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Phosphorus and Potassium Fertilization of Disk-Till and No-Till Cotton

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INTERPRETIVE SUMMARY

Increases in conservation tillage have resulted in renewed interest in evaluating fertilization response by cotton (*Gossypium hirsutum* L.). Research evaluating P fertilization has been limited to conventional-tillage systems, with little research conducted on conservation-tillage systems. This research was conducted to evaluate P and K fertilization of cotton using two tillage systems. Field research was established in 1994 and continued through 1999 on a Loring silt loam (Oxyaquic Fragiudalf) having a low Mehlich-I extractable P level and a medium extractable K level.

The cotton cv. DPL 50 was planted 1994 through 1996, and cv. DPL 5409 was planted 1997 through 1999. The experimental design was a split-plot, with the main plot being tillage (disk-till and no-till) and subplots were a factorial arrangement of P and K rates. Broadcast P rates were 0, 40, 80, and 120 lb P_2O_5 acre^{-1}, while broadcast K rates were 0, 30, and 60 lb K_2O acre^{-1}. Phosphorus was applied as triple superphosphate and K was applied as potassium chloride. Nitrogen was broadcast at 80 lb acre^{-1}, using ammonium nitrate (34% N) immediately after planting. The disk-till plots were disked two or three times to a 4-in depth after fertilizers were applied. Cotton was planted between 24 April and 16 May each year in 40-in rows. Individual plots were four rows wide and 30 ft long.

Before planting, existing vegetation was killed by using recommended weed-control practices followed by postemergence weed-control measures. Current recommended production practices for insecticides, defoliants, etc., were used.

Tissue materials were collected from the two center rows the first week of bloom. Twenty fully expanded (mature) leaves and petioles were collected from the upper portion of the plant. The plant materials were extracted with a weak acid for P and K concentration determinations. A defoliant was applied when 60% of the bolls were open. Lint yields were determined by mechanically picking the two center rows of each plot 2 wk after leaf drop, with a second picking 3 to 4 wk later.

Lint yields within each tillage system were increased by fertilization. Phosphorus fertilization increased lint yields for both tillage systems while the response to K fertilization was limited to certain years. The response to the P and K fertilizer rate combinations varied with tillage system and year. Disk-till cotton yields increased by P and K rates were expressed by the regression function $RY_{DT} = 0.6848 + 0.0026\,P - 0.0000128\,P^2 + 0.00049\,K$, where RY_{DT} is the relative yield of the disk-till system, *P* is the fertilizer P_2O_5 rate, and K is the fertilizer K_2O rate. No-till response to P and K fertilization was expressed as $RY_{NT} = 0.643 + 0.00447P - 0.0000263\,P^2 + 0.00052\,K$, where RY_{NT} is the relative yield for the no-till system, *P* is the fertilizer P_2O_5 rate, and *K* is the fertilizer K_2O rate. The calculated P fertilization rate, from the response function and corresponding to the highest yield, differed with tillage system. For the disk-till system, the rate was 102 lb P_2O_5 acre^{-1} and 60 lb K_2O acre^{-1}. Highest no-till yields corresponded to a fertilization rate of 82 lb P_2O_5 acre^{-1} and 60 lb K_2O acre^{-1}. Phosphorus concentrations in both leaves and petioles were increased by P and K

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fertilization, and were higher for the no-till system than for the disk-till system. Potassium concentrations of leaves and petioles were reduced by P fertilization but increased by K fertilization. Mehlich-I extractable P levels were increased with P fertilization, and were higher from surface broadcasting 80 and 120 lb P_2O_5 acre^{-1} compared with soil incorporation. Extractable soil P concentrations were increased from a low to high categorization by the applied fertilizer rates. Yield response varied with the level of Mehlich-I extractable P and rate of P fertilization. Potassium fertilization rates used in this study increased extractable K, but the increase was insufficient to raise soil test ratings above the medium level. Critical fertilizer P_2O_5 rates of 97 and 81 lb acre^{-1} were calculated from fertilizer response functions for disk- and no-till systems, respectively. The critical extractable P levels were 40 lb acre^{-1} for both tillage systems, which is higher than the current critical extractable P level (30 lb acre^{-1}) for a high-testing soil.

ABSTRACT

Conservation-tillage practices have renewed interest in research evaluating fertilization responses of cotton. Research was conducted to evaluate the cotton-yield response to P and K fertilization under two tillage systems. Field research was established in 1994 and continued through 1999 on a Loring silt loam having Mehlich-I extractable P and K levels of 4 and 50 mg kg^{-1}, respectively. The experimental design was a split-plot, main plots were tillage (disk-till and no-till), and subplots were a factorial arrangement of 0, 20, 39, and 59 kg P ha^{-1} rates and 0, 28, and 56 kg K ha^{-1} rates. Disk-till yields were higher than no-till yields. Broadcast P and K rates increased yields of both tillage systems. The P and K rate producing highest yields varied with year and tillage system. The calculated P rates producing the highest yields were 50 and 41 kg P ha^{-1} for the disk-till and no-till systems, respectively. The calculated critical P rates were 47 and 39 kg P ha^{-1} for the disk-till and no-till systems, respectively. Yields of both tillage systems were increased with K rates increased to 56 kg ha^{-1}. Petiole and leaf P concentrations increased with P fertilization, but K concentrations were reduced by P fertilization. Petiole P and K concentrations were higher for the no-till system. Mehlich-I extractable P was increased with P fertilization, and was greater for surface broadcasting 39 and 59 kg P ha^{-1}, compared with soil incorporation. The critical extractable P levels were 20 mg kg^{-1} for both tillage systems.

