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Cotton response to in-row subsoiling and potassium fertilizer placement in Alabama

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Abstract

In the USA a suggested method for correcting late season K deficiencies in cotton (*Gossypium hirsutum* L.) is by in-row deep placement of K fertilizer. Experiments were conducted on three Alabama soils (southeastern USA) for 3 years to evaluate cotton response to K fertilizer when surface broadcast with and without in-row subsoiling (to 38 cm depth) or deep placed in the in-row subsoil channel. Potassium was applied at rates ranging from 0 to 84 kg K ha^{-1}. Deep placement was achieved with a fertilizer applicator developed to distribute dry fertilizer at three depths down the back of the subsoil shank. All three soils also had deep placement treatments of 1680 kg ha^{-1} agricultural limestone with and without 84 kg K ha^{-1}. Soils were an Emory silt loam (fine-silty, siliceous Fluventic Umbric Dystrochrepts), a Norfolk sandy loam (fine-loamy, siliceous Typic Kandiudults), and a Lucedale sandy clay loam (fine-loamy, siliceous Rhodic Paleudults). All three soils had medium soil test K concentrations in the plow layer and medium or low concentrations of K at greater depths. The Norfolk soil had a well-developed traffic pan and in-row subsoiling increased seed cotton yields by an average of 22% during the 3 years of the study. Cotton responded to K fertilization in 2 out of 3 years at each location (6 out of 9 site-years) regardless of the method of K application. Annual applications of 84 kg K ha^{-1} increased 3 year average seed cotton yields by 17%, 10% and 19% on the Emory, Norfolk and Lucedale soils, respectively. Deep placement of agricultural limestone with or without K fertilizer for cotton did not increase cotton yields.

Keywords: Deep fertilization; Deep tillage; Cotton nutrition; Liming; Methods of fertilization; Potassium nutrition

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1. Introduction

Interest in K nutrition of cotton has increased recently in the southeastern USA owing to more frequent reports of late season K deficiency symptoms. Potassium deficiency in cotton is not restricted to the USA and has been reported in several other countries (e.g. Dastur et al., 1952; Combrink, 1988). Development of K deficiency late in the season may be due to a combination of faster maturing and higher yielding modern cultivars and/or low availability of K in the subsoil (Maples et al., 1989). A survey of 108 cotton fields in Alabama during 1990 showed that 81% of the subsoil samples had medium or lower soil test ratings for K (Mitchell et al., 1992). Tupper et al. (1988) conducted an extensive survey of Mississippi Delta soils and reported that 76% and 89% of the samples had low available K concentrations in the 15–30 cm and 30–45 cm depths, respectively.

For soils whose subsoil has been depleted of K through several years of continuous cropping, it is not known if K cotton deficiency can be totally corrected by higher rates of surface applied K. Previous work in California (Gulick et al., 1989) has shown that the cotton root system fails to adequately exploit available K in the topsoil. Gulick et al. (1989) suggested that K uptake by cotton will be optimized only if a large proportion of the root system is exposed to adequate available K. The results of Gulick et al. (1989) suggest that deep placement of K fertilizer might be an effective method of meeting the K needs of cotton.

Acidic and naturally infertile soils are widespread in the southeastern USA (Adams, 1981) and other high rainfall areas around the world (Sanchez and Salinas, 1981). Deep placement or deep incorporation of fertilizer and lime has been the focus of several studies. Improved crop yields and/or root growth have been observed in some studies, whereas in many instances no measurable benefits from deep fertilizer placement were observed (Woodruff and Smith, 1947; Woodhouse and Smith, 1956; Fehrenbacher et al., 1958; Patrick et al., 1959; Doss et al., 1979; Gonzalez-Erico et al., 1979; Rowse and Stone, 1980; Marks and Soane, 1987; Reeves et al., 1990; Jayawardane et al., 1995). Contradictory results are not surprising, given the potential interactive effects that deep tillage and nutrient availability (fertilizer placement) may have on root development and subsequent water and nutrient extraction from some soils.

