Subsoiling and Potassium Placement Effects on Water Relations and Yield of Cotton

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ABSTRACT

Deep placement of K fertilizer may alleviate late-season K deficiency of cotton (*Gossypium hirsutum* L.) on soils adequate in surface soil K but low in subsoil K. This 2-yr study in Alabama evaluated effects of deep tillage (in-row subsoiling) and K fertilizer placement on yield, leaf K deficiency, soil water depletion, and stomatal conductance of cotton grown on a soil with a root-restricting hardpan. The Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Kandiudults) soil tested medium for K in the top 15 cm and low at greater depths. Treatments were: (i) no K, no subsoiling; (ii) no K, subsoiled; (iii) surface application (84 kg K ha^{-1}), no subsoiling; (iv) surface application, subsoiled; and (v) deep placement in the subsoiled channel. Surface application without subsoiling resulted in the greatest soil water content (0- to 80-cm depth); deep placement, the lowest. Stomatal conductance was highest with no-K, no subsoiling and lowest with K (surface or deep), subsoiled. There was no evidence of K or drought stress-induced stomatal closure, and stomatal closure was not related to severity of leaf K deficiency. All three K treatments increased leaf K concentration at early bloom. Subsoiling without K fertilizer increased plant size and severity of leaf K deficiency; with surface K, subsoiling more than doubled total leaf area but did not affect leaf K deficiency. Within subsoiled treatments, leaf K deficiency was more severe with deep placement of K than with surface application. Subsoiling, especially with K fertilizer, maximized seed cotton yield in both years (avg. 3261 kg ha^{-1}) but reduced stomatal conductance. Stomatal closure and premature leaf senescence are not the likely mechanism for late-season leaf K-deficiency in cotton. Although subsoiling was necessary to maximize cotton yields on this Coastal Plain soil with a root-restricting hardpan, deep placement of K fertilizer was not superior to surface application.

POTASSIUM DEFICIENCY in cotton is responsible for yield reductions averaging 15 to 20% in California (Cassman et al., 1989) and is also a major concern of producers and researchers in the U.S. Southeast (Maples et al., 1989). The increased occurrence of K-deficiency symptoms in cotton has been attributed in part to improved earlier-maturing and higher-yielding cultivars (Maples et al., 1989); however, the problem has been a concern since at least 1932 (Sawhney, 1932).

Many soils in the Southeast where cotton is grown have medium to low soil test ratings for K in the subsoil (Tupper et al., 1989; Mitchell et al., 1992); late-season K deficiency can occur where surface soil is not considered K deficient but where subsoil K is low. Poor root distribution in surface soil layers adequate in K, due to sensitivity to low soil water potential, has been linked to poor K nutrition in cotton when subsoil K is low (Gulick et al., 1989). Subsoil K fertilization has been recommended as a means of alleviating late-season K deficiencies (Tupper et al., 1989). Results from deep placement of K fertilizer studies have been contradictory, however, and in some instances the effect of K fertilizer placement per se has been confounded by subsoiling effects (Tupper et al., 1992).

Alleviation of soil compaction by deep tillage can affect K uptake due to improved root growth and increased soil water availability. Increased root exploitation of the soil improves K uptake since diffusion to root surfaces is the primary mechanism responsible for K^+ uptake (Barber, 1984). Soil compaction is one of several plant stresses that have been linked to the K-deficiency syndrome (Combrink, 1988). The number and distribution of roots, as well as the amount and distribution of available soil K, affect both plant demand and uptake of water and K^+ in cotton.

Potassium deficiency and water stress are both known to reduce stomatal opening (Peaslee and Moss, 1966; Hsiao, 1975). Stomatal closure and accompanying premature leaf senescence has been hypothesized as the mechanism for the characteristic leaf deficiency symptoms associated with late-season K deficiency in cotton (Combrink, 1988). To date, there have been no studies to determine the comparative effects of subsoiling and K fertilizer placement on water relations of cotton relative to occurrence of late-season K-deficiency syndrome.

The purpose of this study was to determine the relative effects of deep tillage (in-row subsoiling) and K fertilizer placement on yield, severity of K-deficiency symptoms, soil water content, and stomatal conductance of cotton grown on a soil with a root-restricting hardpan.

