Subsoiling for Sunflower Production in the Southeast Coastal Plains

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ABSTRACT

Crops grown on the Paleudult soils of the South Atlantic Coastal Plain often benefit from disruption of root-restrictive subsoil layers. In this physiographic area, the response of sunflower (*Helianthus annuus* L.) to subsoiling was unknown. We hypothesized that in-row subsoiling would benefit sunflower performance, and that plant performance could be related to profile penetration-resistance patterns. Sunflower was grown on Norfolk loamy sand in Florence, SC, and on Orangeburg loamy sand (both fine-loamy, siliceous, thermic Typic Paleudults) in Blackville, SC, in 1985 and in Blackville only in 1987. Plots were either subsoiled using 0.45-m shanks or not subsoiled. Distribution (and, in most instances, magnitude) of cone indices were significantly different for subsoiled and nonsubsoiled profiles. Accumulation frequency of low cone indices was greater for Florence and Blackville in 1985 but not for Blackville in 1987. For subsoiled treatments, lower cone indices below planted rows persisted to late summer in 1985 at both locations, which favored plant growth. Reduction of soil profile strength produced increased seed yield, oil concentration, oil yield, and seed size in these cases. In 1987, accumulation frequency of soil strength was similar for nonsubsoiled and subsoiled plots shortly after tillage. In this case, plant parameters were not statistically improved with subsoiling. No tillage × N-rate, hybrid × tillage, or hybrid × N-rate interactions were observed. If low-cone-index isopleths persist throughout the season, then a positive response to subsoiling can be expected.

SUNFLOWER PRODUCTION, which is relatively new to the South Atlantic Coastal Plain, has been increasing in recent years to supply local markets. The ability of the southeastern USA to produce a sunflower crop several months ahead of the northern Great Plains makes it attractive for potential market development. Unger et al. (1975) showed the double-cropping potential of sunflower with small grains in the Texas high plains. Sojka et al. (1989) showed a high yield potential for sunflower by using planting dates suitable for double cropping in South Carolina and planting either early in spring or in midsummer. Little published research is available on specific sunflower production practices under southeastern conditions (Smith et al., 1981; Robertson and Green, 1981; Morrison et al., 1984).

Because of a belief that not all crops need subsoiling due to differences in rooting capability, some growers question the need to deep subsoil at sunflower planting. The E horizons of Coastal Plain Paleudult soils are commonly coarse textured, with particle-size distributions that easily attain the minimum void ratio when exposed to traffic or other consolidating forces. Other work has suggested a need to disrupt the traffic/tillage pans and genetic hardpans in the compaction-suscpetible Paleudult soils of this region because of extensive variability in depth to the restrictive layer and year-to-year reconsolidation of disrupted layers (Cassel and Nelson, 1979; Threadgill, 1982; Vepraskas, 1988). Two major soils in the areas with sunflower-production potential are Norfolk and Orangeburg loamy sands. We hypothesized that subsoiling at planting would benefit sunflower yield and quality on these soils. We initiated a study to document the effects of in-row subsoiling on several short-season oil hybrids suited to production in the South Atlantic Coastal Plain. Cone index, seed yield, oil concentration, seed weight, and flowering interval were measured to monitor tillage effects on soil properties and plant response. Because N-fertility requirements under local conditions have not been established, a range of N rates were used in the study.

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MATERIALS AND METHODS

In 1985, field studies were established near Florence and Blackville, SC. The study was repeated at Blackville in 1987, with minor modifications. An attempt to repeat the study in 1986 failed due to severe drought. Soils at Florence and Blackville are Norfolk and Orangeburg loamy sand, respectively.

