Kilen, T.C. 1977. Inheritance of a brachytic character in soybean. Crop Sci. 17:853–854.
Kilen, T.C. 1990. Brachytic stem and narrow leaflet effects on soybean seed composition and yield. Crop Sci. 30:1006–1008.
Kilen, T.C., and E.E. Hartwig. 1975. Short internode character in soybeans and its inheritance. Crop Sci. 15:878.
Kilen, T.C., and E.E. Hartwig. 1987. Effect of morphological traits upon seed composition in soybean. p.67. *In* Agronomy abstracts. ASA, Madison, WI.
Wells, R., J.W. Burton, and T.C. Kilen. 1993. Soybean growth and light interception: response to differing leaf and stem morphology. Crop Sci. 33:520–524.

Tillage Management for Doublecropped Soybean Grown in Narrow and Wide Row Width Culture

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ABSTRACT

Leaving residues on the soil surface and deep tillage may reduce the severity of yield-reducing, plant water stress on the southeastern Coastal Plain. For narrow (<75 cm) row width culture, little is known about the seed-yield response of doublecropped soybean [*Glycine max* (L.) Merr.] to surface tillage or deep tillage. We conducted a 2-yr field study on a Goldsboro sandy loam soil to (i) determine the seed-yield response of doublecropped soybean to surface tillage and deep tillage when grown using 19- and 76-cm-row widths and (ii) determine the effects of surface tillage and deep tillage on branch and mainstem yield components. Doublecropped soybean was grown following winter wheat (*Triticum aestivum* L.) harvest using all combinations of surface tillage (disked or no surface tillage), spring deep tillage (deep tilled or no deep tillage before soybean planting), row width culture (production practices for row widths of 19 or 76 cm), and fall deep tillage (no deep tillage or deep tilled before wheat planting) treatments. Averaged across years and all other treatments, the soybean grown with the 19-cm-row width had a 53 and 83% greater seed yield than the soybean grown with the 76-cm-row width in the disked and no-surface-tillage plots, respectively. When deep tilled, soybean yields were consistently higher with no surface tillage, compared with disking, only when the 19-cm-row width was used. Seed-yield increases due to deep tillage were greatest when plots were deep tilled before planting both crops and when no surface tillage and the narrow row width culture were used. Across all treatments and years, seed yield was highly correlated with seed number per square meter (r = 0.93), but less so with individual seed weight (r = 0.52). Results indicate that seed-yield increases due to deep tillage and no surface tillage are greater when doublecropped soybean is planted using production practices established for narrow row width culture.

Because of the long growing season, doublecropping soybean after wheat harvest is a viable alternative to monocropped soybean production in the southeastern USA. Potential benefits from doublecropped soybean, in comparison to monocropped soybean, include a more extensive use of fixed resources, reduced soil erosion, improved cash flow, and increased net cash returns (Sanford et al., 1986). Doublecropping also spreads the risk of substantial yield loss resulting from environmental stresses over two crops.

Winter wheat production in the southern USA usually reduces stored soil water supplies (Pearce et al, 1993), increasing the likelihood of significant plant water stress occurring in the subsequent soybean crop. Conservation tillage practices may reduce the severity or delay the development of drought stress in doublecropped soybean. For many soils, surface residues can enhance crop productivity by increasing rainfall infiltration into the root zone (Bruce et al., 1987; Dick et al., 1987), reducing water runoff (Langdale et al., 1979; Mills et al., 1986), decreasing soil losses (Mills et al., 1986), and improving soil tilth (Langdale et al., 1984, 1990). Surface residues also moderate soil temperatures, impede the diffusion of water vapor from the soil surface, act as an absorbent for water vapor diffusing from the soil, and reduce wind velocity at the soil surface (Greb, 1966; Wilhelm et al., 1989). Reduced cultivation with conservation tillage and the suppression of weed emergence by surface residues (Crutchfield et al., 1985; Putnam et al., 1983) also favors improved soil water conditions.

Doublecropped soybean is usually grown in wide (≥76 cm) row widths on the southeastern Coastal Plain. Interest has increased concerning the use of narrower (19 or 38 cm) row widths since canopy closure usually occurs earlier with narrow than with wide row widths, making the soybean crop more competitive with weeds. Planting with a grain drill and increasing the seeding rate are two of the practices generally recommended for narrow row width culture (Palmer and Privette, 1992). The higher plant population associated with the use of narrow row widths should also contribute to earlier canopy closure. Other benefits from the use of narrow row widths include higher soybean pod placement, less soil water evaporation, greater root dispersion throughout the soil, and less soil erosion (Palmer and Privette, 1992).

Deep tillage is recommended for southeastern Coastal Plain soils that contain a tillage pan, a naturally forming hardpan (located just above the clay subsoil), or both (NeSmith et al., 1987). Disruption of these compacted layers promotes faster and deeper root growth into the subsoil. Because these hardpans reform naturally, annual deep tillage is usually necessary (Busscher et al., 1986). For doublecropped soybean interseeded

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Abbreviations: SWC, gravimetric soil water content.

into standing wheat, deep tilling once in the fall prior to wheat planting may be sufficient for optimum soybean yields (Khalilian et al., 1991). When planting soybean using wide row widths, growers usually deep till prior to or at planting, using in-row chisels to fracture soil hardpans below the crop row. However, the amount of soil fracturing across the Ap soil horizon by in-row subsoiling may not be sufficient for soybean grown in narrow row widths. There are several deep tillage devices available, such as the ParaTill[1] (Bigham Brothers, Inc., Lubbock, TX), which fracture almost the entire Ap and E soil horizons and could be used with narrow row widths. However, the optimum time to deep till (fall, spring, or both) has not been determined for doublecropped soybean grown in either wide or narrow row width culture.

