Long-term effects of two tillage systems on soybean (Glycine max (L.) Merrill) (var. Forrest) production, soil properties and plant nutrient uptake

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Abstract
Zero-tillage (no-tillage, NT) system of crop production is attractive to farmers because of savings in fuel, labor and machinery, increased potential for double-cropping, reduced soil erosion, reduced environmental pollution, and various other advantages. To compare two tillage systems --- NT and conventional tillage (CN) --- as to their influence on soybean (*Glycine max* (L.) Merrill var. Forrest) production, soil properties and nutrient uptake, an eight-year field study was conducted at a university (USA) research farm on a Byler silt loam soil (Typic Fragiudalf). Soybean grain yields in NT were comparable to those in CN. At the conclusion of the study, organic matter (OM) levels were higher in NT. NT surface-soil evidenced a tendency to be acidic. Generally, surface accumulations of nutrients in NT did not occur. With the exception of seed nitrogen, plant nutrient-uptake remained uninfluenced by tillage; seed nitrogen tended to be higher in NT. It is estimated that with comparable soybean yields expected in NT, potential savings in fuel and labor should more than make up for the possible added equipment and chemical (herbicide) cost, and potential lime costs to ameliorate possible increased acidity in long-term no-tillage.

Key Words
No-till, conventional tillage, soil properties, nutrient uptake, soil pH, organic matter.

Introduction
Zero-tillage (no-tillage, NT) systems for crop production are generally more economical with equal, or even slightly reduced, crop yields in NT. Due to its potential for double-cropping, for reduced soil erosion, for reduced environmental pollution, and due to savings in fuel, labor and machinery upkeep, NT is generally attractive to farmers and is becoming increasingly popular. The objectives of this research were to determine the influence of two tillage systems (Conventional (CN) and no-till (NT) on: (1) the performance and yield of soybean (*Glycine max* (L.) Merrill) (var. Forrest), (2) on soil pH and soil organic matter (OM), and (3) on the dynamics of soil-nutrients, and plant-uptake of these nutrients.

Methods
Field treatments and general management
Starting in the year 1980, this field-plot research was conducted for 8 years at the Tennessee State University (USA) Agriculture Research and Extension Center ($36^0$9'9"N, $86^0$48'0"W) on a Byler silt loam soil (Typic Fragiudalf). An uncultivated old sod-field was utilized for the study in the first year. The site had a 5% land slope and is classified as moderately well-drained. Initial surface (15 cm) soil pH was 6.4. The same plots were used for eight years for the following treatments without re-randomization. No further soil amendments or lime applications were made, except the below-noted fertilizer treatments. The two tillage systems (CN and NT) were "main" plots in a split-plot statistical design with four replications. The main plots measured 29x4.6m and the subplots were 4.6x4.6m. Conventional tillage consisted of plow/disc and plant; the NT comprised of either glyphosate (N-(phosphonomethyl) glycine) or paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) application, and planting with a no-till planter. The "splits" comprised of three herbicides in the first 4 years. Five potassium (K) rates (0, 45, 90, 135, and 180 kg K_2O/ha) were superimposed on the main tillage plots during the last 4 years of the study. Fertilizers were surface-applied. 'Forrest' soybeans were planted in eight rows 51 cm apart with a 'Cole' Model 400 no-till planter.

At the end of 4^{th} season, soil cores (20 mm diameter) were taken in 5-6 randomly chosen areas from all plots and separated into 0-2.5, 2.5-5, 5-10, and 10-15 cm depths. The cores from each plot were combined by depth. Precipitation was recorded from near-field gauges on the experimental site; temperature data reported were obtained from the National Oceanic and Atmospheric Administration's National Weather Station in Nashville, TN about 20 km away from the experimental site.

Data collection and analyses

Soybean growth characteristics (plant height, plant vigor, root-lodging, and leaf senescence were measured or visually estimated for each treatment plot. Soybean plant counts were taken at the time of crop harvest. Except in the year 1984, which was a crop failure, soybean crop was hand-harvested at maturity from the middle four rows of each plot each year of the study. Soil pH, organic matter, and soil N, P, K, Ca, and Mg, as well as seed and leaf nutrient-uptake by soybeans were determined at the end of the first four years of study. Analysis of Variance was performed to determine main plot, subplot, and interaction effects using GLM in SAS (SAS Institute 2004).

Results

Growth/Yield

The 1984 crop season was unusually dry, resulting in crop failure. The 1980, 1982 and 1986 years experienced below normal precipitation as well. These conditions were reflected in grain yields in these years (Table 1). Tillage x year interactions were insignificant for soybean plant population counts and for general plant growth characteristics (vigor, height) measured (data not shown). The grain yields in the normal and above normal rain years ranged from 2201 to 3074 kg/ha. Herbicide x tillage and fertilizer x tillage interactions were insignificant (p=0.05) for the yields; thus, these were averaged over the three herbicide treatments and the four fertilizer rates. Comparable grain yields resulted from the two tillage systems in each of the seven years (Table 1), irrespective of the climatic conditions.

