiency depressed the rate of photosynthesis in spinach. Our results confirmed those obtained by Kashyap et al. (1988) and Sawan et al. (1989). Calcium applied at all rates significantly increased seed index in both seasons, as compared with the control. The highest increase was obtained from the higher Ca concentration (60 ppm). Similar results were obtained by Sabino et al. (1991).

Lint Index. Lint index was increased by raising the phosphorus rate in both seasons (Table 3). Sawan (1986) reported earlier that lint index tended to increase slightly by increasing phosphorus rate. Application of

Table 4. Effect of P Rate and Foliar Application of Zn and Ca on Yield and Yield Earliness in Cotton[a]

	seed cotton yield/plant (g)		seed cotton yield/ha (kg)		lint yield/ha (kg)		yield earliness (%)	
treatment	season I	season II	season I	season II	season I	season II	season I	season II
P_2O_5								
44 kg/ha	26.05	27.35	2762.5	2848.0	955.6	980.8	76.13	67.64
74 kg/ha	28.68**	30.54**	3046.9**	3185.2**	1049.4**	1095.6**	77.29*	68.97*
lsd 0.05	0.681	1.022	80.75	104.10	27.83	33.81	0.977	1.240
lsd 0.01	0.910	1.365	107.86	139.04	37.17	45.16	NS	NS
Zn								
0 ppm, control	26.44	27.60	2804.8	2875.4	969.8	990.1	76.16	67.78
40 ppm	28.28**	30.29**	3004.6**	3157.8**	1035.2**	1086.4**	77.26*	68.83
lsd 0.05	0.681	1.022	80.75	104.10	27.83	33.81	0.977	NS
lsd 0.01	0.910	1.365	107.86	139.04	37.17	45.16	NS	NS
Ca								
0 ppm, control	25.31	27.10	2688.0	2819.3	924.4	968.8	76.26	67.71
20 ppm	27.49**	28.91*	2906.9**	3011.2*	1007.9**	1041.0**	76.89	68.21
40 ppm	28.21**	29.63**	2993.4**	3090.8**	1035.1**	1063.8**	76.74	68.68
60 ppm	28.43**	30.14**	3030.5**	3145.2**	1042.6**	1079.3**	76.95	68.61
lsd 0.05	0.963	1.445	114.20	147.22	39.36	47.82	NS	NS
lsd 0.01	1.287	1.931	152.53	196.64	52.57	63.87	NS	NS

[a] *, significant at 5% level; **, significant at 1% level; and NS, not significant.

Table 5. Effect of P Rate and Foliar Application of Zn and Ca on Fiber Properties of Cotton[a]

	2.5% span length (mm)		50% span length (mm)		uniformity ratio (%)		Micronaire reading		flat bundle strength (g/tex)	
treatment	season I	season II	season I	season II	season I	season II	season I	season II	season I	season II
P_2O_5										
44 kg/ha	31.19	31.18	15.55	15.83	49.87	50.76	3.99	4.12	29.75	30.34
74 kg/ha	31.13	31.22	15.51	15.79	49.82	50.58	4.06*	4.17	30.19*	30.52
lsd 0.05	NS	NS	NS	NS	NS	NS	0.054	NS	0.410	NS
Zn										
0 ppm, control	31.18	31.20	15.54	15.82	49.86	50.72	4.00	4.13	29.88	30.35
40 ppm	31.15	31.20	15.52	15.80	49.83	50.62	4.04	4.15	30.07	30.51
lsd 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Ca										
0 ppm, control	30.93	31.12	15.36	15.71	49.67	50.49	3.99	4.11	29.82	30.27
20 ppm	31.19	31.17	15.55	15.84	49.87	50.84	4.02	4.15	29.99	30.48
40 ppm	31.28*	31.26	15.61*	15.87	49.91	50.76	4.03	4.16	30.11	30.53
60 ppm	31.24*	31.26	15.59*	15.81	49.92	50.59	4.05	4.14	29.97	30.44
lsd 0.05	0.264	NS	0.193	NS	NS	NS	NS	NS	NS	NS

[a] *, significant at 5% level; and NS, not significant.