MATERIALS AND METHODS

Data for this study were collected in 1990 and 1991 from selected treatments of a larger study initiated in 1989 on a Norfolk fine sandy loam in east-central Alabama. The larger study was an incomplete factorial arrangement of K fertilizer rates, placement methods and deep placement of lime. A description of the larger study and yield data from 1989 were reported by Mullins et al. (1991). The site had a well-developed hardpan, 12 to 18 cm thick and beginning 15 to 20 cm deep. The soil had a medium soil test rating for K in the top 15 cm (102 kg Mehlich I extractable K ha^{-1}) and a low soil test rating at greater depths (76 kg Mehlich I extractable K ha^{-1} from 15 to 30 cm and 94 kg Mehlich I extractable K ha^{-1} from 30 to 45 cm). For cotton grown on this soil, the breaking point between a medium or low soil test rating established by the Alabama Agricultural Experiment Station is 102 kg Mehlich I extractable K ha^{-1} (Cope et al., 1981).

Five treatments were selected for evaluation in order to determine the role of subsoiling and K fertilizer placement on cotton soil water content, cotton stomatal conductance, plant growth, K-deficiency symptoms, and seed cotton yield. The five treatments from which data were collected were as follows: (i) a no-K, no-subsoiling check; (ii) a no-K, in-row subsoiled check; (iii) surface application of 84 kg K ha^{-1} without in-row subsoiling; (iv) surface application of 84 kg K ha^{-1} plus in-row subsoiling; and (v) deep placement of 84 kg K ha^{-1} in the in-row subsoiled channel. All treatments were applied annually in the same plots each year. Subsoiling depth was 40 cm. Deep placement of fertilizer (KCl) and subsoiling were accomplished with

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Abbreviations: DAP, days after planting.

a two-row deep fertilizer applicator described by Tupper and Pringle (1986). The applicator has twin parabolic shanks with rectangular steel tubes welded to the back of each shank. Each tube has deflector plates designed to distribute the fertilizer in the subsoil channel at the 15- to 40-cm depth. Treatments were applied 5 d before planting in 1990 and 4 d before planting in 1991. Immediately after subsoiling and applying the surface K treatments, the experimental area was disked (10-cm depth) to level the area and incorporate K applied to the soil surface.

'Deltapine 50' cotton was seeded at 163 000 seed ha^{-1} in 102-cm rows on 30 Apr. 1990 and on 22 Apr. 1991. Individual plots were four rows, 6.1 m long. Treatments were applied to all four rows of each plot. The five treatments selected for study were part of a set of 14 treatments arranged in a randomized complete block with four replications.

In 1990 and 1991, parallel-paired stainless steel rods (6.4 mm diam.) were vertically installed in the row at three depths (20, 40, and 80 cm). A Tektronix 1502B cable tester[1] was used to measure soil water by time-domain reflectometry (TDR) (Topp et al., 1980). In 1990, measurements were taken six times, beginning 21 August (113 days after planting, DAP) and ending 11 September (134 DAP). Peak bloom occurred approximately 18 d before soil water measurements were initiated in 1990. In 1991, measurements were taken 12 times, beginning 22 July (90 DAP) and ending 5 September (135 DAP). Peak bloom was approximately 6 d after initiation of soil water measurements in 1991. There were no treatment differences in soil water content to the 20-cm depth in either year, and treatment effects on soil water content were similar for the 0- to 40-cm and 0- to 80-cm depths; therefore, soil water data are presented for the 0- to 80-cm depth only.

In 1990 and 1991, leaf stomatal conductance was measured with a LI-1600 steady state porometer (LI-COR, Lincoln, NE) from the abaxial side of unshaded, uppermost fully expanded leaves in the canopy. Measurements were made from single leaves from 10 individual plants per plot from the middle two rows of each plot. Measurements were made three times from 24 August (116 DAP) to 11 September (134 DAP) in 1990 and six times from 29 July (97 DAP) to 3 September (132 DAP) in 1991 on cloudless days from 1400 to 1600 h when solar radiation and transpiration would be maximum.