In 1985, lime was applied at rates of 455 and 685 kg ha^{-1} $CaCO_3$ equivalent at Florence and Blackville, respectively. Field preparation at Florence was disking a fallow field twice with preplant incorporation of 0.70 kg a.i. trifluralin ha^{-1} (α,α,α-trifluoro-2,6-dinitro-*N*,*N*-dipropyl-*p*-toluidine); at Blackville, it was disking the previous year's soybean [*Glycine max* (L.) Merr.] crop residue twice, with preplant incorporation of 0.85 kg a.i. trifluralin ha^{-1}, followed by preemergence application of 2.25 kg a.i. alachlor ha^{-1} [2-chloro-2′-6′-diethyl-N-(methoxymethyl) acetanilide]. Available N following soybean on these soils does not exceed 45 kg ha^{-1} and is below 30 kg ha^{-1} for fallow fields. Fertilizer treatments at Florence were preplant incorporation of 85, 135, or 200 kg N ha^{-1}, plus 85 kg P_2O_5 ha^{-1} and 170 kg K_2O ha^{-1}. At Blackville, the fertilizer treatment was preplant incorporation of 70 kg N ha^{-1}, 50 kg P_2O_5 ha^{-1} and 100 kg K_2O ha^{-1}, followed by a sidedressing of 65 kg N ha^{-1} by surface banding 10 cm from plants and incorporating with shallow cultivation at the V8 growth stage (Schneiter and Miller, 1981). Four sunflower hybrids (Dahlgren 855, Masters Choice 605, TriState 549, and Interstate 7000)[1] were planted at Florence, and five were planted at Blackville (the first four plus Seed Tech 24906) on 8 and 17 April 1985, respectively. Sunflower was planted with John Deere 71 Flexi-planters at a 2-cm depth and was either in-row subsoiled (as an integral part of the planting operation, using a two-row Brown-Harden Super Seeder with 0.45-m inclined straight subsoil shanks) or were nonsubsoiled (shanks removed). The final plant population at both sites was approximately 60 000 plants ha^{-1}. Row spacings were 0.76 m at Florence and 0.97 m at Blackville.

In 1987, a similar study was planted at Blackville, on an Orangeburg loamy sand using the following cultural practices. A single sunflower hybrid, Interstate 7111, was planted

[1] Names of specific products and suppliers are provided for the benefit of the reader and do not imply endorsement by the USDA.

10 April. Field preparation was disking a fallow field twice, with preplant incorporation of 0.85 kg a.i. pendimethalin ha^{-1} [*N*-(1-ethypropyl)-3,4-dimethyl-2,6-dinitrobenzenamine], followed by a pre-emergence application of 2.25 kg a.i. alachlor ha^{-1}. The field was also limed with 685 kg $CaCo_3$ equivalent ha^{-1}. Fertilizer practices included broadcast application and preplant incorporation of 50 kg P_2O_5 ha^{-1} and 50 kg K_2O ha^{-1}, and 10 by 10 cm banding at planting with 70 kg N ha^{-1} as a 30% urea-NH_4NO_3 solution. Nitrogen treatments were established by surface banding on 22 May with 15, 40, 65, or 130 kg N ha^{-1} as NH_4NO_3, which was incorporated by cultivation. Sunflower was planted as above, with a final plant population of approximately 60 000 plants ha^{-1}.

At Florence, treatments were in a split-split-plot design with four replications, with hybrid main plots and tillage subplots split for three N rates. At Blackville in 1985, a split-plot design was employed with four replications, with hybrid main plots and tillage subplots at a single N rate. In 1987, a split-plot randomized complete-block design with tillage main plots and four N-rate subplots was used at Blackville.

In 1985, soil water content was determined gravimetrically in each tillage main plot at four 0.15-m depth increments shortly after planting (12 and 26 April for Florence and Blackville, respectively) and again near harvest (2 and 8 August, respectively). On the same date at each of these sites, cone index was determined in the top 0.55 m of soil across two rows from midrow to midrow with a commercially available hand-operated recording penetrometer with a 13-mm-diam. 30 ° cone, similar to one described by Carter (1967). In 1987, soil characterization following tillage was delayed until 7 May by rainfall of 50.3 mm, with 26.9 mm occurring on 5 May. Probings were made at 17 positions across two rows (0.10 and 0.11-m intervals at Florence and Blackville, respectively) with three penetration profiles recorded per position. Analog tracings were digitized at 5-cm depth increments on a Hewlett Packard HP9872A plotter and 87XM microcomputer and summarized as 0.5-, 1.0-, 2.0-, 3.0-, and 4.0-MPa strength contours (Busscher et al., 1986a,b). Cone indices were log transformed before analysis, as suggested by Cassel and Nelson (1979), to reduce the effects of nonnormality. Cone index was then modeled as a function of depth and position across the row using a regression procedure (SAS Institute, 1985) as in Busscher and Sojka (1987). Statistical significance among treatments was determined by calculating a simple *F* statistic from the sum of the error mean squares of individual tillage treatments and the error mean squares of the combined tillage treatments (Draper and Smith, 1966), and applied using techniques described in detail in Sojka and Busscher (1988), and Busscher and Sojka (1990). Correction of cone index for soil-water-content differences between dates of measurement used the following equation:

