Soil and Plant Growth Response to Interseeding and Double-Cropping Systems

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INTRODUCTION

Two of the most promising methods for increasing crop water use efficiency and reducing costs of double-cropping while protecting the environment are relay intercropping and reduced tillage. Interseeding or relay intercropping of soybean into standing wheat has been investigated by a number of researchers (Wendte and Nave, 1979; Chan et al., 1980; Reinbott et al., 1987; Buehring et al., 1990; Hargrove and Ford, 1990; Hood et al., 1990; Khalilian et al., 1990). Where successful interseeded stands of soybean were established, a general conclusion was that wheat and soybean yields were reduced as much as 20% of conventional full-season yield. However, intercropped soybean always equaled or outperformed conventional double-cropped soybean. Using a cropping system with controlled traffic patterns and deep tillage in the fall, Hood et al. (1990) found that interseeded soybean (1987-1990) yielded significantly higher than those double-cropped with a wide-row (97-cm) no-till planter after wheat harvest. They found wheat yields were not affected by interseeding in the Coastal Plain test location. Khalilian et al. (1990) found that deep tillage effects from para-plowing before wheat planting persisted and benefitted the interseeded soybean. Eliminating subsoiling just before soybean planting resulted in a savings of $8 to 10 per acre (Khalilian et al., 1988).

While these studies surveyed the agronomic feasibility of intercropping, few investigated changes in the soil physical environment to explain the crop performance differences. Khaliiian et al. (1990) found distinct differences in soil compaction patterns under interseeded vs. conventional double-cropped systems. Mechanical impedance was highest in the traffic lanes for the interseeded system but was very low in the plant growth zone. Uncontrolled traffic in the double-cropped system caused compaction in areas where plants were growing, resulting in shallower and smaller root systems. Soil moisture utilization was observed to be best with the interseeded plots but was not monitored closely enough to compare treatments.

Many of the important agricultural soils in the Atlantic Coastal Plain have compacted layers primarily in the E horizon but may extend upward into the base of the Ap horizon. Yields of crops grown on sandy Coastal Plains soils are frequently reduced due to the presence of hardpans, which prevent root acquisition of subsoil moisture and nutrients (Smittle et al., 1977). Soil physical properties that have been found to correlate with crop yield response to deep tillage may be associated with the soil water retention characteristics or propensity of the soil for hardpan formation (Simmons et al., 1989). Conservation tillage cropping systems can be used to enhance subsoil water accumulation and delay recompaction of the E horizon. Busscher and Sojka (1987) found that a conventional tillage treatment (which included disking and numerous trips over the field) left many areas of the field with higher soil strength, which inhibited root growth, while a reduced tillage system resulted in a more even distribution of soil penetration resistance across the field.

MATERIAIS AND METHODS

Field experiments with various double-crop rotation systems were established at the Edisto Research and Education Center at Blackville, South Carolina, on a Varina loamy sand (clayey, kaolinitic, thermic Plinthic Paleudult; Rogers, 1977). Test 1, initiated in 1987, used five cropping systems (Table 1) in a randomized complete block design with six replications. Test 2, initiated in the fall of 1990, used a randomized complete block design with four replications to compare "conventional" interseeding (Table 1; treatment 3 fall disking 12 cm deep followed by a four-shank paratill with a 51-cm spacing operating 33 cm deep, wheat planted with the Clemson interseeder, no spring tillage and soybean planted with the Clemson interseeder following the diagram in Fig. 1) and conventional double-cropping (Table 1; treatment 5: fall tillage with a tandem disk operating 12 cm deep and a 30-cm-spaced, eleven-shank chisel plow operating 28 cm deep, wheat planted with a grain drill in 20-cm rows, spring tillage of subsoiling at planting with a 96-cm-

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Table 1. Tillage/planting treatment combinations.