Soil penetrometer recordings were made in 1991 at 28 DAP. Measurements were made with a hand-held Bush recording penetrometer (Mark 1 Model 1979; Findlay Irvine Ltd., Penicuik, Scotland). The readings were taken when the soil water content was near field capacity, after a heavy rain (24 mm). Five penetrations to a depth of 52 cm (3.5-cm increments) were made at five positions within subsoiled and nonsubsoiled check (no K applied) plots. The positions were: 0, 12.5, 25, 37.5, and 50 cm away from the in-row position. Complete penetrometer data have been presented elsewhere (Mullins et al., 1994). Data from only the in-row position are presented here, to illustrate the presence of the hardpan and to correlate with the soil water readings made in the in-row position.

Leaf samples (20 per plot) were collected at early bloom from uppermost mature leaves on main stems each year. On 27 Aug. 1991 (119 DAP), prior to leaf shed, four intact cotton plants were harvested from each plot. Harvested plants were separated into stems, leaves, and bolls. Leaf samples and plant parts were dried at 60°C. Plant parts from the intact plants were then weighed. Subsamples were ground to pass a 0.44-mm screen, ashed at 450°C, and digested with 1 *M* HNO_3 and 1 *M* HCl. Potassium in the digests was determined by inductively coupled argon plasma (ICAP) spectrophotometry (ICAP 9000, Thermo Jarrell-Ash, Franklin, MA).

[1] Reference to a trade or company name is for specific information only and does not imply approval or recommendation of the company by the USDA or Auburn University to the exclusion of others that may be suitable.

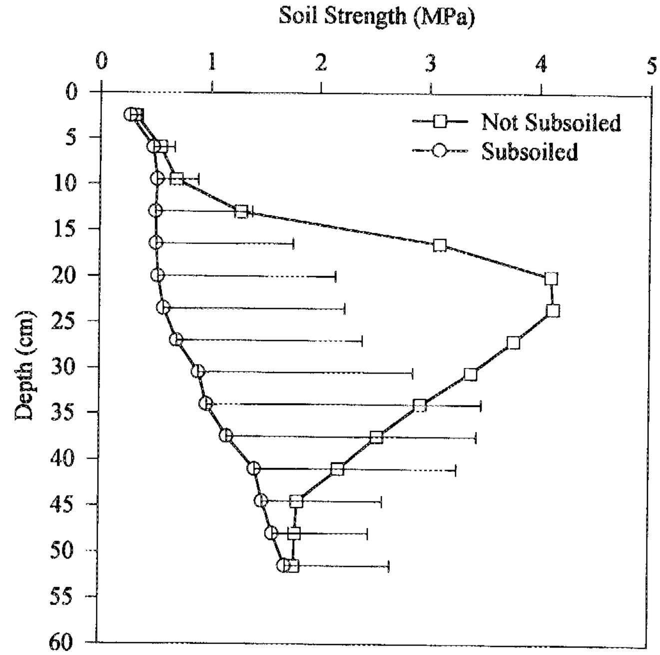

Fig. 1. Soil strength under the row of cotton as affected by in-row subsoiling. Measurements taken 28 d after planting in 1991. Horizontal bars indicate LSD (0.05).

Fresh weights were also recorded from the plant parts taken from the intact plants on 27 Aug. 1991. Prior to drying plant parts, leaves were visually rated for K-deficiency symptoms, separated by degree of deficiency, and measured for total surface area using a Li-Cor LI-3000 area meter. Leaves were rated and separated according to the following scale: 1 = dead; 2 = severe deficiency symptoms; 3 = moderate deficiency symptoms; 4 = slight deficiency symptoms; and 5 = healthy, with no deficiency symptoms.

All data were analyzed using general linear models (GLM) and stepwise regression procedures of SAS (Freund and Littell, 1991; Littell et al., 1991). Fisher's protected LSD ($P \leq 0.05$) and single degree of freedom tests were used for means separation of preplanned comparisons.

RESULTS AND DISCUSSION

Penetrometer Measurements

Soil penetrometer measurements taken within the row showed the presence of a well-developed hardpan and disruption of the pan by subsoiling (Fig. 1). Soil strength from the 15-cm depth to the 40-cm depth ranged from 2.0 to 4.0 MPa. In the absence of subsoiling, this thick hardpan reduced rooting below the 20-cm depth in both years (Mullins et al., 1994).