The utilization of no-till practices to control soil erosion has renewed interest in conducting research evaluating fertilization practices for cotton (*Gossypium hirsutum L.*). Past research has been conducted to evaluate N and K fertilization of no-till cotton. Research evaluating P fertilization has been limited to conventional-tillage systems conducted two to three decades ago (Maples and Keogh, 1973; Cope, 1981, 1984a, 1984b). Over the past decade, P fertilization of no-till cotton has been researched primarily as a component of starter fertilizers (Touchton et al., 1986; Howard and Hoskinson, 1990; Hutchinson and Howard, 1997).

Surface broadcasting P for no-till corn (*Zea mays* L.) has been reported to be equivalent to or better than soil incorporation (Belcher and Ragland, 1972; Moscheler et al., 1972; Hargrove, 1985). Other research suggests that surface-broadcast P is as effective for no-till corn production as subsurface band P applications (Howard and Tyler, 1987).

Cotton-yield response to P fertilization on coarse-textured soils has been reported to be limited to soils low or very low in extractable P (Cope, 1970, 1981, 1984a, 1984b). Cope (1970) summarized the P fertilization rate to obtain a yield response on the basis of soil extractable P categorization. Very low extractable P soils responded to 29 kg P ha^{-1}; low extractable P soils responded to 20 kg P ha^{-1}; medium extractable P soils responded to 10 kg P ha^{-1}; while high extractable P soils did not respond to P fertilization for optimum yields. Maples and Keogh (1973) reported a yield response to P fertilization on two Arkansas soils classified as having a medium Bray-1 extractable P level. Yields on these two soils were increased by broadcast applications of 15 kg P ha^{-1}. They reported that the yield response to P fertilization was expressed in earlier fruit set.

Research conducted on medium-textured soils showed similar responses to P as observed for the coastal plain soils in Alabama. Cope (1984a) reported a conventional-till cotton yield response to applying 10 kg P ha^{-1} to a Dewey silt loam having an average Mehlich-I extractable P level of 7 mg kg^{-1}. Mitchell (2000) reported that the critical soil test Mehlich-I extractable P concentration for the Dewey silt loam was 15 mg P kg^{-1}. The critical soil test concentration has been defined as that concentration at which 95% of the maximum relative yield is achieved, and it usually coincides with the inflection point of a curvilinear yield response curve (SSSA, 1997). Thom (1981) reported lint yield increases from applying both P and K to five silt loam soils in Mississippi. The extractable P levels of these soils were classified as medium (9 to 18 mg P kg^{-1}), while the extractable K levels of these soils were classified as high (60 to 90 mg K kg^{-1}). He reported a P by K fertilizer interaction for 3-yr-average lint yields from one soil. Increasing K fertilization increased yields when P fertilization rates were 0 or 15 kg P ha^{-1}. Applying 30 kg P ha^{-1} eliminated the response to K fertilization.

Potassium deficiency of high-yielding fast-fruiting cotton cultivars has been reported to occur in the upper third of the plant (Maples et al., 1989). This finding spurred research throughout the Cotton Belt to evaluate K fertilization of cotton. Howard et al. (1998) reported the need for applying a combination of foliar and soil K to maximize conventional- and no-till yields on a low Mehlich-I extractable K soil. The combination of foliar and soil K was required to maximize yields until the extractable K level was increased through fertilization to be categorized as high (80 mg K kg^{-1}). Research conducted on two high-extractable-K soils suggests the need for higher K rates, greater than currently recommended (EPSS, 2001), to maximize no-till yields (Howard et al., 1997). Conventional-till yields were increased 1 of 8 site-years (4 yr by 2 soils) by applying K at rates higher than currently recommended (>28 kg ha^{-1}). No-till yields were increased 4 of the 8 site-years by applying K at rates higher than currently recommended (EPSS, 2001). These data suggest that K may be positionally unavailable (surface applications versus soil incorporation) for cotton production. A field study was established to evaluate the influence of tillage (no-till versus disk-till) on cotton production as influenced by P and K fertilization rates.

MATERIALS AND METHODS

Field research was conducted in 1994 through 1999 on a loess-derived Loring silt loam (fine-silty, mixed, active, thermic, Oxyaquic Fragiudalf) at the Milan Experiment Station, Milan, TN (35°59´N, 88°50´W; elevation 124 m). Average annual rainfall at Milan is 138.4 cm; the average annual temperature is 14.3EC. Mehlich-I (Mehlich, 1953) extractable P and K levels for the site were categorized as low P and medium K.

The cv. DPL 50 was planted 1994 through 1996 and cv. DPL 5409 was planted 1997 through 1999. The experimental design was a split-plot arrangement of treatments replicated four times. The main plot was tillage (disk-till and no-till) with a factorial arrangement of P and K rates as subplots. Broadcast P rates were 0, 20, 39, and 59 kg ha^{-1}, while broadcast K rates were 0, 28, and 56 kg ha^{-1}. Phosphorus was applied as triple superphosphate and K was applied as potassium chloride. Nitrogen was broadcast as ammonium nitrate (34% N) at 90 kg N ha^{-1} immediately after planting. Disk-till plots were disked two or three times to a depth of 10 cm immediately after fertilizer treatments were applied. All plots were planted between 24 April and 16 May each year in 102-cm rows. Individual plots were four rows wide and 9.1 m long.