Treatment	Tillage before wheat			Wheat planting method		Tillage before soybean	Soybean planting method	
no.	Disk	Ch'	Para	Clem	Drill	Para	Clem	KMC/Sub
1	x			x			x[2]	
2	x	x		x			x[2]	
3	x		x	x			x[2]	
4	x		x	x		x	x3	
54	x	x			x			x3

[1]Ch = chisel plow; Para = paratill; Clem = Clemson interseeder; Drill = conventional grain drill with 20-cm rows; KMC/sub = KMC subsoiler-planterwith 96cm rows.
[2]Mid-May soybean interseedingdate.
[3]Soybean planted in June after wheat harvest.
[4]Conventional doublecropping method for wheat and soybean in Coastal Plain soils

spaced KMC subsoiler/planter). Test 2 will also include monocropped soybean **as** a summer crop.

Coker 9766 wheat was planted at 100 kg seed/ ha in late November immediately after tillage. Kirby soybean was interseeded at 67 kg seed/ha between rows of standingwheat in mid-May (Table 1).Wheat from all plots was harvested the first week of June and soybean planted in the remaining treatments (Table 1).Fertilizer was applied based on soil analysis and broadcast before fall tillage and in the spring as topdress application as needed. Post-emergence herbicides were applied as needed. A conventional combine with a 4-m-wide header was used to harvest the crops.

A microcomputer-based, tractor-mounted recording penetrometer was used to assess in-situ mechanical impedance of the soil profile in a transect extending from the wheel traffic lane to the fourth row as indicated by asterisks in Fig. 1. The location of the penetrometer readings are indicated as tire, row 1, and row 2, respectively, in Tables 2, 5, 6 and 7. Soil compaction values were calculated from the measured force required to push a 3.2-cm2 basal area, 30° cone into the soil. Immediately after penetrometer data were recorded, undisturbed soil samples were taken with Uhland sampler attached to the hydraulic coring device. Each soil core was trimmed flush with the ends of the aluminum ring, capped at both ends, placed in a plastic bag and stored at 4 C until analysis. The core was then slowly saturated with water, and saturated soil hydraulic conductivity (KSAT) was measured using a constant-head permeameter with a hydraulic gradient of 1.8 cm/cm (Klute and Dirksen, 1986). The core was oven dried at 105 C and weighed for bulk density (BD) determination.

Plant shoot and root growth parameters were assessed following soybean harvest in 1990 and 45 days after planting wheat. Root samples were taken within one day of penetrometer measurements in 1990 and 1991. Soil cores 7.5 cm in diameter were taken in trafficked and nontraflicked areas in 15-cm increments to a depth of 45 cm with a tractor-mounted hydraulic probe. The cores were washed and sieved on a Gillison hydropneumatic elutriator, and the roots were measured using a modified Delta-T area meter (Harris and Campbell, 1989). Each sample was oven dried to determine root dry weight. Analysis of variance procedures were performed using the Statistical Analysis System (Ray, 1982). The error term used to test significance for each effect was the block (rep) x effect interaction for that effect.

RESULTS AND DISCUSSION

Cone index values before tillage indicated that the field had a hardpan in the E horizon at a depth of 22 to 30 cm in the soil profile. In Test 1, deep tillage significantly reduced penetration resistance compared to disked plots in the 0- to 15-cm and the 30- to 45-cm soil layers for non-traffic rows (Table 2). At the 15- to 30-cm depth of the row locations, KMC subsoiler/planter and paratill treatments significantly reduced penetration resistance of the hardpan layer compared to chiseled and disked plots. There were no significant differences in penetrometer measurements between plots paratilled once in the fall compared to those using a second deep tillage operation (paratill or subsoiler) prior to planting soybean. Cone index values for these plots were less than 1000 kPa in the top 30cm of soil (Table 2). For the row locations the highest soil compaction values were found in the E horizon, although compaction effects were also noted for the 30- to 45-cm layer. Cone index values were high enough to restrict root penetration into the B horizon (Table 3) and reduce crop yield (Table 4). Cone index val-