$$C_1/C_2 = (W_1/W_2)^{-b} \quad [1]$$

where C is cone index and W is water content on a weight basis. Subscripts 1 and 2 refer to original and subsequent conditions. The exponent b (>0) is a unitless, empirically determined parameter that was found to vary with depth (Busscher and Sojka, 1987).

Some variations in plot dimensions occurred between 1985 and 1987, but minimum dimensions were 3.1 by 10.8 m at Florence and 3.9 by 9.2 m at Blackville. The harvest area was 10 m^2 taken from the center two rows of each plot. Dates of 50% flowering (R5.1 growth stage) were noted in both years. Plots were hand harvested as soon as possible after physiological maturity in order to avoid bird depredation. Seed was removed from heads using a small-plot thrasher. Debris and low-test-weight seed were removed through air cleaning before weighing seed for yield. Seed weight was determined on 200-seed samples and expressed as weight of 100 seeds. Oil percent was determined using methods described in Morrison et al. (1984). Yield and plant parameters were tested by analysis of variance. Monthly rainfall for both sites is recorded in Table 1.

Table 1. Monthly rainfall during the growing season at the two experimental sites in South Carolina.

	1985			1987	
	Florence		Blackville	Blackville	
Month	Normal	Actual	Actual	Normal	Actual
	mm				
April	78	22	12	90	28
May	88	56	76	106	52
June	127	138	129	134	181
July	151	194	133	133	59
August	121	128	170	114	67

RESULTS

In both 1985 and 1987, the rainfall varied at both sites in a manner typical of the region (Table 1). Rainfall was delayed in early spring at Blackville in 1985 resulting in a dry seedbed. Under these conditions, emergence was 5 to 7 d earlier and more uniform in the subsoiled plots than in the nonsubsoiled plots. At Florence, however, emergence was uniform with and without subsoiling. Subsoiling resulted in a 6-d increase in time to 50% flowering for the nonsubsoiled treatment in 1985 at Blackville (Table 2).

Subsoiling increased yield and oil concentration at both sites for both years of the study (Table 2). While consistent with previous data, the increase in seed yield, oil concentration, and oil yield at Blackville in 1987 were not statistically significant, possibly because of the distribution of growing-season precipitation, better initial seedbed soil-water conditions at planting, and less persistent subsoiling effect in 1987 (discussed below). Oil yield (the product of seed yield and oil

Table 2. Subsoiling (SS) and no subsoiling (NSS) effects on flowering, seed yield, oil content, and 100-seed weight of sunflower at Florence (F) and Blackville (B), SC.

		50% flower		Yield		Oil				100 seeds	
Site/yr	*H*†	SS	NSS	SS	NSS	SS	NSS	SS	NSS	SS	NSS
		d		kg/ha		%		kg/ha		g	
F 1985	4	61a‡	60a	1715a	1459b	46.2a	44.9b	793a	660b	4.7b	5.0a
B 1985	5	60b	66a	2180a	1744b	44.8a	41.6b	933a	728b	6.8a	6.0b
B 1987	1	64a	64a	1334a	1044a	43.0a	42.6a	489a	447a	5.0a	5.1a
Mean		61b	62a	1715a	1448b	45.2a	43.7a	780a	635b	5.3a	5.2a

† The *H* column designates number of hybrids included in the means.
‡ Means in the same row followed by the same letter are not statistically different using 0.05 to separate means.

concentration) was favored significantly by subsoiling at both sites in 1985 and was numerically consistent but not significant in 1987.