Before planting, winter vegetation was killed using glyphosate {N-(phosphonomethyl) glycine} at 1.12 kg a.i. ha^{-1}. Immediately after planting, a tank mixture was applied, consisting of paraquat {1,1´ -dimethyl-4,4´-bipyridinium ion} at 395 g a.i. ha^{-1}; pendimethalin {N- (1-ethylpropyl)-3, 4-dimethyl-2,6-dinitrobenzenamine} at 1.03 kg a.i. ha^{-1}; fluometuron {N,N-dimethyl-N´-[3-trifluoromethyl-phenyl]urea} at 1.88 kg a.i. ha^{-1}; and a 0.5% (vol vol^{-1}) nonionic surfactant. Postdirected weed control was applied as needed. The postdirected materials included clethodim {(E,E)-(+)-2-[1-[[(3- chloro-2- propenyl) oxyl]imino]propyl] -5-[2- (ethylthio)propyl]-3-hydroxy -2-cyclohexen-1-one} at 140 g a.i. ha^{-1}; a tank mixture of pyrithiobac sodium {sodium 2-chloro -6-[(4,6-dimethoxypyrimidin- 2-yl) thio]benzoate} at 71.5 g a.i. ha^{-1}; or a tank mixture of cyanazine {2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl] amino]-2- methyl propionitrile} at 1.12 kg a.i. ha^{-1} plus MSMA {monosodium salt of methylarsonic acid} at 2.24 kg a.i. ha^{-1}. Additional recommended production practices (insecticides, defoliants, etc.) were used for production of the crop each year (Shelby, 1996).

Plant materials (leaves and petioles) were collected from the two center rows of each plot the first week of bloom. Twenty fully expanded (mature) leaves and petioles were collected from the upper portion of the plant. Petioles and leaves were separated, rinsed in tap water, rinsed twice in distilled water, oven-dried at 64ºC, and ground. The plant materials were extracted with a 2% acetic acid solution (Baker et al., 1994). Potassium concentrations were determined on a Perkin-Elmer Model 3100 (Norwalk, CT) atomic absorption spectrophotometer, while P concentrations were determined using the ascorbic acid colorimetry procedure (Watanabe and Olsen, 1965) and a Model 20 Bausch and Lomb spectrophotometer (Rochester, NY).

A recommended defoliant was applied when 60% of the bolls were open. Lint yields were determined by mechanically picking the two center plot rows approximately 2 wk after leaf drop followed by a second picking approximately 3 wk later. In 1994, first harvest was delayed sufficiently so that only one picking was needed.

Percent lint was determined by combining subsamples of seed cotton from individual treatments across replications (<4.5 kg) and ginning on a 20-saw gin with dual lint cleaners. Lint yields were calculated by multiplying the lint percentage by seed cotton weights. Total annual lint yields were calculated by adding the first- and second-harvest yields.

Soil samples were collected to a 15-cm depth in the fall of selected years for Mehlich-I extractable P and K determinations. An equal number of cores were collected from the row and between-row positions to compensate for K segregation associated with no-till cotton production (Howard et al., 1999). Mehlich-I (Mehlich, 1953) extractable P and K were determined using a 1:5 soil-to-extractant ratio. Solubilized P and extractable K were determined with colorimetry and atomic absorption spectrophotometry as for the plant tissues. The fall-extracted P and K concentrations were correlated with yields produced the following year.

Daily weather data (maximum and minimum air temperatures, total precipitation) were collected at a National Weather Service Cooperative Station at the Milan Experiment Station. Heat units as degree-days (base 15.5ºC) were calculated as the average daily temperature in ºC –15.5 and, along with precipitation, were summed from the planting dates for the first and second harvest.

Statistical analyses of treatment effects on lint yields by harvest and leaf and petiole P and K concentrations were conducted using SAS Mixed Model procedures (SAS Institute, 1997). The Mixed Model procedure provides Type III F values, but does not provide mean square values for each element within the analysis or the error terms. Mean separation was evaluated through a series of protected pair-wise contrasts among all treatments (Saxton, 1998). Means having Type III F error probabilities greater than 0.05 were categorized as nonsignificant. Regression analyses were used to evaluate P and K fertilization effects on relative yields by tillage. Relative yields were used to reduce yield differences between years. Relative yields were a calculated ratio of individual plot yields to the highest yield within a tillage system and year. Polynomial terms were tested and eliminated when *P* was >0.05. To evaluate the yield response to P and K fertilization as affected by tillage, yield-response functions were developed through regression analyses for the two tillage systems and tested for significant differences using the *F*-test (Chow Tests) (Kennedy, 1992). The Chow Test is an F-test with $T_1 + T_2 - 2K$ degrees of freedom and takes the form: $F = \{[SSE\ (constrained) - SSE\ (unconstrained)]\ K^{-1}\}$ _ $[SSE\ (unconstrained)\ (T_1 + T_2 - 2K)^{-1}]^{-1}$ where T_1 and T_2 are the number of observations in each of the regressions being compared, *K* is the number of variables in each regression including the intercept, and SSE the sum of squares error. The SSE (unconstrained) is the sum of the SSEs when the two regressions are performed separately, and SSE (constrained) is the SSE from performing one regression using all the data from both regressions.