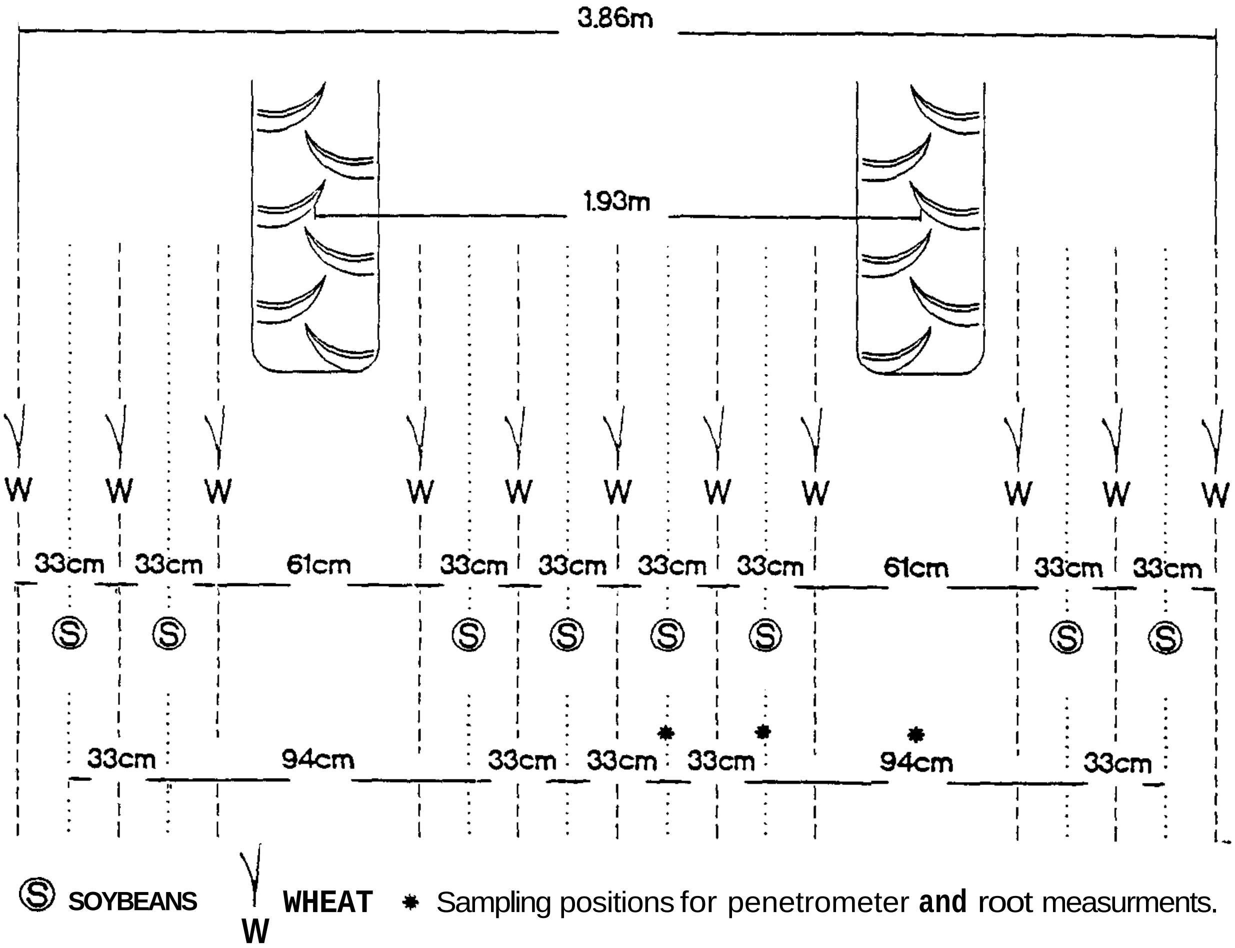

Fig. 1. The intercropping planting pattern for wheat and soybean.

ues above 1000 kPa generally reduce crop yield, and values above 2000 kPa stop root growth (Taylor and Gardner 1963; Carter and Tavernetti 1968).