Yield-reducing drought stresses frequently occur on the southeastern Coastal Plain primarily because of the coarse texture of the Ap soil horizons. Soybean produced at higher plant populations with narrow rather than wide row widths probably utilize more soil water early in the growing season and, consequently, may undergo more severe plant water deficits. Therefore, soybean grown with narrow row widths may benefit more from production practices that improve soil water conditions during the growing season, such as conservation tillage and deep tillage. The objectives of this study were to (i) determine the seed-yield response of double-cropped soybean to surface tillage and deep tillage when grown using 19- and 76-cm-row widths and (ii) to determine which yield components have the greatest effect on soybean yield response to surface and deep-tillage treatments.

MATERIALS AND METHODS

Site Description and Cultural Practices

Soybean (cv. Hagood) was planted after winter wheat harvest on a Goldsboro loamy sand (fine-loamy, siliceous, thermic Aquic Kandiudult) soil in 1994 and 1995 at the Pee Dee Research and Education Center located near Florence, SC. Hagood, a maturity group VII cultivar, was selected for this experiment because of its good nematode and disease resistance and its high yield performance in Clemson University's variety tests (Shipe et al., 1991). The experimental site was the same, and the same treatments were applied to each plot in both years. Conventionally tilled soybean was grown prior to the first year of the study. Management practices used to produce the wheat crop have previously been described (Frederick and Bauer, 1996).

Phosphorus and potassium fertilizers and lime were broadcast applied to all plots in the fall before wheat planting at rates based upon soil test results. All plots were sprayed with alachor plus glyphosate [2-chloro-2′-6′diethyl-*N*-(methoxymethyl) acetanilide plus isopropylamine salt of *N*-(phosphonomethyl)glycine] at a rate of 3.9 kg a.i. ha^{-1} prior to spring tillage and soybean planting. Chlorimuron [chlorimuron, ethyl 2-[[[4-chloro-6-methoxypyrimidin-2-yl)amino]-carbonyl]-amino]sulfonyl]benzoate] and sethoxydim [2-[1-(ethoxyimino)butyl-5-[2-(ethylthio) propyl]-3-hydroxy-2-cyclohexen-1-one] were applied to all plots 21 and 28 d after planting, respectively, at rates of 0.013 and 0.21 kg a.i. ha^{-1}, respectively. Weed plants were hand-removed throughout the growing season.

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

Treatments Applied

Treatments were all combinations of surface tillage (disked or no surface tillage), spring deep tillage (deep tilled or no deep tillage before soybean planting), row width culture (production practices for row widths of 76 or 19 cm), and fall deep tillage (deep tilled with a four-shanked ParaTill prior to wheat planting or no deep tillage). Each treatment was replicated four times. The same level of surface tillage was used to produce both the soybean and wheat crops. Plots assigned to be disked were disked twice to a depth of 18 cm before planting. After disking, the 19-cm-row width plots assigned to be deep tilled were deep tilled to a depth of 41 cm (top of B soil horizon) with a four-shanked ParaTill. A four-shanked Kelley (Kelly Mfg. Co., Tifton, GA) in-row subsoiling unit mounted in front of a four-row planter was used to deep till to a depth of 41 cm the plots having the 76-cm-row width. Shanks were mounted as opposed pairs and spaced 71 cm apart on the ParaTill and spaced 76 cm apart on the Kelley subsoiling unit. Both deep tillage devices were equipped with a serrated cutting coulter mounted in front of each shank.

Soybean seeds were planted 30 May and 1 June in 1994 and 1995, respectively, in rows oriented in a north-south direction. For the 76-cm-row width, seeds were planted at a rate of 35 seeds m^{-2} with a John Deere (Deere and Co., Moline, IL) 7200 four-row planter. A 16-row John Deere 750 grain drill was used to plant soybean seed at a rate of 70 seeds m^{-2} in the plots having the 19-cm-row width. Seeding rates were selected based on Extension recommendations (Palmer and Privette, 1992). All plots were 3 m wide and 15 m long. The disked plots having soybean planted with 76-cm-row width were cultivated to a depth of 8 cm 40 d after planting to break up any soil crust that might have formed.

Parameters Evaluated

Plant residue cover was determined by a line-transect method. Immediately after planting, a measuring tape was stretched diagonally across each plot. Whether plant residue greater than 0.25 cm wide was touching the tape or not was determined every 30 cm. Residue cover was calculated by dividing the number of points having residue touching the tape by the total number of points evaluated.

Gravimetric soil water contents (SWC) were monitored approximately twice a week throughout most of each growing season with gypsum electrical conductivity blocks. Two sets of blocks were placed at soil depths of 23 and 46 cm at a location half way between crop rows (non-wheel-track row middles used) for both levels of row width treatment and at the same depths within the row of the plots having the 76-cm-row width. Only the plots which were not fall deep tilled but spring deep tilled were used to monitor SWC. Blocks were read between 0800- and 0900-h solar time. Soil temperature data were collected at each sampling depth and date with dial-type thermometers so the gypsum block readings could be corrected for differences in soil temperature. By means of a small growth chamber, a calibration curve of SWC versus block conductivity reading was made for every 2.8°C between 10 and 24°C.

Light interception by the crop canopy midway between rows was monitored about every 7 d throughout the 1995 growing season with an LI-191SA line quantum sensor connected to a LI-1000 Datalogger (LI-COR, Inc, Lincoln, NE). A quantum sensor was not available for data collection in 1994. Measurements were taken parallel to and midway between crop rows at two locations within each plot between 1130- and 1230-h solar time. Only the disked plots were used, and the same locations within each plot were used throughout the growing season. The plots with no surface tillage were not used since the wheat residues would have also intercepted light. Measurements were taken at the soil surface and above the canopy, and percent light interception was calculated by dividing the soil surface value by the above-canopy value.