At Blackville, subsoiling significantly increased 100-seed weight in 1985 but, at Florence, it slightly decreased 100-seed weight. In 1987 at Blackville, there was no significant effect of subsoiling on 100-seed weight. Increased seed size at Blackville in 1985 may have resulted from earlier emergence with subsoiling. The lack of response in 1987 may relate to a shallower depth of the 3-MPa isopleth following subsoiling. The reduction in seed size with subsoiling in 1985 at Florence may have been associated with an increase in seed number as yield increased.

Subsoiling generally had a pronounced effect on cone-index isopleths within the soil profile. A cone index of 2 MPa corresponds to soil strengths that cause root restriction (Blanchar et al., 1978) and 3 MPa has been interpreted as a total barrier to root growth in the absence of macropore channels (Busscher et al., 1986a). As seen in Fig. 1 and 2, the depth to zones of higher cone indices is greater beneath the row in subsoiled plots following subsoiling than in nonsubsoiled plots. Subsoiling at both sites in 1985 nearly eliminated zones of strength >2 MPa to 0.4-m depth in the row and to 0.2 m between the rows. Subsoiler-planters like the one used in this study usually create zones of disruption sufficiently deep to allow rooting into the B horizon (Campbell et al., 1984). The B horizon is generally more favorable to rooting than the dense E (formerly A2) horizon in these soils (Campbell et al., 1974; Reicosky et al., 1976, 1977). At Blackville in 1985, the 2-MPa isopleth of the nonsubsoiled treatment (Fig. 2a) shows some evidence of a remnant subsoiling effect from a previous year's operations. The depth of the remnant 2-MPa isopleth, however, is not consistent under both planted rows, and the 1-MPa isopleth is nearly at the surface, unlike the deep 1-MPa isopleth of the subsoiled treatment. Earlier work demonstrated the inefficacy of biannual subsoiling (Busscher et al., 1986a).

The accumulative frequency of cone indices in the profile (Fig. 3) provides an estimate of percent cross-sectional area at or below a given soil strength. The total volume of soil in the profile below cone indices

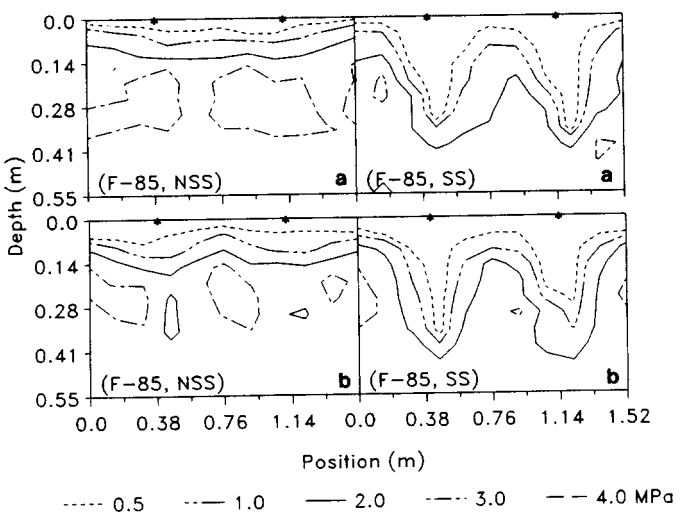

Fig. 1. Penetration resistances of nonsubsoiled (NSS) and subsoiled (SS) plots in Florence, SC, in 1985 as measured in (a) spring and (b) late summer. Asterisks indicate row positions.