As many soils in the southeastern USA may not have high concentrations of available K throughout the rooting zone, a proposed method of correcting K deficiency in cotton is by in-row, deep placement of K in the subsoil. Research in the Mississippi Delta has reported increased lint yields on some soils as a result of the deep placement of K fertilizer and/or lime (Tupper et al., 1988; Tupper, 1992). In these studies, fertilizer was applied with a dry fertilizer applicator (Tupper and Pringle, 1986) designed to place the fertilizer behind a subsoil shank in a narrow vertical band. The applicator had twin parabolic super-chisel shanks with rectangular steel tubes welded to the back of each shank. Each tube had deflector plates at 0, 12.7 and 21.6 cm above the base of the shank; these are intended to allow the fertilizer to be distributed in a band of 5 cm width from 15 to 38 cm depth in the soil if the shanks are run at a depth of 38 cm. Initial use of this applicator resulted in reported increases in lint yield of up to 95 kg ha^{-1} from the in-row deep application of K. Interpretation of these results is difficult, however, because subsoiling and K fertilizer effects were confounded as the soil was also subsoiled when the K fertilizer was deep placed.

To date, there has been little work to separate the effects of K from those of subsoiling when using the technique proposed by Tupper and Pringle (1986). There is a need to make this distinction, as growers are using or are interested in using this energy-intensive technique. Thus a series of field studies was conducted on three distinct soil types in cotton growing areas of Alabama to evaluate cotton response to surface and deep applications of fertilizer. The objectives were: (1) to determine cotton yield response to in-row subsoiling alone and when used in combination with surface and deep placement of fertilizer; (2) to compare the efficiency of K fertilizer applied as a surface broadcast application with deep placement; (3) to determine if cotton yields can be increased by the deep placement of K fertilizer and/or agricultural limestone.

2. Methods

Field studies were initiated in 1989 on an Emory silt loam in northern Alabama (USA), in 1989 on a Norfolk sandy loam in central Alabama, and in 1990 on a Lucedale sandy clay loam in central Alabama. The studies were conducted for three consecutive years at each location. Before initiation of the tests, samples were collected at regular depth increments as shown in Table 1. Several cores were collected from each location and composited for each depth increment. The samples were analyzed by the Auburn University Soil Testing Laboratory (Hue and Evans, 1986). Soil pH was determined with a glass electrode using slurries consisting of a 1:1 soil:water (volume) ratio. The samples were also extracted with the Mehlich I or dilute double acid extractant (Mehlich, 1953) and analyzed for extractable P, K, Mg and Ca. Cation exchange

Table 1
Initial chemical properties of the three soils

Depth (cm)	CEC ($cmol_c\ kg^{-1}$) [a]	pH	Mehlich I extractable ($mg\ kg^{-1}$)			
			P	K	Mg	Ca
Emory silt loam						
0–25	10.94	6.5	35(VH) [b]	98(M)	41(H)	1372
25–50	10.56	5.5	20(H)	64(L)	30(H)	947
50–75	9.84	5.0	18(H)	54(L)	28(L)	717
Lucedale sandy clay loam						
0–15	6.77	6.3	48(H)	89(M)	132(H)	661
15–30	6.30	6.5	22(M)	62(M)	160(H)	588
30–45	5.85	6.3	9(L)	32(L)	132(H)	468
Norfolk sandy loam						
0–15	4.77	7.0	52(H)	51(M)	94(H)	409
15–30	4.84	6.2	47(H)	38(L)	44(H)	325
30–45	4.96	5.6	10(L)	47(L)	51(H)	308

[a] c mol_c, centimoles of charge.
[b] Soil test ratings by Adams et al. (1994). VH, 'Very high'; H, 'high'; M, 'medium'; L, 'low'.

capacity was determined as the sum of Mehlich I extractable Ca, Mg and K plus exchangeable acidity (Hue and Evans, 1986). The soils had a medium soil test rating for K (Adams et al., 1994) in the surface layer (Table 1) and medium or low soil test ratings for K at greater depths. Soil test ratings in Alabama are based on soil cation exchange capacity and the concentration of dilute-double acid extractable nutrients. According to this system, soils with low and medium ratings would yield less than 50% of their potential and 75–100% of their potential, respectively. Soils with a high rating have an adequate concentration of nutrient, and a very high rating would correspond to soils having more than double an adequate concentration of nutrient.

Mullins et al. (1994) evaluated the effects of in-row subsoiling and deep placement of K on cotton root growth and K uptake on the Norfolk soil only. Their measurements were taken from this single location during the second and third years of the study. In this paper we present the complete yield response data to K fertilization, deep lime applications and in-row subsoiling for three soils that are representative of soils used to produce cotton in Alabama.