Dates of initial flowering (R1 growth stage) and the beginning of seed fill (R5 growth stage) were determined in each plot according to the growth staging system described by Fehr et al. (1971). Growth stages were determined every other day on 10 randomly selected plants from each plot beginning about 4 d before each of those stages occurred.

Seed yield and yield components were determined by hand-harvesting six 1-m-long sections of crop row from the center rows (between wheel tracks) of each plot at harvest maturity (growth stage 8). The number of plants harvested in each plot was counted at the time of sampling. For the samples collected from the plots having no fall deep tillage, branches were separated from the main stem so the yield and yield components on the branch and mainstem portions could be determined separately. For all plots, the seed from each sample was threshed, cleaned, dried at 75°C for 48 h, and weighed. Individual seed weight was determined by counting, drying, and weighing 200 seeds from each sample. Seed number per square meter was calculated from the seed yield and seed weight data. Seed yield data were converted to a 130 g kg^{-1} water basis. Rainfall data were collected during the growing season at a weather station located about 200 m from the experimental field.

Statistical Analyses

All data collected in this 2 × 2 × 2 × 2 factorial experiment were subjected to analysis of variance as a randomized complete block design with four replications. Significance was set at the 0.05 probability level. Analysis of seed yield data over years showed significant year × treatment interaction effects. Therefore, data for each year were analyzed and reported separately. A LSD (0.05) was calculated for the seed yield and yield component data to compare interaction means when at least one interaction effect was significant at the 0.05 probability level. When the location effect was significant for the SWC data, a LSD (0.05) was calculated for evaluation of SWC differences between locations at the same level of surface tillage when the interaction effect was significant and for comparison of location means across levels of surface tillage when the interaction effect was not significant. Linear regression analysis was used to examine the relationship between seed yield and yield components. Regression analysis was conducted over treatments and years using plot values from each year. Significance was set at the 0.05 probability level.

RESULTS AND DISCUSSION

Residue Cover

Residue cover averaged 56 and 90% across years and treatments in the disked and no-surface-tillage plots, respectively (Table 1). There was less residue cover in the disked plots in 1995 than in 1994, which was associated with less wheat vegetative growth in 1995 (Frederick and Bauer, 1996). Across all treatments, deep tillage in the fall prior to wheat planting increased residue cover an average of 4% in 1995, although there was no fall-deep-tillage effect in 1994. In both years, spring deep tillage had no effect on residue cover in the disked plots but decreased residue cover by an average of 12% in the no-surface-tillage plots.

Table 1. Percentage of soil surface covered by residues after soybean planting as affected by row width culture, surface tillage, spring deep tillage, and fall deep tillage treatments in 1994 and 1995.

			Fall deep tillage			
		Spring	No		Yes	
Row width	Surface tillage	deep tillage	1994	1995	1994	1995
cm			%			
76	Disked	Yes	64	38	70	47
76	Disked	No	69	39	69	50
76	None	Yes	85	87	87	94
76	None	No	94	96	96	92
19	Disked	Yes	71	41	70	50
19	Disked	No	68	40	68	36
19	None	Yes	80	76	82	81
19	None	No	94	98	95	96
Treatment effects†			1994	1995		
Row width (RW)			NS	**		
Surface tillage (ST)			**	**		
Spring deep tillage (SDT)			**	**		
Fall deep tillage (FDT)			NS	**		
ST × SDT			**	**		
ST × FDT			NS	*		
LSD‡			5	4		

† Only treatment effects significant at 0.05 (*) or 0.01 (**) probability levels are listed.
‡ LSD (0.05) for comparison of interaction means.

Rainfall and Soil Water Conditions

Rainfall amounts during the soybean growing season were higher in 1995 than in 1994 until the R1 (initial flowering) growth stage (Fig. 1). Rainfall amounts after the R1 growth stage were lower in 1995 than in 1994, but still above normal in both years. Soil water contents at the 46-cm depth began to decrease near Day 40 in

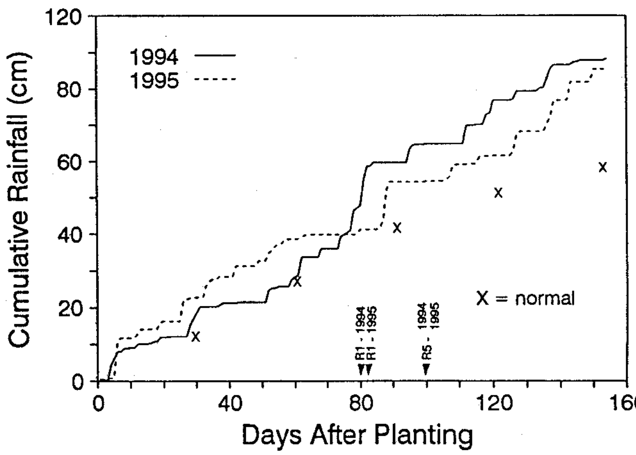

Fig. 1. Cumulative rainfall for the 1994 and 1995 growing seasons. The X symbols indicate normal cumulative rainfall, based on monthly 30-yr. averages (1951–1980). Arrows indicate average date of initial flowering (R1) and beginning of seed fill (R5) over all treatments in 1994 and 1995.