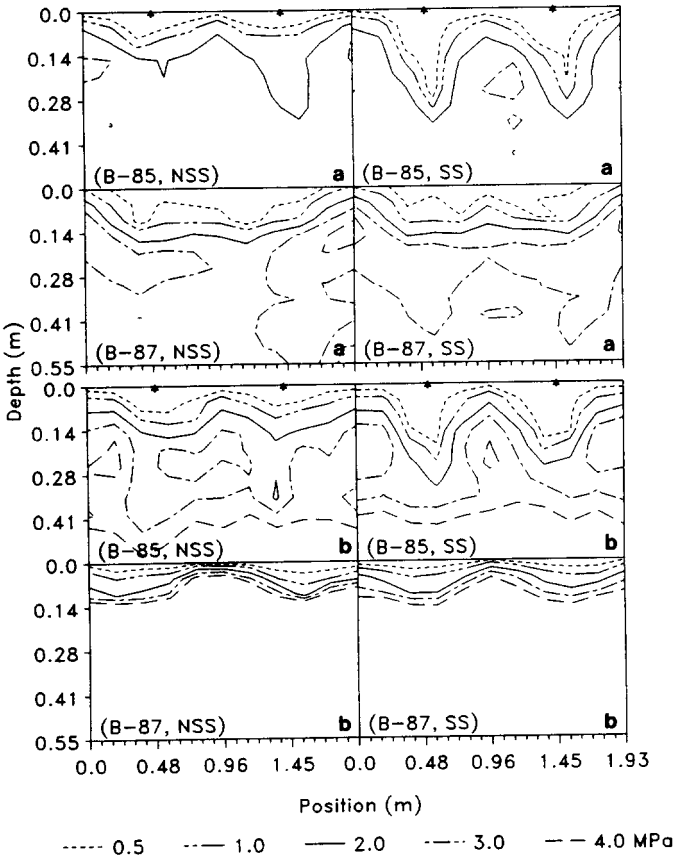

Fig. 2. Penetration resistances of Blackville, SC, tillage plots for 1985 and 1987 nonsubsoiled (NSS) and subsoiled (SS) as measured in (a) spring and (b) late summer. Asterisks indicate row positions.

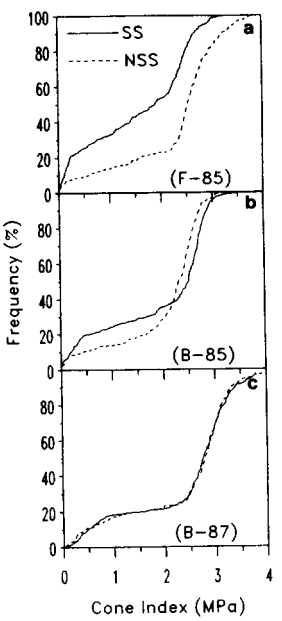

Fig. 3. Accumulative frequency of spring penetration-resistance values from subsoiled or nonsubsoiled profiles from (a) Florence, SC, in 1985, (b) Blackville, SC, in 1985 and (c) Blackville in 1987.

restrictive to root growth (<2 MPa) increased under the subsoiled treatments at both sites in 1985. In the spring of 1985, the volume of soil with cone indices below 2.0 MPa was 53% and 22% with and without subsoiling, respectively, on the Norfolk soil, and 36 and 24% on the Orangeburg soil. In August of 1985, the volume of soil with cone indices below 2.0 MPa was 49 and 27% with and without subsoiling on the Norfolk soil, and 32 and 24% on the Orangeburg soil. In 1987, the volume of soil with cone indices below 2.0 MPa in the spring was 23% for both treatments, and was 15 and 12% for subsoiled an nonsubsoiled treatments, respectively, in August. However, the volume fractions (accumulative frequency) of cone indices for the two tillage treatments were similar. Nonetheless, cone indices for the soil profile were significantly different between the subsoiled and nonsubsoiled plots at the beginning of the growing season in all cases (Table 3). This statistical difference was based on both the magnitude of cone indices and their spatial distribution in the profile, using statistical comparisons developed earlier to accommodate analysis of the two-dimensional arrays (Sojka and Busscher, 1988; Busscher and Sojka, 1990). For example, profile cone indices in the spring of 1987 differed significantly because of their distribution patterns (Fig. 2a), in spite of sometimes similar overall mean cone indices (Table 3). Differences between subsoiled and nonsubsoiled plots remained statistically significant even at season's end for all sites and years (Table 3).