RESULTS AND DISCUSSION

Yield Data

Lint yields were affected by the rate of P and K fertilization and the tillage system, as well as by interactions including four two-way interactions (*P*Y, T*P, K*Y,* and *P*K*), three three-way

Table 1. Mixed model F statistical values for evaluating P and K fertilization effects on yield of disk-till and no-till cotton produced on a Loring silt loam.

Source	df	Yield	
		F	Pr > *F*
Year (Y)	5	80.9	0.0001
Error a	15		
Tillage (T)	1	99.7	0.0001
T*Y	5	2.3	0.092
Error b	18		
Phosphorus (P)	3	216.1	0.0001
P*Y	15	5.3	0.0001
T*P	3	6.6	0.0002
T*P*Y	15	1.9	0.0258
Potassium (K)	2	19.5	0.0001
K*Y	10	3.2	0.0006
T*K	2	0.2	0.852
T*K*Y	10	1.2	0.281
P*K	6	8.4	0.0001
P*K*Y	30	2.2	0.0004
T*P*K	6	2.8	0.0107
T*P*K*Y	30	1.9	0.0041
Error c	386		

interactions (*T*P*Y*, *P*K*Y*, and *T*P*K*), and one four-way interaction (*T*P*K*Y*) (Table 1).

Interactions involving year (Y) would be expected with rain-fed production. The following discussion centers on those interactions not involving years, except for the four-way interaction (*T*P*K*Y*). Yield response to P and K fertilization varied not only with year but also with tillage as indicated by the interactions *T*P* and *T*P*K* (Table 1). To evaluate the *T*P*K*Y* interactive effects, yield data were analyzed using the annual P and K fertilization response for the two tillage systems. These analyses (not presented) showed annual lint yields of both tillage systems responded to P fertilization. Annual lint yield response to K fertilization was not consistent among years for the two tillage systems.

A P–K interaction affected disk-till yields in 1994, 1995, 1996, and 1998 (Table 2). Even though a P–K interaction was not observed for 1997 and 1999, yields were increased by P fertilization (data not presented). The 1997 lint yields were increased by K fertilization (data not presented). Several P and K fertilizer combinations produced higher but similar yields in 1994, 1995, 1996, and 1998, compared with yields produced by other P and K combinations. This would be expected when the applied nutrients meet or exceed plant needs. The P and K fertilizer combinations resulting in higher yields differed each year. For instance, disk-till lint yields in 1994 were similar for 10 of the 12 P–K fertilizer combinations. In 1995, the number of high-yielding fertilizer combinations were 7 of the 12 combinations. The effect was continued in 1996, except the P and K fertilizer combinations were reduced to four and six in 1998. Within these 4 yr, the P and K fertilizer combinations that consistently resulted in higher disk-till lint yields were 39 kg P ha^{-1} plus 28 kg K ha^{-1}, and 59 kg P ha^{-1} plus 56 kg K ha^{-1}. There were other P and K combinations that produced similar yields that were not significantly different from the yields of some of the higher-yielding P–K combinations. For instance, the 1996 disk-till yields were not different from the yields resulting from applying 0 kg P plus 28 kg K ha^{-1}, and 20 kg P ha^{-1} plus 0 kg K, which was considered a higher-yielding treatment.

The P–K interactive effect on no-till yields was similar to the disk-till yields, in that the response to fertilization was inconsistent over the 6 yr (Table 2). The interactive P and K fertilizer effect on yields was observed in 1994, 1998, and 1999. No-till yields were increased each year by P fertilization but K fertilization did not increase the 1995, 1996, and 1997 yields (data not presented). For the 12 P and K fertilizer treatment combinations, 8 combinations resulted in similar high yields in 1994, 7 in 1998, and 2 in 1999. Two P and K fertilizer combinations, 39 kg P ha^{-1} plus either 28 or 56 kg K ha^{-1}, consistently produced higher no-till yields. For the 6 yr, P and K fertilizer interactions affected lint yields of both tillage systems in 1994 and 1998. Neither disk- nor no-

Table 2. Effect of P and K fertilization on annual total lint yields as affected by tillage.

		Disk-till				No-till			
		P rate							
Year	K rate	0	20	39	59	0	20	39	59
		kg ha^{-1}							
1994	0	712c†	1055ab	1048ab	1083ab	640c	1039ab	1055ab	1020ab
	28	780c	1043ab	1186a	1041ab	735c	1033ab	1016ab	1119a
	56	1055ab	1156ab	1016b	1121ab	943b	1048ab	1125a	925b
1995	0	893e	1152a	1056a-d	1130ab	823	1023	969	1056
	28	1011cd	968de	1059a-d	1112abc	828	915	949	997
	56	1024cd	1037bcd	1031bcd	1068a-d	860	1021	977	896
1996	0	1315c	1415abc	1371bc	1377bc	1004	1334	1346	1286
	28	1320c	1522a	1429abc	1320bc	1074	1338	1312	1233
	56	1326bc	1310c	1357bc	1442ab	1142	1314	1333	1266
1997	0	831	1161	1229	1262	692	938	1020	1172
	28	948	1122	1280	1230	858	989	1061	1018
	56	977	1168	1298	1407	798	1168	1070	1073
1998	0	1292ef	1379de	1384cde	1507a	1025e	1346bc	1413abc	1331cd
	28	1240f	1477abc	1478abc	1410bcd	1115e	1374bc	1454a	1442ab
	56	1334def	1500ab	1571a	1504ab	1239d	1398abc	1411abc	1405abc
1999	0	907	1086	1155	1215	678g	971cde	996cde	958de
	28	1039	1182	1113	1217	822f	978cde	1144a	999cde
	56	1001	1145	1116	1236	944e	1045bc	1114ab	1032cd

†Annual yield means within a tillage system and year followed by the same letter are not significantly different at a = 0.05.

till lint yields were affected by a P and K fertilizer interaction in 1997.