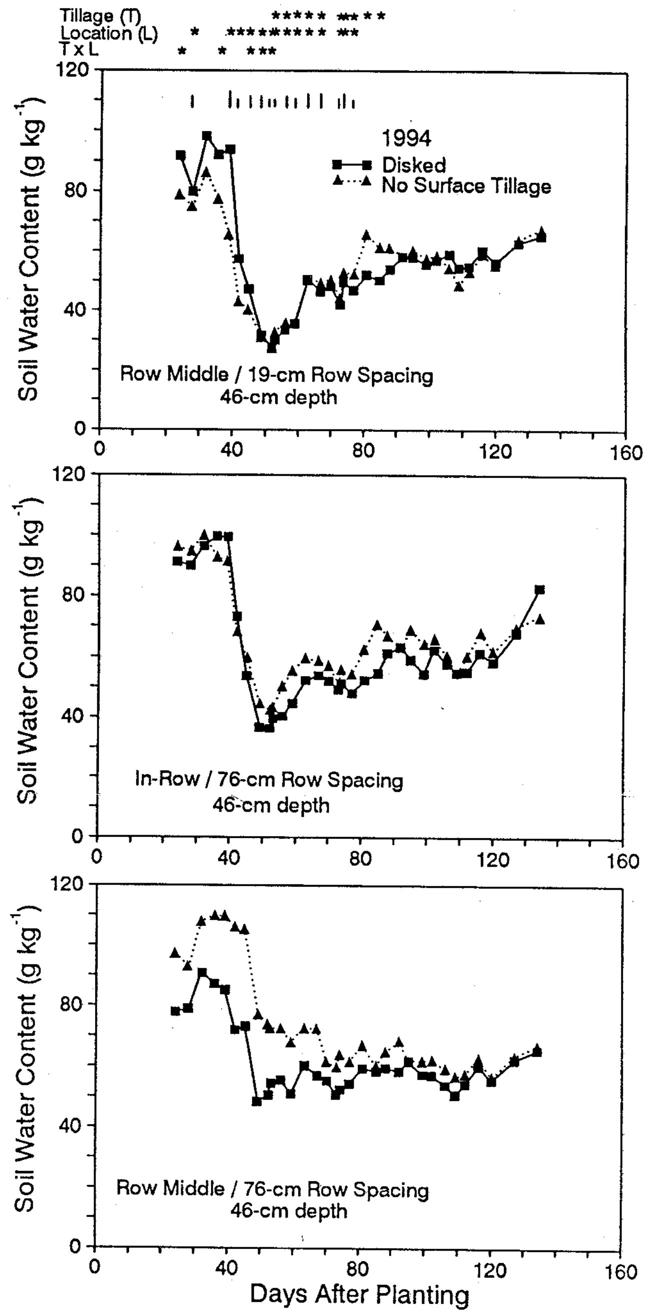

Fig. 2. Gravimetric soil water contents at the 46-cm depth measured in the row middle of the plots having the 19- and 76-cm-row widths and within the row of the plots having the 76-cm-row width in 1994. Asterisks above graph indicate dates the surface tillage (tillage) and location of measurement (location) effects were significant at the 0.05 probability level. Vertical lines are LSDs (0.05) for location comparsions at the same level of surface tillage when interaction effect was significant and for comparison of location means when interaction effect was not significant.

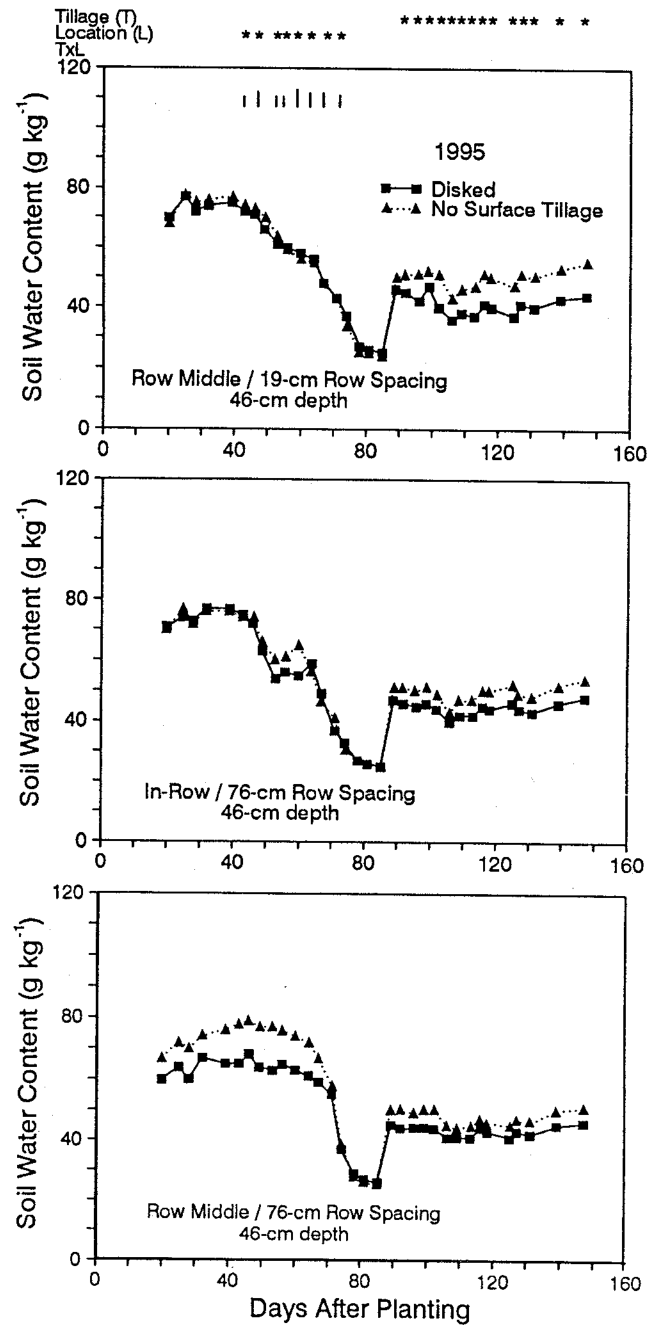

Fig. 3. Gravimetric soil water contents at the 46-cm depth measured in the row middle of the plots having the 19- and 76-cm-row widths and within the row of the plots having the 76-cm-row width in 1995. Asterisks above graph indicate dates the surface tillage (tillage) and location of measurements (location) effects were significant at the 0.05 probability level. Vertical lines are LSDs (0.05) for comparsion of location means.