On these Paleudult soils, soil strengths at low water contents can easily prevent cone penetration. Values as high as 20 MPa at water contents of 10.7% have been measured (Karlen et al., 1990, unpublished data). Therefore, cone indices were determined after rains had wet the profile. Soil gravimetric water contents at the beginning of the growing season, before tillage, were uniform across replicates. Mean profile water contents were 16.0, 10.1, and 13.3% for Florence and Blackville in 1985 and Blackville in 1987, respectively. Water contents at season's end (18.9, 13.3, and 9.1%, respectively) differed significantly from the early-season water contents. Water contents also differed with sample depth, both in spring and late season. Water contents in late season did not differ statistically between tillage treatments. Corrections for changes in strength due to water-content changes between dates of measurement were made in all three sets of data for each depth (Table 3). Even after correction, cone indices differed significantly with date of measurement and among treatments.

An important consideration in evaluating the effectiveness of subsoiling operations lies in determining the depth of subsoiler penetration and the degree of shattering that persists through the season in the profile. The comparisons in 1987 of subsoiled and nonsubsoiled treatments in Fig. 2a and Fig. 3c, when interpreted together, indicate that the 1987 subsoiling operation did not result in persistence of a 2.0-MPa isopleth at depths comparable to those measured at either site in 1985. While Fig. 2a indicates the position of the subsoilers by their effect on the spacial distribution of strengths, Fig. 3c demonstrates that the accumulative frequency of strengths was nearly the same

Table 3. Mean profile cone indices in subsoiled (SS) or nonsubsoiled (NSS) plots for Florence (F) and Blackville (B), SC.

Time	Tillage	Mean cone indices		
		F-1985	B-1985	B-1987
		MPa		
Spring	SS	1.58	1.98	2.43
	NSS	2.31	2.06	2.41
Preharvest	SS	1.67	2.97	4.88
	NSS	2.06	2.96	5.43
Preharvest (corrected)†	SS	2.15	3.97	2.76
	NSS	2.72	3.98	3.25

† Corrected to cone index at spring profile water content using Eq.[1.]. All values presented differed statistically at the 0.05 level, following the procedures described by Sojka and Busscher (1988) and Busscher and Sojka (1990).

for either operation by the date of cone-index characterization. This probably contributed to the poorer statistical significance in 1987 of measured plant properties affected by tillage.

In 1987, inability to enter the field because of heavy rain between 10 April and 7 May delayed measurement of cone indices an additional 3 wk, compared with the 1985 measurements. Reconsolidation of tilled soil after rainfall is a common problem on Coastal Plain soils. Despite a controlled tillage operation with discreet and distinct tillage treatments, cone-index profiles favorable to crop performance did not persist under the subsoiled treatment to the date of characterization under these conditions. The trace remaining of the 3.0-MPa isopleth suggests the extent to which subsoiling probably disrupted the profile. The area between the 3.0-MPa isopleth and the 1.0-MPa isopleth indicates the area reconsolidated by the heavy rains, which occurred between tillage and penetrometer characterization. Figure 1b and 2b demonstrate that, although subsoiling persisted throughout the season at both sites in 1985, the subsoiling effect was completely lost by season's end in 1987. It is difficult to assess the extent to which minor operation adjustments may influence such an effect, though the differences in isopleth placement and persistence were quantifiable with this penetrometer methodology.

In the absence of specific soil-N guidelines for sunflower on these soils, several rates were used. Analysis of variance showed no significant interaction of tillage with N rate. No effect of N rate on flowering interval was observed. Sunflower responded positively to rates above 110 kg ha^{-1} only for seed weight at Florence in 1985 (Table 4). Oil yield declined at the higher N rates at Florence in 1985 due to the combined significant responses of oil concentration and seed yield. No significant response to higher N rates occurred for seed weight, seed yield, oil concentration, or oil yield in 1987, though negative trends were observed. Research from outside the physiographic area (Deakov and Panchenko, 1974; Cheng and Zubriski, 1978) has shown that, with increasing N availability, oil concentration decreases and protein-N and seed yield increases. The combined effect still increases oil yield per hectare.