Treatments consisted of four rates of K (0, 28, 56 and 84 kg ha^{-1}) broadcast on the surface with and without in-row subsoiling, or deep placed in the subsoil channel. Subsoiling and deep placement of fertilizer to a depth of 38 cm were accomplished with the two row, deep fertilizer applicator described by Tupper and Pringle (1986). Two additional in-row, deep placement treatments received either 1680 kg ha^{-1} limestone or 1680 kg ha^{-1} limestone plus 84 kg K ha^{-1}. The liming material was a finely ground commercial source of dolomitic limestone. It had been ground so that 100%, 95%, 75%, 60%, 55%, 50% and 40% by weight would pass through 8, 10, 20, 40, 50, 60 and 100 mesh screens, respectively. Treatments (Table 2) were established in the spring just

Table 2
Surface and deep fertilizer treatments applied at each location; fertilizer was applied just before planting

Treatment number	In-row subsoil	K Fertilizer		Limestone (kg ha^{-1})
		Rate (kg ha^{-1})	Placement	
1-(Check)	No	0	–	0 [a]
2-(SS-Ck) [b]	Yes	0	–	0
3	No	28	Surface [c]	0
4	No	56	Surface	0
5	No	84	Surface	0
6	Yes	28	Surface	0
7	Yes	56	Surface	0
8	Yes	84	Surface	0
9	Yes	28	Deep [d]	0
10	Yes	56	Deep	0
11	Yes	84	Deep	0
12	Yes	0	Deep	1680
13	Yes	84	Deep	1680

[a] Limestone application in selected treatments refers to placement of agricultural lime into the subsoil channel.
[b] SS-Ck, Subsoiling check treatment.
[c] Potassium fertilizer broadcast on soil surface after in-row subsoiling but before secondary tillage.
[d] Deep placement—K fertilizer placed in subsoil channel.

before planting and arranged in a randomized complete block design with four replications.

Plots on the Emory soil consisted of six rows of 9.1 m length. On the Norfolk soil, plots were four rows of 6.1 m length, whereas on the Lucedale soil plots were six rows of 15.2 m length. Row spacing was 1 m at all three locations. Cotton, variety 'Deltapine 50', was planted at each location in mid-April each year. In 1989, seed cotton was picked by hand on the Norfolk soil. For the remaining site-years (1990–1992), seed cotton yields were determined by mechanically picking the two center rows from each plot. All data were analyzed by analysis of variance and contrasts using the SAS procedures (SAS Institute, Inc., 1985). An a priori $P \leq 0.10$ level of significance was chosen for separating treatment effects.

3. Results and discussion

3.1. Subsoiling effects

Throughout the test, seed cotton yields were near or above normal (Alabama average 10 year (1983–1992) yields were approximately 1700 kg ha^{-1}; Alabama Agricultural Statistics Service, 1992) for the Norfolk and Lucedale soils (Table 3). On the Emory soil, seed cotton yields were high in 1989, and near normal in 1990 and 1991. Lower yields on the Emory soil in 1991 compared with 1990 and 1989 were due to drought conditions experienced in July and August. The high yields in 1989 were due to an excellent rainfall distribution during the growing season.

A comparison of subsoiled and nonsubsoiled treatments showed that the Norfolk soil was the only site where a consistent and positive response to in-row subsoiling was

Table 3
Effect of in-row subsoiling (averaged across treatments receiving surface applications of K; Table 2) on seed cotton yields (kg ha^{-1})

Subsoiling	1989	1990	1991	1992	Mean
Emory silt loam					
No	3963a	2223a	1757a	– [1]	2648a
Yes	4050a	2137a	1780a	–	2656a
Norfolk sandy loam					
No	1985b	2427b	2949b	– [1]	2439b
Yes	2407a	2900a	3598a	–	2968a
Lucedale sandy clay loam					
No	– [2]	2876b	3104a	3624a	3201a
Yes	–	3043a	3223a	3278b	3182a

[1] Test was run for 3 years at each location and was thus terminated on the Emory and Norfolk soils after the 1991 growing season.
[2] Test on Lucedale soil was not initiated until 1990.
For a given soil and year, means followed by different letters differ significantly, based on single degree of freedom contrasts at $P \leq 0.10$.