both 1994 (Fig. 2) and 1995 (Fig. 3). Decreases in SWC occurred later midway between rows of the 76-cm-row width plots than midway between rows of the 19-cm-row width plots or within the row of the 76-cm-row width plots. This delay in SWC decrease midway between rows of the wide row width probably was due to fewer roots in that area early in the growing season than in the other two locations. On many measurement dates, SWC at the 46-cm depth were higher in the no-surface-tillage plots than in the disked plots at all three locations. Similar SWC differences were found at the 23-cm depth, except SWC were higher for the no-surface-tillage treatment only at the location midway between rows of the 76-cm-row width plots (data not shown).

Rainwater infiltration into the soil can be increased by surface residues (Bruce et al., 1987; Dick et al., 1987). Increased water infiltration due to surface residues may

Table 2. Doublecropped soybean seed yield as affected by row width culture, surface tillage, spring deep tillage, and fall deep tillage treatments in 1994 and 1995.

Row width	Surface tillage	Spring deep tillage	Fall deep tillage: No 1994	No 1995	Yes 1994	Yes 1995
cm			kg ha^{-1}			
76	Disked	Yes	2809	2278	2862	2090
76	Disked	No	2983	2130	2654	2096
76	None	Yes	3212	2056	3380	2143
76	None	No	2768	1713	3010	2103
19	Disked	Yes	4932	3346	4891	3736
19	Disked	No	3850	2775	4287	2688
19	None	Yes	5832	4092	6571	4844
19	None	No	4334	2788	5187	3722
Treatment effects†			1994	1995		
Row width (RW)			**	**		
Surface tillage (ST)			**	**		
Spring deep tillage (SDT)			**	**		
Fall deep tillage (FDT)			*	**		
RW × ST			**	**		
ST × SDT			*	NS		
ST × FDT			*	**		
RW × SDT			*	**		
RW × FDT			*	*		
LSD‡			314	234		

† Only treatment effects significant at 0.05 (*) or 0.01 (**) probability levels are listed.
‡ LSD (0.05) for comparison of interaction means.

explain why we found higher SWC with no surface tillage than with disking. A greater root density and, consequently, greater capacity for soil water uptake within or near the crop row, than in the row middle, may explain why there were little SWC differences between surface tillages within the crop row of the plots having the 76-cm-row width or in the row middle of the plots having the 19-cm-row width.

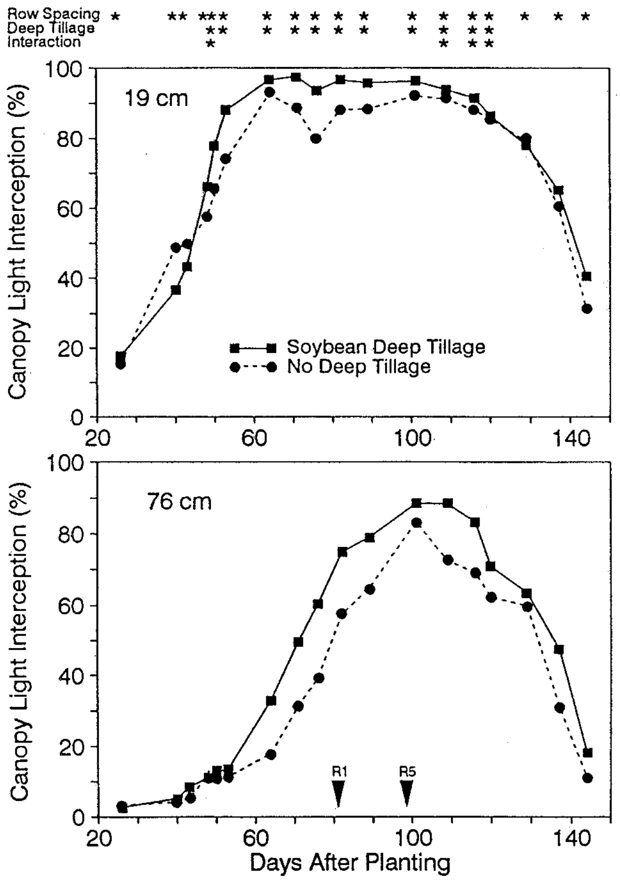

Fig. 4. Percent light interception by crop canopy midway between crop rows in 1995 as affected by row width and soybean deep tillage treatment. Arrows indicate average date of initial flowering (R1) and beginning of seed fill (R5) over all treatments. Asterisks above graph indicate dates treatment effects were significant at 0.05 probability level.

Seed Yield

Averaged across treatments, soybean grown with the narrow row width culture had a 68 and 69% higher seed yield than the soybean grown with the wide row width culture in 1994 and 1995, respectively (Table 2). Compared with the wide row width, the higher seed yield with the narrow row width was associated with greater canopy light interception and an almost 40 d earlier occurrence of maximum light interception (Fig. 4). These associations support the proposal that increased light interception is one of the main factors responsible for greater soybean yield in narrow- compared with wide row width culture (Board and Harville, 1992). The greater total seed yield with the 19- compared with the 76-cm-row width in our study was associated with a greater yield from both the mainstem and branch fractions with the 19-cm-row width (Table 3).