Traffic significantly increased penetrometer resistance compared to the plant row areas in Test 1 (Table 2). The wheel traffic lanes in all plots were highly compacted with the only significant differences found between the chisel/subsoiler and the disk-only treatment, with the E horizon showing no differences. There were no significant differences in penetrometer readings between wheel traftic lanes and soybean row zones in the disked plots except in the top 15 em of soil (Table 2).

Saturated soil hydraulic conductivity (KSAT) and BD were affected by tillage treatments in Test 1 (Table 5). At the 2.5- to 10-cm depth (A horizon), KSAT differed between row positions for most tillage treatments and between tillage treatments at the row adjacent to the traffic lane. Limited differences were found for KSAT in the E horizon (23- to 30.5-cm depth). Tillage treatments had no effect on BD for the A horizon, but differences were found

Table 2. Penetration resistance at soybean harvest as affected by tillage and traffic eleven month8 after fall tillage, 1990.

Tillage		Cone index (kPa)								
		015 cm depth			15-30 cm depth			30-45 cm depth		
Fall	Spring	Row 1[1]	Row2	Tire	Row 1	Row2	Tire	Row 1	Row 2	Tire
Disk	None	877a[2]	884a	1875a	1973a	2058a	2211a	1788a	1696a	2172a
Chisel	None	458ab	391b	1978ab	1142b	1086b	1892a	1594a	1288b	2012ab
Paratill	None	441b	380b	1820ab	841c	730c	1679a	1264b	1261b	2070ab
Paratill	Paratill	456b	428b	1807ab	912c	650c	1820a	1340b	1400b	2008ab
Chisel	Subsoiler	335b	--	1564b	750c	--	2058a	1354b	--	1757b

[1]Tire = wheel traffic lane; Row 1 = row adjacent to traffic lane; Row 2 = row farthest from traffic lane.

[2]values in a column followed with the same letter are not significantly different (Duncan's Multiple Range Test, α = 0.05).

Table 3. Soybean root lengthand dryweight at soybean harvest as affected by Ullage, 1990.

Tillage		0-15 cm depth		15-30 cm depth		30-45 cm depth	
Fall	Spring	wt	length	wt	length	wt	length
		9	mm	g	mm	g	mm
Disk	None	2.59[1]	5060	0.07	380	0.07	470
Chisel	None	2.54	5230	0.24	890	0.17	1380
Paratill	None	1.64	4570	0.16	1170	0.11	980
Paratill	Paratill	2.06	3400	0.13	1110	0.12	930
Chisel	Subsoiler	2.80	4500	0.75	2230	0.15	1260
$LSD_{0.05}$		NS[2]	NS	0.39	1010	NS	700
CV (%)		46	36	149	80	73	59

[1]Values are averaged over two row positionsfor each plot.
[2]NS = nonsignificant.

Table 4. Crop yield response (kg/ha) to tillage systems.

Tillage		Planter		Wheat		Soybean	
Wheat	Soybean	Wheat	Soybean	1989	1990	1989	1990
Disk	None	Clem.[1]	Clem.[2]	2465b[3]	3112C	1810b	1368b
Chisel	None	Clem.	Clem.[2]	2992a	3346bc	1973ab	1478ab
Paratill	None	Clem.	Clem.[2]	3092a	3718ab	2242a	1704a
Paratill	Para.	Clem.	Clem.[4]	3161a	3908a	1723b	1672a
Chisel	Subsoil	Drill	KMC[4]	3089a	3246bc	1570b	1471ab

[1]Clem. = Clemson interseeder; Drill = conventional grain drill with 20-cm rows; KMC = KMC subsoiler-planterwith 96-cm rows.
[2]Mid-May soybean interseeding date.
[3]Values in a column followed with the Same letter are not significantly different (Duncan's Multiple Range Test, $\alpha = 0.05$).
[4]Soybean planted in June after wheat harvest.