Soil Water Content

Rainfall amount and distribution was greater in 1991 than 1990 (Fig. 2). This, as well as the different time periods (DAP) that soil water content measurements were taken in 1990 and 1991, resulted in different treatment effects on soil water between years. Although soil water content varied with treatment and day of measurement, there was no treatment × day interaction (Fig. 3). Averaged over

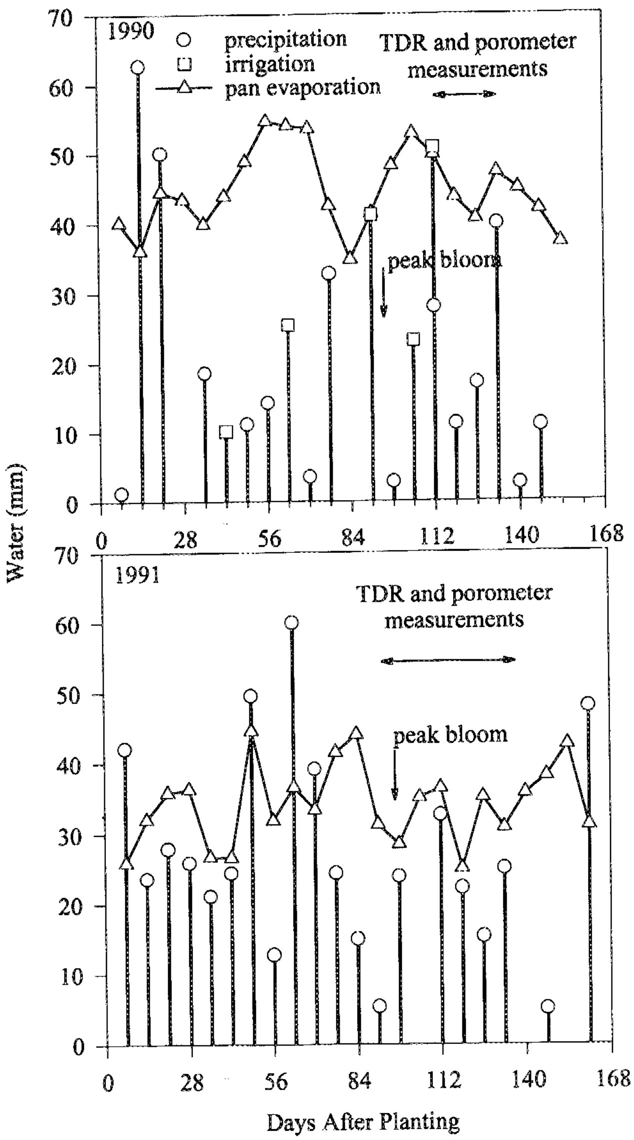

Fig. 2. Weekly total rainfall, pan evaporation, and irrigation (applied in 1990 only) during the cotton growing season in 1990 and 1991. TDR measurements: soil water measurements using time-domain reflectometry; porometer measurements: cotton leaf stomatal conductance measurements. Horizontal double-headed arrows denotes period when measurements were taken.