Compared with disking, planting with no surface tillage resulted in higher seed yields in both years, especially when the 19-cm-row width and deep tillage were used (Table 2). When deep tilled prior to planting both crops, soybean yields averaged across years were 10 and 30% higher in the no-surface-tillage plots than in the disked plots when the 76- and 19-cm-row widths were used, respectively. Higher seed yields with no surface tillage were entirely due to higher branch yields (Table 3). As for total yield, branch yield increases due to not disking were greater with the narrow row width than with the wide row width.

Yield increases due to fall or spring deep tillage were greatest when no surface tillage and the 19-cm-row width were used and were the least when the soil was disked and the 76-cm-row width were used (Table 2). Yield increases, when found, were due to an increase in yield from both the mainstem and branch fractions (Table 3). Spring deep tillage also increased canopy light interception in the row middle of both row widths throughout most of the growing season (Fig. 4).

The optimum timing of deep tillage depended on the row width and surface tillage used. For the soybean grown in the disked plots with the 76-cm-row width, there was little response to deep tillage in either year no matter when the plots were deep tilled (Table 2). For the soybean grown in the no-surface-tillage plots with the 76-cm-row width, deep tillage increased seed yields, but there were no consistent differences in the magnitude of the increase between the various times of deep tillage (fall, spring, or both). When the 76-cm-row width was used, soybean yields of the plots receiving no deep tillage were lower with no surface tillage than with disking, but were similar or higher with no surface

Table 3. Effects of row width culture, surface tillage, and spring deep tillage treatments on doublecropped soybean mainstem and branch seed yields in 1994 and 1995.

Row width	Surface tillage	Spring deep tillage	Mainstem yield 1994	Mainstem yield 1995	Branch yield 1994	Branch yield 1995
cm			kg ha^{-1}			
76	Disked	Yes	786	1297	2016	981
76	Disked	No	719	1156	2264	941
76	None	Yes	692	1054	2420	1001
76	None	No	652	887	2123	833
19	Disked	Yes	1639	2043	3292	1303
19	Disked	No	1438	1888	2405	894
19	None	Yes	1720	2217	4112	1868
19	None	No	1209	1680	3131	1109
Treatment effects†			1994	1995	1994	1995
Row width (RW)			**	**	**	**
Surface tillage (ST)			NS	NS	**	*
Spring deep tillage (SDT)			**	*	**	**
RW × ST			NS	NS	**	**
ST × SDT			NS	NS	*	NS
RW × SDT			**	NS	**	**
LSD‡			134	–	246	187

† Only treatment effects significant at 0.05 (*) or 0.01 (**) probability levels are listed.
‡ LSD (0.05) for comparison of interaction means.

tillage when the plots were deep tilled. Yields were higher for soybean grown in the disked plots with the 19-cm-row width if the deep tillage was done in the spring, compared with the fall. With these practices, there was no yield difference between deep tilling only in the spring and deep tilling both in the fall and spring. For soybean grown in the no-surface-tillage plots with the 19-cm-row width, the timing of deep tillage for highest seed yield was as follows: both fall and spring > spring > fall > no deep tillage.

Plant Population

Compared across all other treatments, the plots having the 19-cm-row width contained about twice the number of soybean plants per square meter as the plots having the 76-cm-row width in both years (Table 4). This plant number difference reflected the difference in seeding rate used for the two row widths. Differences in plant number per square meter between levels of surface tillage were greater with the 76-cm-row width than with the 19-cm-row width. Deep tilling before planting either wheat or soybean increased the number of soybean plants per square meter in 1994, but not in 1995. Averaged across treatments, plant numbers per square meter were 20% lower in 1994 than in 1995. Although data were not collected, many plants were observed to die during a period of drought stress which occurred between Days 30 and 50 after planting in 1994

Table 4. Doublecropped soybean plant number per m^2 measured at harvest maturity as affected by row width culture, surface tillage, spring deep tillage, and fall deep tillage treatments in 1994 and 1995.

Row width	Surface tillage	Spring deep tillage	Fall deep tillage: No 1994	No 1995	Yes 1994	Yes 1995
cm			m^{-2}			
76	Disked	Yes	20.4	29.3	22.4	29.0
76	Disked	No	18.3	28.2	21.1	29.6
76	None	Yes	20.4	22.4	21.7	23.8
76	None	No	15.8	21.9	15.8	21.7
19	Disked	Yes	44.6	53.8	44.7	54.5
19	Disked	No	43.2	54.0	49.1	51.4
19	None	Yes	41.2	49.2	43.7	53.1
19	None	No	32.5	44.6	40.6	53.1
Treatment effects†			1994	1995		
Row width (RW)			**	**		
Surface tillage (ST)			**	**		
Spring deep tillage (SDT)			**	NS		
RW × ST			*	**		
ST × SDT			**	NS		
ST × Fall deep tillage			NS	*		
LSD‡			2.6	2.4		

† Only treatment effects significant at 0.05 (*) or 0.01 (**) probability levels are listed.
‡ LSD (0.05) for comparison of interaction means.

Table 5. Doublecropped soybean total seed number per m^2 as affected by row width culture, surface tillage, spring deep tillage, and fall deep tillage treatments in 1994 and 1995.