Detailed investigation of fertility effects on sunflower in the Coastal Plain have not been published. Since interaction of N rates and tillage was not observed and since some negative responses occurred at

Table 4. Nitrogen-fertilization effects on flowering, seed yield, oil content, and 100-seed weight of sunflowers at Florence (F) and Blackville (B), SC in 1985 and 1987.

N	50% flower		Yield		Oil				100 seeds	
	B-1987	F-1985	B-1987	F-1985	B-1987	F-1985	B-1987	F-1985	B-1987	F-1985
kg/ha	d		kg/ha		%		kg/ha		g	
85	64a†	60a	1143a	1694a	43.3a	46.3a	497a	786a	5.3a	4.7b
110	64a	–	1118a	–	43.3a	–	486a	–	5.0a	–
135	64a	60a	1048a	1506b	41.9a	45.3b	440a	686b	4.9a	5.0a
200	64a	60a	1048a	1562ab	42.6a	45.0b	448a	707b	4.9a	4.8ab

† Means in the same column followed by the same letter are not statistically different using 0.05 to separate means.

Table 5. Days to flowering, yield, oil content, oil yield, and 100-seed weight for the different sunflower hybrids at Florence (F) and Blackville (B), SC.

Hybrid	50% Flower		Yield		Oil				100 seeds	
	F-1985	B-1985	F-1985	B-1985	F-1985	B-1985	F-1985	B-1985	F-1985	B-1985
	d		kg/ha		%		kg/ha		g	
Dahlgren 855	60.3b†	61.3a	1631b	2237ab	45.5b	43.9a	726b	925ab	5.2a	6.8b
Masters Choice 605	61.1a	64.0a	1590b	1833c	47.3a	44.5a	699b	746ab	4.3b	5.2c
Tristate 549	61.3a	62.3a	1897a	2422a	45.5b	43.9a	835a	977a	4.9a	6.5ab
Interstate 7000	59.1c	62.4a	1511b	2281ab	43.9c	43.2a	647b	920ab	5.0a	6.4b
Seed Tech 24906	–	64.4a	–	1982bc	--	40.5b	–	712b	–	7.1a

† Like letters in the same column indicate no significance by 0.05 LSD test.

higher rates, further research under southeastern conditions is warranted. Rainfall distribution or irrigation can affect the subsoiling efficacy on Coastal Plain Paleudults. Smaller yield responses to subsoiling were observed for corn (*Zea mays* L.) when rainfall distribution or irrigation frequency was highly favorable throughout the growing season (Camp et al., 1984). When water is more limiting, however, subsoiling, can increase available water and N by enlarging the volume of soil accessible to roots. Vepraskas (1988) showed that favorable rainfall could be expected to diminish subsoiling benefits for tobacco (*Nicotiana tabacum* L.) in the Coastal Plain in 3 yr out of 10.

Little difference was noted in time to 50% flowering among the hybrids (Table 5). Hybrid Tristate 549 was significantly higher in seed yield and oil production at Florence and numerically highest at Blackville in 1985, though not significantly higher than Dahlgren 855 and Interstate 7000 in seed yield or Dahlgren 855, Masters Choice 605, and Interstate 7000 in oil production. Although Seed Tech 24906 had the highest seed weight at Blackville in 1985, it was not among the highest yielding hybrids. The hybrid Masters Choice 605 had a consistently high oil concentration. Because it also was not among the higher yielding varieties, however, it did not have the highest oil production. Analysis of variance showed no tillage × hybrid or hybrid × N-rate interactions in the studies where these combinations of treatments were present.

CONCLUSIONS

Subsoiling was a highly effective method of improving soil profile strength characteristics beneath planted sunflower rows grown on two southeastern Paleudult soils. The benefit of profile disruption depended on the depth and extent of initial disruption and its persistence into the growing season. Seed yield and quality of sunflower were generally improved under nonirrigated conditions if adequate profile disruption was achieved. Subsoiling improved stand establishment in a dry seedbed. Although there was no observed interaction between tillage and N rates in this study, some negative crop response occurred at high application rates, suggesting the need for further research.

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