Table 4
Effect of annual deep applications of lime (1680 kg ha^{-1}) on seed cotton yields (kg ha^{-1}) as compared with the in-row subsoiled check treatment

Deep lime	1989	1990	1991	1992	Mean
Emory silt loam					
No	3745a	2218a	1491a	–[1]	2484a
Yes	3806a	1949b	1488a	–	2414a
Norfolk sandy loam					
No	2499a	3119a	3202a	–[1]	2940a
Yes	2235a	2936a	3010a	–	2727a
Lucedale sandy clay loam					
No	–[2]	2659a	2758a	2692a	2703a
Yes	–	2900a	2940a	2776a	2872a

[1] Test was run for 3 years at each location and was thus terminated on the Emory and Norfolk soils after the 1991 growing season.
[2] Test on Lucedale soil was not initiated until 1990.
For a given soil and year, means followed by different letters differ significantly, based on single degree of freedom contrasts at $P \leq 0.10$.

obtained (Table 3). On the Norfolk soil, in-row subsoiling in the surface K treatments increased seed cotton yields by an average of 529 kg ha^{-1} during the 3 years of the test. The Norfolk site had a well-developed traffic pan at the base of the Ap horizon (Mullins et al., 1994), which was effectively disrupted by in-row subsoiling. On the Lucedale soil, in-row subsoiling gave slightly higher yields during the first 2 years of the test (Table 3) and a significant reduction in yield during 1992. The reason for a reduction in yield owing to subsoiling in 1992 is not immediately obvious. This site received an above normal rainfall (23% higher) during June and July of 1992, which may have contributed to better yields in the non-subsoiled treatments. With adequate moisture there may have been less dependence on roots in the subsoil.

3.2. Deep limestone effects

Deep placement of 1680 kg ha^{-1} agricultural limestone did not affect seed cotton yields as compared with the in-row subsoiled check treatment during 8 of 9 site-years (Table 4). For the Emory soil in 1990 there was a depression in yield owing to deep lime application. Likewise, the deep placement of 1680 kg limestone plus 84 kg K ha^{-1} as compared with deep placement of 84 kg K ha^{-1} alone (Table 5) had little effect on seed cotton yield. A significant increase in yield (649 kg ha^{-1}) owing to the mixture of K and lime was observed only on the Norfolk soil in 1991. The results show that for Alabama soils there was no yield advantage for cotton from the in-row deep placement of agricultural limestone alone or when mixed with K fertilizer. The lack of response to deep placed lime may have been due in part to inadequate mixing with the soil by the applicator. Poor mixing of lime with the soil has been attributed to a lack of response to lime in other placement studies (Adams, 1981).

Table 5
Effect of annual deep applications of K (84 kg ha^{-1}) alone or when mixed with lime (1680 kg ha^{-1}) on seed cotton yields (kg ha^{-1})

Deep lime	1989	1990	1991	1992	Mean
Emory silt loam					
No	3992a	2316a	1781a	– [1]	2696a
Yes	4208a	2486a	1936a	–	2877a
Norfolk sandy loam					
No	2771a	3064a	3284a	– [1]	3040a
Yes	2377a	3302a	3933b	–	3204a
Lucedale sandy clay loam					
No	– [2]	3014a	3127a	3284a	3142a
Yes	–	2856a	3251a	3160a	3089a

[1] Test was run for 3 years at each location and was thus terminated on the Emory and Norfolk soils after the 1991 growing season.
[2] Test on Lucedale soil was not initiated until 1990.
For a given soil and year, means followed by different letters differ significantly, based on single degree of freedom contrasts at $P \leq 0.10$.

3.3. K placement effects

Deep placement of K on the Lucedale soil resulted in a significantly lower seed cotton yield as compared with the surface treatments in 1990 (Table 6). The reduction in the 3 year average yields on the Lucedale soil was nearly significant ($P \leq 0.12$). For the remaining site-years, there were no significant differences (Table 6) between the two methods of K application.

Table 6
Effect of K fertilizer placement (averaged across K rates; Table 2) on seed cotton yields (kg ha^{-1}); all surface treatments had been in-row subsoiled before applying K fertilizer

Placement	1989	1990	1991	1992	Mean
Emory silt loam					
Surface	4050a	2137a	1780a	– [1]	2656a
Deep	3871a	2226a	1652a	–	2583a
Norfolk sandy loam					
Surface	2407a	2900a	3598a	– [1]	2968a
Deep	2668a	3110a	3519a	–	3099a
Lucedale sandy clay loam					
Surface	– [2]	3043a	3223a	3278a	3182a
Deep	–	2856b	3122a	3182a	3053a

[1] Test was run for 3 years at each location and was thus terminated on the Emory and Norfolk soils after the 1991 growing season.
[2] Test on Lucedale soil was not initiated until 1990.
For a given soil and year, means followed by different letters differ significantly, based on single degree of freedom contrasts at $P \leq 0.10$.