Row width	Surface tillage	Spring deep tillage	Fall deep tillage: No 1994	No 1995	Yes 1994	Yes 1995
cm			m^{-2}			
76	Disked	Yes	1915	1795	1981	1626
76	Disked	No	2062	1663	1826	1622
76	None	Yes	2146	1596	2271	1635
76	None	No	1901	1387	2041	1613
19	Disked	Yes	3313	2580	3276	2789
19	Disked	No	2668	2161	3047	2058
19	None	Yes	3902	3101	4426	3589
19	None	No	2925	2214	3564	2872
Treatment effects†			1994	1995		
Row width (RW)			**	**		
Surface tillage (ST)			**	**		
Spring deep tillage (SDT)			**	**		
RW × ST			**	**		
ST × SDT			*	NS		
ST × Fall deep tillage			*	**		
RW × SDT			**	**		
RW × Fall deep tillage			*	*		
LSD‡			225	190		

† Only treatment effects significant at 0.05 (*) or 0.01 (**) probability levels are listed.
‡ LSD (0.05) for comparison of interaction means.

Table 6. Effects of row width culture, surface tillage, and spring deep tillage treatments on doublecropped soybean mainstem and branch seed number per m^2 in 1994 and 1995.

Row width	Surface tillage	Spring deep tillage	Mainstem seed 1994	Mainstem seed 1995	Branch seed 1994	Branch seed 1995
cm			m^{-2}			
76	Disked	Yes	549	1045	1366	749
76	Disked	No	515	925	1569	738
76	None	Yes	460	847	1686	749
76	None	No	451	725	1450	661
19	Disked	Yes	1118	1620	2195	960
19	Disked	No	1017	1475	1651	686
19	None	Yes	1152	1716	2750	1385
19	None	No	840	1337	2086	878
Treatment effects†			1994	1995	1994	1995
Row width (RW)			**	**	**	**
Surface tillage (ST)			NS	NS	**	*
Spring deep tillage (SDT)			**	*	**	**
RW × ST			NS	NS	**	**
ST × SDT			NS	NS	*	NS
RW × SDT			**	NS	**	**
LSD‡			99	–	174	148

† Only treatment effects significant at 0.05 (*) or 0.01 (**) probability levels are listed.
‡ LSD (0.05) for comparison of interaction means.

(Fig. 1). In contrast, little plant mortality was noted during that time period in 1995. The higher plant population with spring deep tillage in 1994 may have been due to deep tillage allowing greater root access to subsoil water, resulting in greater plant survival during the dry period which occurred in that year.

Seed Number per Square Meter

Treatment effects on seed number per square meter (Table 5) were the same as those reported for seed yield (Table 1). Averaged across treatments, 71 and 42% of the total seed number per square meter (Table 5) were produced on the branches (Table 6) in 1994 and 1995, respectively. Across all treatments and years, total seed number per square meter was significantly correlated with branch seed number per square meter (r = 0.80), but not so with mainstem seed number per square meter (r = 0.42). Increases in total seed number per square meter, because of fall or spring deep tillage and because of no surface tillage, were greater when the 19-cm-row width was used. A higher total seed number per square meter with the 19-cm-row width, compared with the 76-cm-row width, was associated with a higher seed number from both the main stem and branch fractions, although row width differences were greater for mainstem seed number (Table 6). In both years, spring deep tillage had a greater positive effect on seed number from both the branch and mainstem fractions when the narrow row width was used. Total seed number per square meter was greater for the soybean in the no-surface-tillage plots than for the soybean in the disked plots because of more branch seeds per square meter for the soybean in the no-surface-tillage plots. Averaged across treatments, mainstem seed number per square meter was 37% lower in 1994 than in 1995. On the other hand, branch seed number per square meter was 117% higher in 1994 than in 1995. A period of drought stress began to occur near Day 60 after planting in 1995 (Fig. 1), when significant branch growth was first observed. Reduced branch growth due to drought stress in 1995 would explain the lower branch seed number in 1995 than in 1994.

Individual Seed Weight

Individual seed weights on a whole plant, main stem, or branch basis are shown in Table 7. There was little relationship between seed yield and individual seed weight (r = 0.52). Deep tilling prior to soybean planting resulted in an increase in individual seed weight in 1994, especially for the soybean grown with the 19-cm-row width. This increase was the result of deep tillage increasing the weight of seed produced on both the main stems and branches. In 1995, deep tillage only increased the weight of the branch seeds. Low soybean seed weights are often found when a high number of seeds is set (Frederick and Hesketh, 1993). However, this inverse relationship was not consistently found in our study (r = 0.50). Rainfall (Fig. 1) and soil water conditions (Fig. 2 and 3) were good during seed fill in both years of our study, which may have favored relatively long seed-filling periods and high seed weights.

Summary and Conclusion

Seed yields were higher for the soybean grown with the 19-cm-row width culture than for soybean grown with the more conventional, 76-cm-row width culture. Although less yield per plant was found with the 19-cm-row width than with the 76-cm-row width (data not presented), the greater plant population with the 19-cm-row width more than compensated for the lower yield per plant. Rainfall was near to above normal in both years, which may have been conducive to high yields with the narrow row width culture.

Soil water depletion was more rapid in the plots having the 19-cm-row width than in the plots having the 76 cm-row width, suggesting that the severity and/or duration of drought stress may be greater in doublecropped soybean produced with narrow row width culture. Production practices that improve soil water

Table 7. Doublecropped soybean individual seed weight as affected by row width culture, surface tillage, and spring deep tillage treatments in 1994 and 1995.