Thom (1981) reported P–K interactive effects on cotton. His research showed yields were increased by K fertilization when applied in combination with either 0 or 15 kg P ha^{-1}. However, the response to K applications was not observed when P fertilization was increased to 30 kg P ha^{-1}. In this current research, lint yields produced by both tillage systems were increased by K fertilizer rates applied with 0 kg P fertilization, but increasing the P fertilization rate reduced the response to K fertilization. For instance, the 1994 disk yields were increased by K rates when applied with the 0 kg P rate, but the effect of increased K fertilization on yields was not observed when 59 kg P ha^{-1} was applied. This same effect was observed for the 1994 and 1998 no-till yields — perhaps the result of reduced minor element nutrition or an increase in available P within the system by the K fertilization. Neither possibility was evaluated in this research.

Fertilizer recommendations are formulated by evaluating yield responses to fertilization over several years. The response to P and K fertilization varied for the two tillage systems, as indicated by the *T*P*K* interaction (Table 1). The data were analyzed again by tillage to evaluate the P and K fertilization interactive effect on 6-yr average yields (Table 3). A number of P and K fertilizer combinations consistently produced higher yields in both tillage systems. For the disk-till system, three P and K fertilizer combinations (59 kg P ha^{-1} plus 56 kg K ha^{-1}, 39 kg P ha-1 plus 28 kg K ha^{-1}, and 59 kg P ha-1 plus 0 kg K ha^{-1}) resulted in similar high yields. Yields from four other P and K fertilizer combinations also were not different from those produced by the 39 kg P ha^{-1} plus 28 kg K ha^{-1}, and 59 kg P ha^{-1} plus 0 kg K ha^{-1} combinations (Table 3). These four combinations included 20 kg P ha^{-1} plus either 28 or 56 kg K ha^{-1}, 39 kg P ha^{-1} plus 56 kg K ha^{-1}, and 59 kg P ha^{-1} plus 28 kg K ha^{-1}.

Table 3. Effect of P and K rates on total lint yields as affected by tillage.

		P rate			
Tillage	K rate	0	20	39	59
		kg ha^{-1}			
Disk-till	0	992f†	1208c	1207c	1262ab
	28	1056e	1219bc	1257ab	1221bc
	56	1119d	1219bc	1231bc	1297a
No-till	0	810f	1109bc	1133abc	1137abc
	28	906e	1105bc	1156ab	1135abc
	56	988d	1165a	1172a	1099c

† Yield means within a tillage system followed by the same letter are not significantly different at a = 0.05.

Six P and K fertilizer treatment combinations consistently resulted in high no-till lint yields

(Table 3). These combinations included applying 20 kg P ha^{-1} plus 56 kg K ha^{-1}, applying 39 kg P ha^{-1} in combination with the 0, 28, and 56 kg K ha^{-1}, and 59 kg P ha^{-1} applied in combination with either 0 or 28 kg K ha^{-1}. As was observed for the disk-till data, yields from three other P–K fertilizer combinations were not different from applying 39 kg P ha^{-1} plus either 0 or 28 kg K ha^{-1}, or 59 kg P ha^{-1} plus either 0 or 28 kg K ha^{-1}.

The response to K fertilization varied across the range of P fertilization rates, as indicated by the *P*K* interaction (Table 1). Regression analysis was conducted to further clarify the yield-response interactions. These yield responses were evaluated using relative yields to minimize production year differences. Disk-till yields were expressed by $RY_{DT} = 0.84 + 0.00532\,P - 0.00005351\,P^2 + 0.000595\,K$, where RY_{DT} is the relative yield for the disk-till system, P is the rate of P fertilizer, and K is the rate of K fertilizer. No-till yields were expressed by $RY_{NT} = 0.766 + 0.00946\,P - 0.000115\,P^2 + 0.00068\,K$, where RY_{NT} is the relative yield for the no-till system, P is the rate of P fertilizer, and K is the rate of K fertilizer. Coefficients of the two equations were compared using the Chow Test (Kennedy, 1992). The first comparison showed yield-response functions for the two tillage systems were different. A second comparison showed the coefficients predicting the P fertilization response differed for the two tillage systems, while the K coefficients were not different.

Even though disk-till lint yields averaged across year (1191 kg ha^{-1}) were higher than no-till lint yields (1076 kg ha^{-1}), the response to P fertilization was greater for the no-till system than the disk-till system. The two P response function coefficients (linear and curvilinear) were greater within the no-till function. The linear K responses of the two functions were similar for both tillage systems. This linear fertilizer K effect on yields allowed predicted yields as a function of P rates to be similar in shape for each K rate but higher for each K rate. The P response functions for the two tillage systems also show the interactive effect for P and K on yield (Fig. 1). Response functions for both tillage systems were calculated for the 56 kg K ha^{-1} rate. Disk-till yields increased with P fertilization up through 50 kg P ha^{-1}. No-till lint yields increased with P fertilization through 41 kg P ha^{-1} and decreased at higher P rates. Assuming the critical fertilizer rate to be 95% of the fertilizer rate for maximum response (SSSA, 1997), the critical fertilizer rate for the disk-till system was 47 kg P ha^{-1} and for the no-till system was 39 kg P ha^{-1}. Response to a lower P fertilization rate for the no-till system agrees with previous no-till corn research (Belcher and Ragland, 1972; Moscheler et al., 1972; Hargrove, 1985).