3.4. K rate response

Contrasts were used to evaluate the effects of K rate (0, 28, 56 and 84 kg ha^{-1}) and method of application on seed cotton yields. Regression equations were developed to explain the response of seed cotton to the rate of applied K only for the years and those methods of application (surface or deep placed) where a significant response to K was observed (Table 7). Analysis of the yield data showed that although K placement had little if any effect on seed cotton yields, average seed cotton yields increased with rate of K. On the Emory soil there was a significant response to surface K treatments and all K treatments averaged across all methods of application in 1989, 1991 and for the 3 year average yields. A surface application of 84 kg K ha^{-1} without in-row subsoiling on the Emory soil increased the 3 year average yields by 16.8%.

On the Norfolk soil, seed cotton yields increased slightly with K rate (Table 7). A significant response to rate of K was observed only for the surface treatments. A response to surface applied K was obtained in 1990, 1991 and for the 3 year average yields. Applying 84 kg K ha^{-1} on the surface in combination with in-row subsoiling increased the 3 year average yields by 10.1% as compared with the 28 kg K ha^{-1} rate.

For the Lucedale soil the most consistent response to surface applied K was obtained in combination with in-row subsoiling (Table 7). For the K treatments applied in combination with in-row subsoiling a significant response to K was observed in 1990,

Table 7
Regression models and corresponding coefficients of determination (r^2) describing the relationship between seed cotton yield (Y; kg ha^{-1}) and K rate (X; kg ha^{-1})

Year	Method of application	Equation	r^2
Emory silt loam			
1989	Surface [a]	$Y = 3749 + 5.0X$	0.87
1989	Average—all methods	$Y = 3772 + 4.16X$	0.90
1991	Average—all methods	$Y = 1539 + 3.61X$	0.80
3 year average	Surface	$Y = 2467 + 3.36X$	0.94
3 year average	Average—all methods	$Y = 2482 + 2.99X$	0.94
Norfolk sandy loam			
1990	Surface	$Y = 2598 + 2.13X$	0.10
1991	Surface	$Y = 2601 + 12.02X$	0.96
1991	Average—all methods	$Y = 2854 + 6.96X$	0.92
3 year average	Surface	$Y = 2571 + 3.06X$	0.30
Lucedale sandy clay loam			
1990	K + in-row subsoiling [b]	$Y = 2644 + 5.56X$	0.99
1990	Average—all methods	$Y = 2713 + 3.69X$	0.89
1992	K + in-row subsoiling	$Y = 3024 + 3.77X$	0.73
3 year average	K + in-row subsoiling	$Y = 2746 + 6.39X$	0.93
3 year average	Average—all methods	$Y = 2901 + 4.15X$	0.87

Equations are given only for the years and those methods of application (surface or deep placed) where a significant response ($P \leq 0.10$) to K was observed. Potassium rates were 0, 28, 56 and 84 kg ha^{-1}.
[a] Surface treatments were applied with and without in-row subsoiling.
[b] Average of all K (surface and deep applied) treatments that were in-row subsoiled.

1992 and for the 3 year average yields (Table 7). There was also a response to K when averaged across all methods of application in 1990 and for the 3 year average yields. Applying 84 kg K ha^{-1} to the Lucedale soil increased seed cotton yields by an average of 19.2% during the 3 years of the test.

4. Conclusions

In this series of field studies covering 9 site-years, cotton responded to K fertilization in 2 of 3 site-years on each soil regardless of the method of application. The yield response of seed cotton to K fertilizer was not affected by the method of application (surface vs. deep placed in-row) or by the deep application of lime alone or when mixed with K fertilizer. A positive response to in-row subsoiling was observed on one soil only, which has a well-developed traffic pan immediately beneath the plow layer. On this soil, in-row subsoiling effectively disrupted the traffic pan and increased seed cotton yields by an average of 22% during the 3 years of the test. Therefore, under the conditions of this study, we conclude that for soils with medium soil test ratings for K in the plow layer, cotton can be expected to respond to K fertilization in 2 out of 3 years and it does not matter how the K is applied. This is consistent with the current soil test calibration and recommendations developed for these soils (Adams et al., 1994). Given the energy requirements and costs associated with deep fertilizer placement, there is no advantage to deep placement of K fertilizer or K fertilizer plus limestone for cotton production. Surface, broadcast application of K fertilizer in combination with in-row subsoiling in the presence of traffic pans remains the best option for cotton production on these soils.

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