Zn also tended to increase lint index over the control in both seasons, but this increase was significant only in season II. Lint index significantly increased with Ca application at all rates examined in both seasons. Similar findings were obtained by Sawan (1985). These results could be due to nutrient response and availability leading to initiation and development of greater number of fibers per seed.

Yield. Seed cotton yield per plant, as well as seed cotton and lint yield per hectare, significantly increased at the high phosphorus rate in both seasons (Table 4). Similar results were obtained by Gomaa (1991) and Malik et al. (1992). Application of Zn significantly increased seed cotton yield per plant, seed cotton and lint yield per hectare, as compared with the untreated control in the two seasons. Phosphorus may have favorably impacted yield components, including number of opened bolls per plant and boll weight, leading to higher cotton yield. Similar findings were obtained by Gomaa (1991). Calcium also significantly increased seed cotton yield per plant and seed cotton and lint yield per hectare as treatment rate was increased up to 60 ppm. Such results reflect the pronounced improvement of yield components due to application of calcium. Addicott and Lyon (1973) listed Ca deficiency as one of the causes of abscission and suggested this plus the role of Ca in the middle lamella (calcium pectate) were the possible reasons for yield improvment. Also, Ca deficiency affected translocation of carbohydrates, causing accumulation in the leaves and a decline in stems and roots. It seems probable that young bolls abscised because of starvation (Guinn, 1984). Ca deficiency may also decrease the basipetal translocation of auxin (De la Fuente and Leopold, 1973). Results obtained here confirm those of Sawan (1985) and Shui and Meng (1990).

Yield Earliness. Experiments in both seasons reflected earliness (percent of yield obtained in the first picking) due to increase in phosphorus rate (Table 4). The promotive effect of increased phosphorus rate on earliness percentage may be through an alteration of the nitrogen balance of the cotton plant as illustrated by the earlier maturation of cotton plants (Mayer and Anderson, 1960). This result agreed with that of Chiles and Chiles (1991). Yield earliness tended to increase with Zn application, but was statistically significant only in season I. No significant difference was noted in earliness due to Ca application in either season, as compared with the control.

Fiber Properties. Phosphorus did not affect fiber length parameters (2.5 and 50% span length and uniformity ratio), Micronaire reading, or flat bundle strength in either season (Table 5), with two exceptions. Micronaire reading and flat bundle strength increased compared to the untreated control in season I. The mean values of these characters tended to increase by increasing phosphorus rate. This may be due to the essential effect of phosphorus on photosynthesis and carbohydrate metabolism (Taiz and Zeiger, 1991). Other fiber characters did not respond to phosphorus rate. Mehetre et al. (1990) found that fiber bundle strength was highest with phosphorus fertilizer, while mean fiber length, uniformity ratio, fineness, and maturity coefficient did not change. Malik et al. (1992) observed that phosphorus had no consistent effect on fiber properties, which is in general agreement with our present findings. Application of Zn did not affect fiber properties in either season. Fiber length parameters did not follow a definite trend, while Micronaire and flat bundle strength tended to slightly increase due to Zn application. Similar results were obtained by Shrivastava and Singh (1988). Calcium had no significant effect on fiber properties in either season compared with the untreated control, with two exceptions in season I. The values for 2.5 and 50% span length tended to significantly increase by the application of calcium at 40 or 60 ppm. All fiber properties tended to improve numerically under different calcium concentrations. Similar findings were obtained by Shui and Meng (1990) and Waissman Assadian and Fenn (1991).

Under conditions of these experiments, the data showed that increasing phosphorus rate and applications of zinc and calcium at different concentrations favored cotton growth and yield.

ACKNOWLEDGMENT

We thank Prof. Dr. Magdy Madkour, Director of AGERI, for his encouragement in progressing with this work, excellent ideas, and helpful discussions. We also thank all GERT staff for assistance.

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Received for review December 15, 1995. Revised manuscript received April 28, 1997. Accepted April 30, 1997.[⊗] We acknowledge the Cotton Improvement Project for financing this work.

JF950816X

[⊗] Abstract published in *Advance ACS Abstracts,* June 1, 1997.