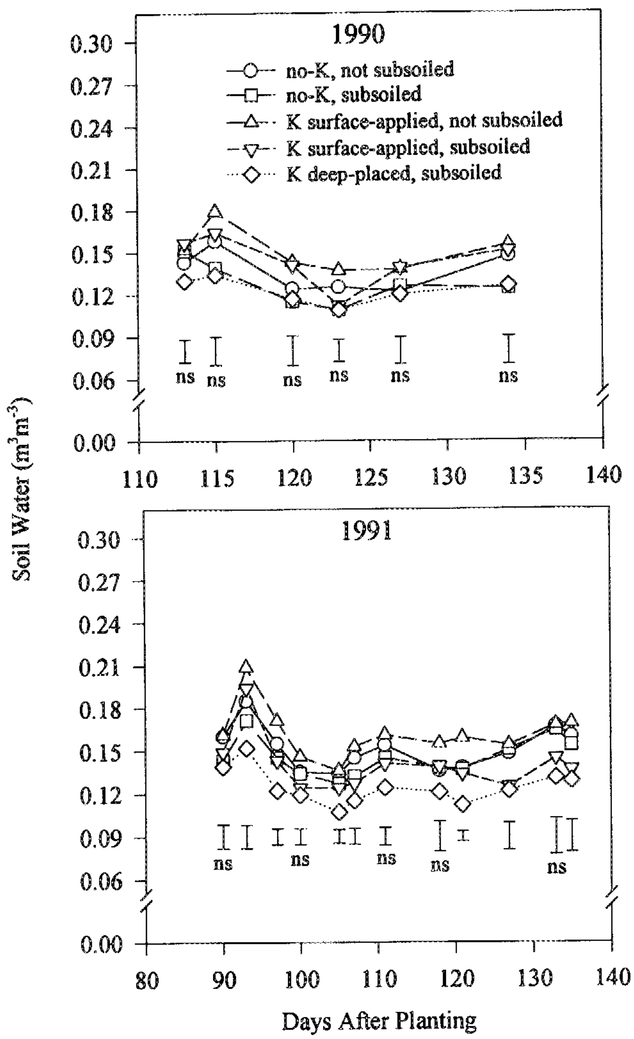

Fig. 3. Volumetric soil water content maintained under the row of cotton during the period 113 to 134 days after planting (DAP) in 1990 and during the period 90 to 135 DAP in 1991 as affected by subsoiling and K fertilizer placement. Vertical bars indicate LSD (0.05); ns, nonsignificant *F*-test ($P \leq 0.05$).

the 31-d period that measurements were taken in 1990 and the 45-d-period in 1991, subsoiling reduced soil water compared with not subsoiling in both years (Table 1). This can be attributed to greater soil water extraction from increased root growth at deeper depths in subsoiled plots. Root density measurements reported previously confirmed that subsoiling increased root length density below the hardpan (Mullins et al., 1994). Deep placement of K fertilizer also resulted in lower soil water contents compared with surface application of K in both years (Table 1). This also correlates with increased rooting below the hardpan for the deep-placed K compared with surface application as previously reported (Mullins et al., 1994).

In 1990 average soil water content was similar for treatments when K fertilizer was not applied or was applied in the subsoil channel, but in 1991 deep placement of K reduced soil water compared with no K fertilizer (Table 1). Conversely, surface application of K fertilizer resulted in increased soil water compared with no K fertilizer in 1990, but no differences in soil water between these two treatments in 1991 (Table 1). These interactions may be explained by the differences in rainfall between 1990 and 1991, as well as the fact that soil water measurements were made over a longer period (45 d) in 1991 than in 1990 and were begun prior to peak bloom, the period of maximum water use by cotton.

Stomatal Conductance

Stomatal conductance varied with the day measurements were taken in 1990 and 1991 (Fig. 4). In 1990 there were no treatment effects on stomatal conductance for any of the three individual days on which measurements were taken. When averaged over days, however, there were significant treatment effects (Table 1). In 1991 there was a day × treatment interaction effect on stomatal conductance due mainly to the greater variability by day for the no-K nonsubsoiled treatment (Fig. 4) in response to rainfall (Fig. 2).

Table 1. Stomatal conductance and soil water (0- to 80-cm depth) maintained by cotton as affected by subsoiling and K placement.

Treatment	Stomatal conductance† 1990	Stomatal conductance† 1991	Soil water‡ 1990	Soil water‡ 1991
	— cm s^{-1} —		— m^3 m^{-3} —	
1. no K, not subsoiled	1.23	1.69	0.136	0.152
2. no K, subsoiled	1.08	1.19	0.127	0.145
3. K surface-applied, not subsoiled	1.12	1.11	0.151	0.162
4. K surface-applied, subsoiled	1.02	0.76	0.144	0.140
5. K deep-placed, subsoiled	1.02	0.88	0.124	0.125
LSD (0.05)	0.16	0.16	0.014	0.006
Comparisons§				
subsoiled (2,4)	1.05	0.98	0.136	0.143
vs. not subsoiled (1,3)	1.18	1.40	0.144	0.157
$P \leq$	0.03	<0.01	0.02	<0.01
K surface (3,4)	1.07	0.94	0.148	0.151
vs. no K (1,2)	1.16	1.44	0.132	0.149
$P \leq$	0.13	<0.01	<0.01	0.31
K deep (5)	1.02	0.88	0.124	0.125
vs. no K (2)	1.08	1.19	0.127	0.145
$P \leq$	0.44	<0.01	0.49	<0.01
K surface (4)	1.02	0.76	0.144	0.140
vs. K deep (5)	1.02	0.88	0.124	0.125
$P \leq$	0.97	0.15	0.02	<0.01