Table 5. Response of roll properties to tillage systems as measured after soybean harvest, Nov.1990.

Tillage		2.510 cm depth				23-30.5 cm depth			
Fall	Spring	Tire[1]	Row 1	Row2	Row $LSD_{.05}$	Tire	Row1	Row 2	Row $LSD_{.05}$
Saturated soil hydraulic conductivity (cm/hr)									
Disk	None	0.53	1.93	1.40	0.80	0.23	0.11	0.24	NS[2]
Chisel	None	0.42	2.17	1.81	0.77	0.11	0.39	0.i9	0.21
Paratill	None	0.33	1.60	1.60	NS	0.42	0.53	1.03	NS
Paratill	Paratill	0.24	1.71	0.76	0.92	0.25	0.52	0.47	NS
Chisel	Subsoiler	0.38	2.80	–	1.30	0.12	0.39	–	NS
Tillage $LSD_{.05}$		NS	1.04	NS		NS	NS	0.64	
Soil bulk density (Mg/m3)									
Disk	None	1.70	1.40	1.41	0.11	1.67	1.75	1.69	NS
Chisel	None	1.74	1.38	1.37	0.12	1.68	1.66	1.71	NS
Paratill	None	1.72	1.45	1.37	0.12	1.69	1.43	1.49	0.25
Paratill	Paratill	1.78	1.44	1.50	0.20	1.68	1.60	1.50	NS
Chisel	Subsoiler	1.75	1.41	–	0.14	1.77	1.66	–	NS
Tillage $LSD_{.05}$		NS	NS	NS		NS	0.28	0.11	

[1]Tire = wheel traffic lane; Row 1 = row adjacent to traffic lane; Row 2 = row farthest from traffic lane.
[2]NS = nonsignificant.

between the traffic lane and the crop rows. In the E horizon, the paratill treatments had lower BD in rows 1 and 2 compared to the other tillage treatments, with the BD of the single paratill operation higher than the BD of the double paratill treatment for row 1, but not for row 2. The traffic lanes in all treatments had the lowest KSAT and highest BD, with no differences found between tillage systems (Table 5). For the row positions, the A horizon had higher KSAT and lower BD than the E horizon almost without exception. In the traffic lanes there were no significant differences in KSAT or BD between soil depths, as the overburden pressure from the equipment was evidently distributed over the coarse-textured A and E horizons.

For Test 1, no significant differences in root length and dry weight were measured in the top 15 cm of soil for soybean root samples after soybean harvest (Table 3). However, at the 15- to 30-cm depth, a difference between deep and shallow tillage treatments was observed in root length and weight. A difference was observed in root weight at the 30- to 45-cm depth. Roots were better able to penetrate the E horizon (15- to 30-cm depth) in plots where deep tillage was performed. Root length increased as soil compaction decreased, with a threshold cone index for reduction in root growth near 1000 kPa for this soil. Khalilian et al. (1988) found a similar correlation between soybean tap root length and soil cone index.

For Test 1, cropping systems incorporating deep tillage (paratill, chisel, subsoiler) produced higher wheat and soybean yields than systems in which disking was the only tillage (Table 4). The paratill treatments tended to produce higher wheat and soybean yield than the other tillage treatments. There was no significant difference in yield between chisel plow plots planted with the Clemson interseeder (33-cm rows) and those planted with a conventional grain drill (20-cm rows) using the same seeding rate. Comparison of interseeded and doubled-cropped plots indicated that interseeding soybean between rows of standing wheat did not reduce wheat yields. Interseeding soybean into standing wheat produced higher soybean yield compared to those planted after wheat harvest for each tillage system (Table 4). Deep tillage before wheat significantly increased soybean yields compared to disked treatments. Due to the controlled traffic patterns provided by the interseeding system, deep tillage before small grain planting carried over and benefitted soybeans. The paratill treatment was the optimum deep tillage operation, and the mid-May planting date was the best time for planting.