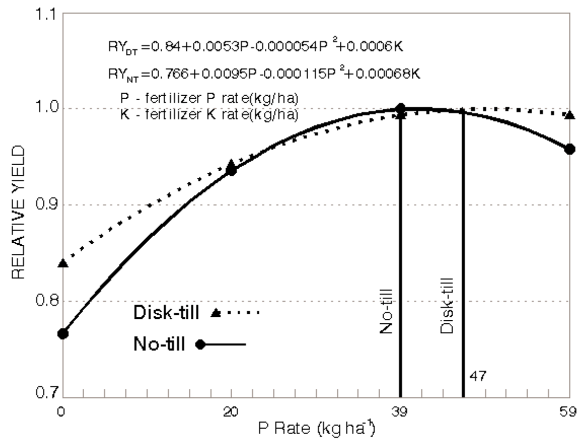

Fig. 1. Effect of P fertilization on relative cotton yields produced using the tillage systems on a silt loam soil.

Plant P and K Concentrations

Extractable P concentrations of cotton leaves were not affected by tillage but were increased by P and K fertilization (Table 4). Extractable leaf P concentrations increased with P rate up to 59 kg P ha^{-1}. Extractable leaf P concentrations were also increased by K fertilization. This increase in extractable P with K fertilization corresponds with the yield increase associated with increased K fertilization of the 0 kg P plots. The extractable leaf P concentrations in this study were lower (1.11 to 2.11 g kg^{-1}) than the total P concentrations (3 to 6.4 g kg^{-1}) reported by Sabbe and Zelinski (1990) as being sufficient for cotton. Extractable P concentrations should be less than the total P concentrations that were determined using a digestion procedure.

Extractable petiole P concentrations were higher for the no-till system (1.34 g kg^{-1}) than the disk-till system (1.26 g kg^{-1}). This difference may be due to higher availability of P from surface broadcasting, compared with soil incorporation, or may be due to dilution of the nutrient resulting from less plant mass associated with the lower-yielding no-till system. Extractable petiole P also increased with P rate and K fertilization.

Table 4. Effect of tillage, P and K fertilization on leaf and petiole extractable P and K concentrations.

	Leaf		Petiole	
Treatment	P	K	P	K
		Tillage		
		g kg^{-1}		
DT†	1.70a‡	12.4b	1.26b	40.9b
NT1.	70a	12.8b	1.34a	41.6a
		P fertilization		
		Kg P ha^{-1}		
0	1.11d	13.0a	0.84d	44.4a
20	1.64c	12.5b	1.28c	41.1b
39	1.89b	12.5b	1.49b	40.7b
59	2.11a	12.3b	1.59a	38.7c
		K fertilization		
		Kg K ha^{-1}		
0	1.65b	11.7c	1.26b	36.8c
28	1.65b	12.8b	1.30ab	42.3b
56	1.77a	13.3a	1.35a	44.6a

† DT, disk-till; NT, no-till.
‡ Leaf and petiole P and K concentrations within a column for each treatment followed by the same letter are not significantly different at a = 0.05.

Extractable K concentrations of leaves were not affected by tillage, as was observed for leaf P concentrations, but petiole K concentrations were higher for the no-till system than for the disk-till system (Table 4). This reduction may be a concentration effect resulting from possible reduced plant growth associated with the lower P fertilization level. Both leaf and petiole extractable K concentrations were reduced by increasing P rates. This reduction may be the result of the increased calcium concentration within the soil solution, resulting from higher P fertilization, that may reduce the chemical K ion activity within the soil solution, thereby reducing plant uptake (Howard and Adams, 1965). As expected, both leaf and petiole extractable K concentrations increased with K fertilization. Extractable K leaf concentrations were within the sufficiency range reported for total K determinations (Sabbe and Zelinski, 1990). Extractable K and total K concentration values have been reported to be similar regardless of the determination method (Percell et al., 1995).

The effect of broadcast P rates on extractable leaf and petiole P concentrations also varied with tillage (Table 5). Broadcast applications of the two higher P rates (39 and 59 kg P ha^{-1}) resulted in higher extractable leaf and petiole P concentrations for no-till production compared with disk-tillage. These higher extractable P concentrations suggest a higher P availability from surface broadcast application of P for no-till production than disk-till production.

Yields of both tillage systems were increased by P fertilization, suggesting a P-deficient environment. Visual observations indicated that the 0 kg P treatments produced plants that were shorter and had a dark green leaf coloration. Extractable leaf and petiole P concentrations for these deficient plants (0 kg P rate) were similar for the two tillage systems and ranged from 1.08 to 1.15 g kg^{-1} for extractable leaf P and 0.83 and 0.85 g kg^{-1} for petiole P (Table 5).

Table 5. Interactive effects of tillage and P fertilization on leaf and petiole extractable P concentrations.