† Average stomatal conductance measured three times during 116 to 134 d after planting (DAP) in 1990 and six times during 97 to 132 DAP in 1991.
‡ Average soil water content (0- to 80-cm depth) measured six times during 113 to 134 DAP in 1990 and 12 times during 90 to 135 DAP in 1991.
§ Single degree of freedom comparison; numbers in parenthesis indicate the treatment used in the comparison.

Averaged over the measurement period, subsoiling reduced stomatal conductance compared with not subsoiling in both years (Table 1). Similarly, surface application of K tended to reduce in 1990 and did reduce in 1991 stomatal conductance compared with treatments that received no K fertilizer. Application method for K placement had no effect on stomatal conductance in either year, although deep placement of K did reduce stomatal conductance compared with no K fertilization in 1991 (Table 1).

Stomatal conductance seemed to be related to plant size; the larger plants resulting from subsoiling, as indicated by total leaf area (Table 2) had the lowest stomatal conductance (Table 1), but the highest seed cotton yields (Table 3). These results agree with those of Young and Browning (1977) who reported lower soil water contents and leaf water potentials from cotton grown with in-row subsoiling on a Norfolk sandy loam compared with plants grown without subsoiling. In their study, subsoiling produced larger plants with more extensive root systems that placed a greater demand on soil water, resulting in lower leaf water potentials. Stomatal conductance remained relatively high in both years, and there were no indications of stress sufficient to cause stomatal closure in 1990 or 1991. Treatment effects on stomatal conductance could not be explained by soil water maintained during the measurement periods in either year. Even under conditions of limited soil water, cotton stomata are reported to be relatively insensitive to closure by water stress (Jordan and Ritchie, 1971; Ackerson and Krieg, 1977).

Leaf Potassium Concentrations

Treatment effects on leaf K concentration at early bloom were similar in both years. Potassium application, regardless of placement/method, increased leaf K concentration

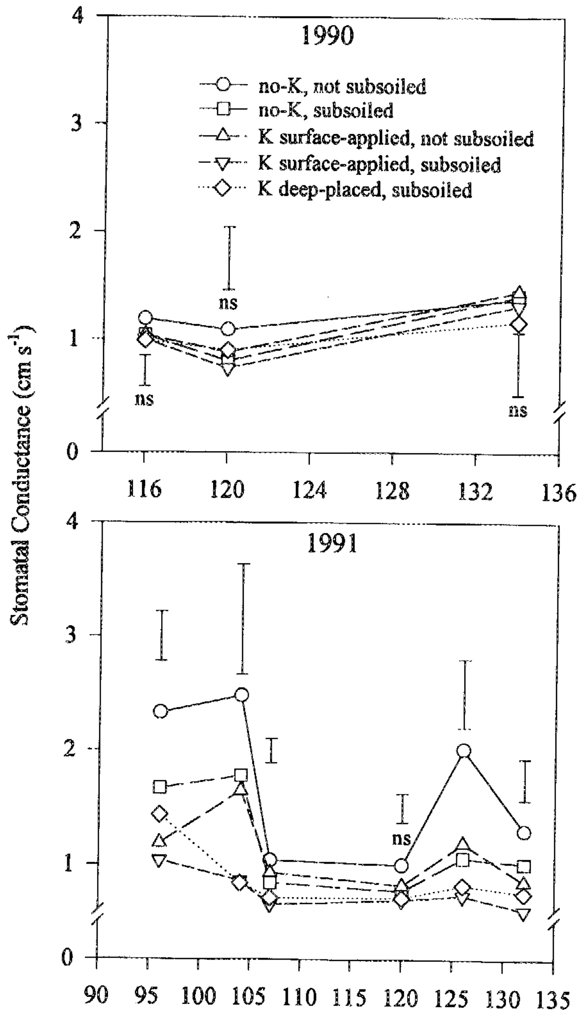

Fig. 4. Stomatal conductance maintained under the row of cotton during the period 116 to 134 days after planting (DAP) in 1990 and during the period 97 to 132 DAP in 1991 as affected by subsoiling and K fertilizer placement. Vertical bars indicate LSD (0.05); ns, nonsignificant *F*-test ($P \leq 0.05$).