			Whole plant		Main Stem wheat deep tillage		Branches	
			Yes		No		No	
Row width	Surface tillage	Spring deep tillage	1994	1995	1994	1995	1994	1995
			mg					
76	Disked	Yes	126	112	124	108	128	114
76	Disked	No	127	113	126	110	125	111
76	None	Yes	129	114	131	109	130	116
76	None	No	129	114	126	107	127	110
19	Disked	Yes	130	118	128	110	130	119
19	Disked	No	123	114	124	111	127	113
19	None	Yes	129	118	130	113	130	118
19	None	No	125	115	125	110	131	110
Treatment effects†			1994	1995	1994	1995	1994	1995
Surface tillage (ST)			*	NS	NS	NS	NS	NS
Soybean deep tillage (SDT)			*	NS	*	NS	*	**
RW × SDT			*	NS	NS	NS	NS	NS
LSD‡			3	–	–	–	–	–

† Only treatment effects significant at 0.05 (*) or 0.01 (**) probability levels are listed.
‡ LSD (0.05) for comparison of interaction means.

conditions during the growing season, such as deep tillage and conservation tillage, may reduce the risk of substantial yield loss due to drought stress when producing soybean in narrow row width culture. Our data support this theory. Seed-yield increases due to deep tillage and no surface tillage were greater for the soybean grown with the 19-cm-row width than for the soybean grown with the 76-cm-row width.

The optimum time of year to deep till for maximum doublecropped soybean yield depended on the row width and surface tillage used. When planted with no surface tillage in 19-cm-row widths, highest soybean yields were obtained when deep tillage was done in the fall and again in the spring before soybean planting. Deep tillage once a year was usually sufficient for the other treatments, although we found little yield response to deep tillage when the soybean was grown with the 76-cm-row width and the plots were disked. Results from this study indicate a potential to substantially increase doublecropped soybean yields on the southeastern Coastal Plain with the use of narrow row widths, conservation tillage, and deep tillage practices.

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REFERENCES

Board, J.E., and B.G. Harville. 1992. Explanations for greater light interception in narrow- vs. wide-row soybean. Crop Sci. 32:198–202.

Bruce, R.R., S.R. Wilkinson, and G.W. Langdale. 1987. Legume effects on soil erosion and productivity. p. 127–138. *In* J.F. Power (ed.) Role of legumes in conservation tillage systems. Soil Conserv. Soc. Am., Ankeny, IA.

Busscher, W.J., R.E. Sojka, and C.W. Doty. 1986. Residual effects of tillage on Coastal Plain soil strength. Soil Sci. 141:144–148.

Crutchfield, D.A., G.A. Wicks, and O.C. Burnside. 1985. Effect of winter wheat straw mulch level on weed control. Weed Sci. 34: 110–114.

Dick, W.A., D.M. Van Doren, Jr., G.B. Triplett, Jr., and J.E. Henry. 1987. Influence of long-term tillage and rotation combinations on crop yields and selected soil parameters: I. Results obtained for a Mollic Ochraqualf soil (Res. Bull. 1180). Ohio State Univ. Res. and Dev. Ctr., Wooster, OH.

Fehr, W.R., C.E. Caviness, D.T. Burmood, and J.S. Pennington. 1971. Stage of development descriptions for soybean, *Glycine max* (L.) Merrill. Crop Sci. 11:929–931.

Frederick, J.R., and P.J. Bauer. 1996. Winter wheat responses to surface and deep tillage on the southeastern Coastal Plain. Agron. J. 88:829–833.

Frederick, J.R., and J.D. Hesketh. 1993. Genetic improvement in soybean: physiological attributes. *In* G.A. Slafer (ed.) Genetic improvement of field crops. Marcel Dekker, New York.

Greb, B.W. 1966. Effect of surface-applied wheat straw on soil water losses by solar distillation. Soil Sci. Soc. Am. Proc. 30:786–788.

Khalilian, A., C.E. Hood, J.H. Palmer, T.H. Garner, and G.R. Bathke. 1991. Soil compaction and crop response to wheat/soybean interseeding. Trans. ASAE 34:2299–2303.

Langdale, G.W., W.L. Hargrove, and J. Giddens. 1984. Residue management in double-crop conservation tillage systems. Agron. J. 76:689–694.

Langdale, G.W., R.L. Wilson, Jr., and R.R. Bruce. 1990. Cropping frequencies to sustain long-term conservation tillage systems. Soil Sci. Soc. Am. J. 54:193–198.

Langdale, G.W., A.P. Barnett, R.A. Leonard, and W.G. Fleming. 1979. Reduction of soil erosion by the no-till system in the southern Piedmont. Trans. ASAE 22:82–86.

Mills, W.C., A.W. Thomas, and G.W. Langdale. 1986. Estimating soil loss probabilities for southern Piedmont cropping-tillage systems. Trans. ASAE 29:948–955.

NeSmith, D.S., W.L. Hargrove, D.E. Radcliffe, E.W. Tollner, and H.H. Arioglu. 1987. Tillage and residue management effects on properties of an Ultisol and double-cropped soybean production. Agron. J. 79:570–576.

Palmer, J.H., and C. Privette. 1992. Guidelines for drilling soybeans. Soybean Leaflet no. 9. Clemson Univ. Coop. Ext. Serv.

Pearce, R.C., L.J. Grabau, J.H. Grove, and H. Lin. 1993. Development of double-crop soybean under different water regimes. Agron. J. 85:576–583.

Putnam, A.R., J. DeFrank, and J.P. Barnes. 1983. Exploitation of allelopathy for weed control in annual and perennial cropping systems. J. Chem. Ecol. 9:1001–1010.

Sanford, J.O., B.R. Eddleman, S.R. Spurlock, and J.E. Hairston. 1986. Evaluating ten cropping alternatives in the Midsouth. Agron. J. 78:875–880.

Shipe, E.R., J.D. Mueller, S.A. Lewis, H.L. Musen, and P.F. Williams, Jr. 1991. Registration of 'Hagood' soybean. Crop Sci. 32:829–830.

Wilhelm, W.W., H. Bouzerzour, and J.F. Power. 1989. Soil disturbance-residue management effect on winter wheat growth and yield. Agron. J. 81:581–588.