	P fertilization (kg ha^{-1})			
Tillage	0	20	39	59
		g kg^{-1}		
		Leaf P concentrations		
DT†	1.15e‡	1.64d	1.83c	2.00b
NT	1.08e	1.65d	1.95b	2.22a
		Petiole P concentrations		
DT	0.85e	1.27d	1.42c	1.51b
NT	0.83e	1.29d	1.57b	1.68a

† DT, disk-till; NT, no-till.
‡ Leaf and petiole P and K concentrations among P fertilization rates and tillage treatments followed by the same letter are not significantly different at a = 0.05.

Extractable Soil P and K

Mehlich-I extractable P, evaluated in fall 1996, was increased with P fertilization of both tillage systems (Table 6). Broadcasting either 39 or 59 kg P ha^{-1} resulted in higher extractable soil P in the no-till system, compared with soil incorporation of the same rates. The soil test rating was low for the two lower P fertilization rates (0 and 20 kg P ha^{-1}), medium for broadcasting 39 kg P ha^{-1}, and high for broadcasting 59 kg P ha^{-1}, regardless of tillage. A yield response to broadcasting 39 kg P ha^{-1} and extractable P, classified as medium, was observed for both tillage systems, compared with applying 20 kg P ha^{-1} and extractable P, classified as low.

In 1998, the soil test ratings for both tillage systems were low for the 0 kg P rate, medium for the 20 kg P ha^{-1} rate, and high for either the 39 or 59 kg P ha^{-1} rates. Again, extractable P was higher for the no-till system than for the disk-till system when the 39 and 59 kg P ha^{-1} rates were applied. Cotton yields were increased by broadcasting 20 kg P ha^{-1} to both tillage systems when extractable P was medium.

Table 6. Effect of P fertilization rate on extractable soil P and yield as a function of tillage.

	Disk-till			No-till		
P rate	EP†	STR‡	Yield	EP†	STR‡	Yield
kg ha^{-1}	mg kg^{-1}		kg ha^{-1}	mg kg^{-1}		kg ha^{-1}
			1997			
0	4e§	L	919b§	4e	L	783d
20	5e	L	1150b	6e	L	1028c
39	10d	M	1269a	15c	M	1048bc
59	20b	H	1300a	23a	H	1089b
			1998			
0	5f	L	1288c	3f	L	1126d
20	11e	M	1452a	13e	M	1373b
39	19d	H	1478a	25c	H	1426ab
59	31b	H	1474a	37a	H	1392b
			1999			
0	3f	L	982c	2f	L	815d
20	11e	M	1136b	10e	M	998c
39	20d	H	1128b	23c	H	1085b
59	30b	H	1223a	38a	H	996c

† EP, extractable P, Mehlich-I extractable P in the 0- to 15-cm soil layer.
‡ STR, soil test rating; L, low; M, medium; H, high.
§ Extractable soil P and yield means for each year followed by the same letter are not significantly different at a = 0.05.

In 1999, applying either 39 or 59 kg P ha^{-1} resulted in higher extractable P for the no-till system, compared with the disk-till system (Table 6). Soil test ratings were unchanged, compared with the 1998 ratings. However, the yield response to P fertilization differed with tillage system and extractable P levels. A lint yield response for the disk-till system resulted from broadcasting 59 kg P ha^{-1} when extractable soil P was classified as high. A yield response resulted in the no-till system from broadcasting 39 kg P ha^{-1} when extractable P was 23 kg P ha^{-1} (high), but the yield was reduced by applying 59 kg P ha^{-1} when the extractable soil P level was 38 mg kg^{-1}.

The yield response of disk-till and no-till cotton to P fertilization varied with application rate and level of Mehlich-I extractable P. In 1997, a yield response resulted from applying 39 kg P ha^{-1} when extractable P was medium, while a yield response in 1998 resulted from applying 20 kg P ha^{-1} when extractable P was classified as medium. In 1999, however, a disk-till response resulted from broadcasting 59 kg P ha^{-1} when soil test P was high. For the no-till system, yields were increased in 1997 by broadcasting 59 kg P ha^{-1} when extractable P was high, compared with applying 20 kg P ha^{-1} and extractable P was low. As would be expected, the response from applying

Table 7. Effect of K fertilization rate on extractable soil K and yield as a function of tillage

	Disk-till			No-till		
K rate	EK†	STR‡	Yield	EK†	STR‡	Yield
kg ha^{-1}	mg kg^{-1}		kg ha^{-1}	mg kg^{-1}		kg ha^{-1}
			1997			
0	51de_	M	1121b§’	48e	M	956c
28	63bc	M	1145ab	58cd	M	979c
56	71a	M	1213a	60ab	M	1026c
			1998			
0	53e	M	1391bc	52e	M	1278d
28	67bc	M	1401b	65c	M	1346c
56	73ab	M	1477a	75a	M	1363bc
			1999			
0	51d	M	1091a	53d	M	901c
28	65c	M	1138a	72bc	M	986b
56	78ab	M	1124a	83a	H	1034b

† EK, extractable K, Mehlich-I extractable K in the 0- to 15-cm soil layer.
‡ STR, soil test rating; L, low; M, medium; H, high.
§ Extractable soil K and yield means for each year followed by the same letter are not significantly different at a = 0.05.

39 kg P ha^{-1} was intermediate between the two rates, and extractable P was medium. In 1998 and 1999, no-till yields were increased by P fertilization, but 1999 yields were decreased when extractable P was 38 mg kg^{-1}.