compared with treatments with no K applied (Table 3). Potassium deficiency can cause stomatal closure in leaves that are normal in appearance (i.e., not showing visible K-deficiency symptoms) (Peaslee and Moss, 1966; Hsiao, 1975). However, leaf K concentrations at early bloom in both years of this study were within reported sufficiency ranges (Sabbe and Zelinski, 1990), and the relationship between leaf K concentration and stomatal conductance was very poor ($R^2 = 0.02$).

Potassium Deficiency Symptoms

Even though leaf K concentrations were sufficient and stomatal conductance was not strongly correlated to leaf K concentration, cotton showed visible leaf K-deficiency symptoms. These symptoms were noted in 1990, and in 1991 they were quantified (Table 2). In 1991, subsoiling increased plant size, as indicated by total leaf area but, in the absence of K fertilizer, subsoiling also increased the severity of leaf K-deficiency symptoms, based on leaf area (Table 2). When K was surface applied, subsoiling

Table 2. Cotton leaf area by K deficiency severity and leaf area per fresh boll weight as affected by subsoiling and K fertilizer placement in 1991.

Treatment	K status, leaf area basis†					Total leaf area	Sound leaves‡	Boll wt.	Leaf area boll wt.$^{-1}$
	H	Sl	M	Sv	D				
	cm^2 plant^{-1}						%	g plant^{-1}	cm^2 g^{-1}
1. no K, not subsoiled	57	152	303	298	39	849	60	80.9	10.2
2. no K, subsoiled	86	165	289	638	121	1298	42	82.2	11.0
3. K surface-applied, not subsoiled	22	185	377	285	68	937	62	126.8	12.4
4. K surface-applied, subsoiled	144	443	774	537	112	2011	68	138.4	14.8
5. K deep-placed subsoiled	30	166	386	516	182	1281	45	119.1	10.1
LSD (0.05)	90	174	236	308	NS	573	22	NS	3.4
Comparisons§									
subsoiled (2,4)	115	304	532	588	117	1655	55	110.3	12.9
vs. not subsoiled (1,3)	40	169	340	292	54	893	61	103.9	11.3
$P \leq$	0.02	0.03	0.03	0.01	0.13	<0.01	0.29	0.03	0.18
K surface (3,4)	83	314	576	411	90	1474	65	132.6	13.6
vs. no K (1,2)	72	159	296	468	80	1074	51	81.6	10.6
$P \leq$	0.70	0.02	<0.01	0.58	0.79	0.05	0.14	0.63	0.02
K deep (5)	30	166	386	516	182	1281	45	119.1	10.1
vs. no K (2)	86	165	289	638	121	1298	42	82.2	11.0
$P \leq$	0.19	0.98	0.39	0.40	0.28	0.95	0.79	0.77	0.60
K surface (4)	144	443	774	537	112	2011	68	138.4	14.8
vs. K deep (5)	30	166	386	516	182	1281	45	119.1	10.1
$P \leq$	0.02	<0.01	<0.01	0.88	0.22	0.02	0.05	0.66	0.01

† K deficiency symptom rating: H, healthy (no symptoms); Sl, slight; M, moderate; Sv, severe; D, dead.
‡ Percent of total leaf area classified as not severely K-deficient or dead.
§ Single degree of freedom comparison; numbers in parenthesis indicate the treatment used in the comparison.

more than doubled total leaf area but caused no difference in severity of leaf K-deficiency symptoms. Within subsoiled plots, total leaf area was reduced 36% and the severity of leaf K-deficiency symptoms was much greater with deep placement of K, as compared with surface application (Table 2). Since stomatal closure did not occur in our study, we cannot absolutely refute nor support the hypothesis of Combrink (1988) that stomatal closure and resultant premature leaf senescence are responsible for the characteristic leaf deficiency symptoms attributed to late-season K deficiency. However, the appearance of deficiency symptoms in the absence of stomatal closure suggests that stomatal closure is not the sole mechanism for the manifestation of deficiency symptoms. This agrees with the findings of Thimann (1985), who found that while stomatal closure accelerated leaf senescence in oat (*Avena sativa* L.) and nasturtium (*Tropaeolum majus* L.), stomatal opening was not directly linked to the prevention of leaf senescence.