Soil pH, organic matter, and soil nutrients

Soil analyses (data not reported) showed that relative to areas left in sod for 4 years, the NT plots contained slightly less N and P; had lower pH, and about equal K levels. However, the P and organic matter levels were still lower in CN compared to NT (Table 2); the K levels were comparable in the two tillage systems at the five soil depths to 15 cm. Soil pH tended to be lower in NT. Available Ca and Mg contents of the soil were also not significantly different in the two tillage systems.

Plant nutrient uptake

Of the nutrient uptake by soybean leaves and seeds, only nitrogen uptake by the seed was enhanced by NT, perhaps reflecting the influence of NT increased soil organic matter and subsequent N mineralization. No fertilizer x tillage interaction was observed as the K application rate was increased from 0 to 4 X. Increasing K rates generally increased the plant uptake of K, Ca and Mg, but not that of P.

Conclusion

In seven years of side-by-side field-plot studies comparing no-tillage and conventional tillage methods of soybean production, no-tillage was equal or superior to conventional tillage. Potential savings in fuel and labor costs should more than make up for the added costs in NT for additional herbicide and for lime (or other materials) costs to possibly ameliorate increased acidity, potentially making the NT systems more profitable for the farmer. In the case of no-tillage, the potential for reduced soil erosion and reduced pollution, with less overall operating costs, should make this method of cultivation a better choice under similar soil/climatic conditions.

Table 1. Soybean grain yields (kgm/ha) as influenced by tillage.

Year	Tillage	
	CN†	NT
1980	2138	2075
1981	2263	2201
1982	1446	1572
1983	2263	2452**
1984	***	***
1985	2452	2578
1986	1760	1949
1987	3049	3074
Average	2225	2194

†CN = Conventional tillage; NT = No-tillage; ** Statistically different at p=0.05

*** Soybean yields were not recorded in this year due to unusually dry growing season.

Table 2. Effect of tillage on soil pH, organic matter, and soil nutrients.

Soil property/ nutrient	Tillage	Soil depth (cm)					
		0-2.5	2.5-5	5-10	10-15	15-30	Average
pH	CN***	6.31	6.26A*	6.03A	6.08	6.34	6.16A
	NT	6.38	6.06B	5.88B	6.1	6.32	6.05B
AV.		6.34P	6.06Q	5.91Q	6.09R	6.33P	
Organic matter (%)	CN	1.98A	1.92A	1.65	1.51	0.85	1.57A
	NT	2.72B	1.86B	1.7	1.49	0.88	1.81B
AV.		2.36P	1.89Q	1.68R	1.50S	0.87T	
P (ppm***)	CN	111.2	128.4	135.2	139.2	72.4	119.6
	NT	124.8	140	146	151.2	80	130
AV.		118P	134.4Q	140.8QR	145.2R	76.4S	
K (ppm)	CN	74.4	48.8	36.4	32.8	25.2	44
	NT	70.4	53.6	37.2	30	25.6	43.2
AV.		72.4P	51.2Q	36.8RS	31.2ST	25.2T	
Ca (ppm)	CN	1508	1600	1576	1644	1416	1552
	NT	1760	1320	1448	1624	1392	1520
AV.		1640P	1456QR	1512PQR	1636P	1404R	
Mg (ppm)	CN	100	54	47.2	51.2	50.8	60.4
	NT	92	56.8	50	46.4	46	57.6
AV.		96P	55.4Q	48.8R	48.8R	48.4R	

* A, B=Statistically significant (p=.05) differences within each depth by the t-test; ** P, Q, R, S, T = Statistically significant (p=.05) differences between depths by the Duncan multiple range test.
*** ppm = parts per million. CN = Conventional tillage; NT = No-tillage

Table 3. Effect of tillage on plant nutrient uptake.

Nutrient	Tillage***		K-rate kgm K_2O/ha				
	CN	NT	0	45	90	135	180
					%		
Leaf N	4.4	4.6	4.5	4.4	4.3	4.6	4.4
Leaf P	0.28	0.29	0.28AB*	0.29A	0.29AB	0.29AB	0.27B
Leaf K	1.2	1.4	1.1A	1.2A	1.2A	1.4B	1.5C
Leaf Ca	1.19	1.13	1.21	1.13	1.16	1.15	1.13
Leaf Mg	0.39	0.39	0.44A	0.39B	0.36C	0.38BC	0.37BC
Seed N	6.3P**	6.5Q	6.3	6.5	6.5	6.3	6.3
Seed P	0.6	0.61	0.61	0.6	0.61	0.61	6
Seed K	1.8	1.9	1.78A	1.84AB	1.90BC	1.94BC	2.0C
Seed Ca	0.23	0.24	0.22A	0.23AB	0.25B	0.23AB	0.24AB
Seed Mg	0.2	0.2	0.2	0.20A	0.20A	0.20A	0.21B

* A, B, C = Statistically significant (p=.05) differences between K-rates by the Duncan multiple range test.
** P, Q = Statistically significant (p=.05) differences between two tillages by the t-test.
*** CN = Conventional tillage; NT = No-tillage

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