Potassium fertilization did not affect soil test ratings regardless of fertilization rate or tillage system (Table 7). In 1997, disk-till lint yields were increased by K fertilization but no-till yields were not affected by K fertilization. In 1998, disk-till lint yields were increased by broadcasting 56 kg K ha^{-1} while no-till yields were increased by broadcasting 28 kg K ha^{-1}. In 1999, disk-till yields were not increased by K fertilization but no-till yields were increased by the 28 kg K ha^{-1} rate.

Extractable P and K functions as affected by increased P and K fertilization were estimated for the 3 yr of soil test data. The extractable P function for the disk-till system was expressed by $EP_{DT} = 4.208 + 0.1488\,P + 0.00403\,P^2$, with $R^2 = 0.75$. For this function, EP_{DT} is the extractable P for the disk-till system and P is the rate of fertilizer P. The extractable P function for the no-till system was expressed by $EP_{NT} = 2.655 + 0.3237\,P + 0.00324\,P^2$, with $R^2 = 0.77$, where EP_{NT} is the extractable P for the no-till system and P is the rate of fertilizer P. Substituting the critical disk- and no-till critical fertilizer levels (47 and 39 kg P ha^{-1}) into the appropriate response functions, the corresponding critical extractable P levels were calculated. The calculated critical extractable P value was 20 mg P kg^{-1} for both systems. This critical extractable P value would be classified as high (no additional yield response) and is higher than the current critical value for high extractable P (15 mg P kg^{-1}). Critical extractable K values cannot be evaluated for the system because the optimum K rate was not determined (yields were increased by the highest K rate).

Weather

The seasonal degree days (base 15.5°C or 60°F) for the 6 yr ranged from 479°C (1856°F) in 1997 to 609°C (2357°F) in 1998 (Fig. 2) The higher heat unit accumulation in 1998 corresponds with the highest lint yields of 1377 kg ha^{-1}. However, the lowest heat unit accumulation in 1997 did not relate to the lowest yields. In 1997, the lint yield averaged across tillage systems was 1075 kg lint ha^{-1}, which is significantly lower than the 1998 yield, but higher than the 1995 and 1996 yields of 1000 and 995 kg lint ha^{-1}, respectively.

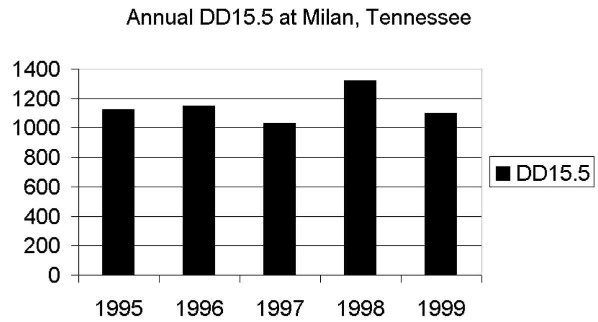

Fig. 2. Annual degree-days, base 15.5^{0}C (DD15.5), at Milan, TN, 1995–1999. (DD15.5 = [high temp °C 15.5])

Precipitation from planting to first harvest ranged from 320 mm in 1999 to 775 mm in 1996. The wettest season was 1996; however, during that year most of the rain fell prior to July (Fig. 3). The driest season was 1999, when only 342 mm of rain were recorded during the entire growing season.

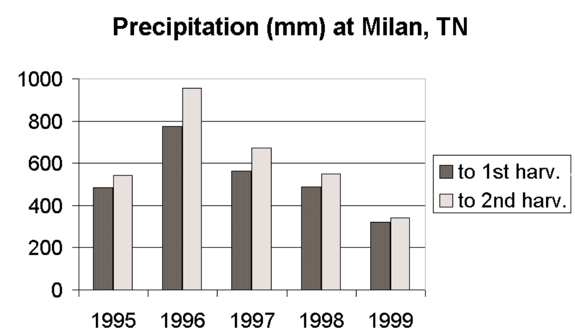

Fig. 3. Precipitation from planting to first and second harvest of cotton produced at Milan, TN. 1995–1999.

SUMMARY

Preplant broadcast applications of P and K increased cotton lint yields produced by disk- and no-till systems. Lint yields were higher for the disk-till system, compared with the no-till system. The P and K fertilization rates producing highest yields varied with tillage system and year. Regression analysis showed the yield response to P and K applied fertilizers to be higher for the no-till system than for the disk-till system. The calculated P fertilizer rates corresponding to the highest yield were 41 kg ha^{-1} for the no-till system and 50 kg ha^{-1} for the disk-till system. The K fertilizer rate corresponding to the highest yields of both tillage systems was 56 kg ha^{-1}. Extractable leaf and petiole P and K concentrations were higher for the no-till system than for the disk-till system, indicating higher nutrient availability within the no-till system. Mehlich-I extractable P levels were increased with P fertilization. Soil-extractable P was greater from surface broadcasting 39 and 59 kg P ha^{-1} to the no-till system, compared with soil incorporation of the disk-till system. Yield response varied with level of preplant (i.e., prior year) Mehlich-I extractable P. Potassium fertilization increased extractable K at the rates used in this study, but was insufficient to change the soil test ratings. The extractable P levels corresponding to the calculated critical P rates of 47 and 39 kg ha^{-1} were 20 mg P ha^{-1} for both tillage systems. This critical P level is higher than that currently used by the soil test laboratory.

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