Seed Cotton Yield

Treatments affected seed cotton yields similarly in 1990 and 1991. The greatest seed cotton yields, averaged over 1990 and 1991, were obtained by subsoiling and incorporating fertilizer K in the soil surface (Table 3). Subsoiling significantly increased seed cotton yields. There was a trend for surface application of K to increase yield compared with no fertilizer K (Table 3); however, deep placement of K fertilizer did not increase seed cotton yield over the no-K treatment.

Stomatal conductance was negatively linearly correlated to yield ($P \leq 0.01$), but the relationship was poor ($r^2 = 0.11$). Hatfield et al. (1987) reported that factors that decreased stomatal conductance of cotton had positive effects on cotton plant growth, presumably due to decreased transpiration resulting in improved water rationing from the soil profile. In our study, no relationship could be established by regression analysis between yield and soil water in either year. In 1991, total leaf area accounted for yield variance better than any other variable ($P \leq 0.0001$, $r^2 = 0.40$). This is not surprising. Provided plants could support the bolls, larger plants with heavier boll loads would result in higher yields. The highest-yielding treatment (subsoiled with K applied to the soil surface) had the greatest leaf area, and the highest percentage of leaf area not classified as severely K deficient or dead (Table 2). Furthermore, this treatment provided the highest leaf area per boll mass (Table 2). Thus, higher yield from this treatment can be explained by the fact that the treatment resulted in the greatest photosynthetic area, as well as the fact that this leaf area was a sufficient K source to support the K demand of developing bolls.

Table 3. Seed cotton yield and leaf K concentration at early bloom of cotton as affected by subsoiling and K placement (averaged over 1990 and 1991).

Treatment	Seed cotton yield	Leaf K
	kg ha^{-1}	g kg^{-1}
1. no K, not subsoiled	2648	14.8
2. no K, subsoiled	3161	14.0
3. K surface-applied, not subsoiled	2900	18.8
4. K surface-applied, subsoiled	3449	18.9
5. K deep-placed, subsoiled	3174	17.8
LSD (0.05)	388	2.4
Comparisons†		
subsoiled (2,4)	3305	16.5
vs. not subsoiled (1,3)	2704	16.8
$P \leq$	<0.01	0.64
K surface (3,4)	3175	18.9
vs. no K (1,2)	2905	14.4
$P \leq$	0.08	<0.01
K deep (5)	3174	17.8
vs. no K (2)	3161	14.0
$P \leq$	0.95	<0.01
K surface (4)	3449	18.9
vs. K deep (5)	3174	17.8
$P \leq$	0.20	0.38

† Single degree of freedom comparison; numbers in parenthesis indicate the treatment used in the comparison.

CONCLUSIONS

Our study shows that stomatal conductance is not well related to the appearance of late-season leaf K-deficiency symptoms. Our results also indicate that subsoiling is necessary for maximum cotton yields on Coastal Plain soils with root-restricting hardpans. However, based on seed cotton yield and leaf K concentrations, deep placement of K fertilizer proved no better than surface application and, in the one year measured, leaf deficiency symptoms were more severe when K was deep placed rather than surface applied. These results agree with those of Patrick et al. (1959), who found no advantage to deep placement vs. surface placement of N–P–K fertilizer to corn (*Zea mays* L.) and cotton grown on a Gallion silt loam soil (fine-silty, mixed, thermic, aeric Typic Hapludalfs) with a plowpan, provided the crops were all deep tilled. Our conclusions are also supported by recent work that showed cotton roots located 30 to 60 cm deep were less effective in P uptake than roots in the surface 30 cm of soil (Nayakekorala and Taylor, 1990). Our results indicate that deep placement of K is not superior to traditional surface application of K fertilizer in alleviating late-season K-deficiency symptoms in cotton grown on Coastal Plain soils.

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