For Test 2, which compared "conventional" interseeding vs. double-cropping early in the cropping season, KSAT and BD did not differ between cropping systems, but some differences did exist between trafficked and non-trafficked row positions (Table 6). Rows 1 and 2 had significant differences between soil depths, but the effect of traffic excluded any differences between soil depths in the tire track. The paratill treatment had more consistent differences between row positions than the chisel/disk system. In the A horizon of the traffic lane, the interseeded system had lower KSAT and higher BD, though not significantly different.

With few soil property differences evident, measured root growth parameters did not show any treatment effects at this early stage of plant growth either (Table 7). These values were composites of three 15-cm sampling depth increments (no significant differences between treatments at any depth, data not shown). There were no differences between row 1 and row 2 for root or shoot growth. Shoot weight was significantly different for cropping systems, with the interseeded system having almost twice as much growth (Table 7).

Table 6. Response of soil properties to Ullage systems as measured on 15 January 1991, 45 days after wheat planting.

Tillage	Planting svstem	2.5-10 cm depth				2530.5 cm depth			
		Tire[1]	Row 1	Row2	Row LSD$_{.05}$	Tire	Row 1	Row2	Row LSD$_{.05}$
Saturated soil hydraulic conductivity (cm/hr)									
Paratill	Interseed	0.05	0.30	0.26	0.23	0.03	0.19	0.10	0.15
Chisel, disk	Grain drill	0.20	0.28	0.37	NS[2]	0.03	0.15	0.04	NS
Tillage LSD$_{.05}$		NS	NS	NS		NS	NS	NS	
Bulk density (mg/m^3)									
Paratill	Interseed	1.84	1.68	1.68	0.11	1.87	1.89	1.83	NS
Chisel, disk	Grain drill	1.79	1.66	1.64	NS	1.84	1.88	1.82	NS
Tillage LSD$_{.05}$		NS	NS	NS		NS	NS	NS	

[1]Tire = wheel traffic lane; Row 1 = row adjacent to traffic lane; Row 2 = row farthest from traffic lane.
[2]NS = nonsignificant.

Table 7. Response of wheat growth to tillage systems as measured on 15 Jan 1991, 45 days after wheat planting.

Tillage	Planting system	Shoot wt		Root wt		Root length	
		Row 1[1]	Row 2	Row 1	Row 2	Row 1	Row 2
		(g/30 cm row)		(g/0.5 l soil)		(mm/0.5 l soil)	
Paratill	Interseed	28.1	28.4	0.47	0.43	6607	5524
Chisel, disk	Grain drill	13.2	15.7	0.38	0.24	6376	4644
Tillage LSD$_{.05}$		6.5	5.6	NS[2]	NS	NS	NS

[1]Row 1 = row adjacent to traffic lane; Row 2 = row farthest from traffic lane.
[2]NS = nonsignificant.

This indicates that one deep tillage operation in the fall to disrupt root-inhibiting hardpans, in conjunction with controlled traffic, could eliminate the need for an additional deep tillage in the spring for soybean in Coastal Plain soils. The controlled traffic approach to managing a field was very evident in the comparison of the interseeded system with the double-cropped system. Soil properties were much more homogeneous between the sample locations (tire, row 1, row 2) in the double-cropped system than in the interseeded system. This homogeneity of soil properties is not advantageous when the needs for vehicle operations and crop growth are considered. Traffic lanes should be managed for vehicle load bearing capacity, which would manifest itself in higher BD and lower KSAT and higher cone index values. Crop growth areas would require just the opposite for optimum root growth and the availability of water and nutrients. Interseeding incorporates the advantages of reduced tillage with the added benefits of better utilization of the long growing season for double-cropping soybean and reduced energy requirements for equipment operation. Based on preliminary results, the use of pesticides may also be reduced by using an interseeded cropping system.

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