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Fall Deep Tillage of Clay: Agronomic and Economic Benefits to Soybeans

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Introduction

Clay soils occupy approximately 9.1 million acres or about 50 percent of the total land area in the lower Mississippi River alluvial flood plain. They also make up 50 percent of the land area (2.5 million acres) in the Yazoo-Mississippi Delta area in Mississippi (15).

Clayey soils are characterized by a high percentage of clay, slow internal drainage, and a high water-holding capacity. The montmorillonitic clays exhibit a high degree of swelling and shrinking as moisture content of the soil profile cycles between wet and dry. As these soils approach maximum water-holding capacities, the clay fraction swells and severely restricts water movement into and through the soil profile. As water is removed from these soils, the clay fraction shrinks and vertical cracks often form in the profile. When this occurs during the summer growing season, roots of crops planted on these soils are damaged and often broken as the cracks widen over time.

Soybeans are planted on the major portions of these land areas. In nonirrigated production systems, soybean yields are usually low, but with irrigation, sizeable yield increases are possible most years (6, 7).

Economic analysis has shown that properly timed irrigation of soybeans (furrow or sprinkler) grown on the clayey soils in Mississippi can result in increased returns to land, management, and general farm overhead (18). Studies conducted in optimum and extremely dry growing seasons indicated an average yield increase of approximately 15 bushels per acre was required to recover the total costs associated with irrigation when based on a seasonal price of $6.00 per bushel. Another study in Mississippi (8) investigated the economic effects of furrow irrigation on soybeans grown in conventional production systems. Data indicate net returns to soybeans grown on clay soil with and without supplemental irrigation averaged $133 and $96/acre, respectively.

Compaction of soil, whether natural or artificial, adversely affects the content and movement of air, water, heat, and nutrients in the soil (16). Early research suggested that an increase in bulk density would automatically reduce crop yield (12, 14, 17). However, recent research indicates there is an optimum level of compaction for each crop, soil, and season (20). As a general rule, responses to tillage and field traffic are variable but can be explained by a combination of site and soil-related factors, plant and crop-related factors, weather and climate-related factors, and soil and crop-management factors that include tillage and traffic (3).

A controlled traffic production system developed in 1973 increased cotton yields over yields produced by conventional systems (4). Deep tillage in the controlled traffic concept also produced significantly higher yields (25). Deep tillage has increased yields of numerous crops (1, 10, 11) and has been proven a practical method for increasing water intake rates and depth of profile wetting of slowly permeable clays (9, 13).

Current tillage practices recommended for soybean production on the heavy soils in the Midsouth do not include deep tillage or deep disking. The natural shrinking, which causes the soil to crack as it dries, is credited for the elimination of the compacted layers caused by machinery traffic.

Deep tillage of a Sharkey clay in late spring when the upper profile of the soil was wet did not increase soybean yields when compared to conventional disking for seedbed preparation (2, 5, 22). Conversely, on a Tunica clay, deep tillage in the fall when the upper profile was dry significantly reduced moisture tension levels during soybean reproductive stages R3 through R6, and thus produced significantly higher yields than produced by conventional (disked) production systems (23). An economic analysis of the same study (24) indicated net returns to the nonirrigated deep tilled treatments averaged 2.5 times the returns to the nonirrigated conventional (disked) treatment ($122 vs $48/acre) and 1.5 times the returns from irrigated conventional (disked) treatment ($122 vs $83/acre).

Excavation and observation of the soil structure of a Tunica clay when the soil was cracked revealed compacted blocks of soil beneath the plow layer (19). A majority of cotton roots observed from excavated pits appeared to be growing between the soil blocks. Therefore, it is possible that much of the soil nutrients and water stored in these soil blocks is not readily available for plant growth.

Deep tillage (subsoiling) in the fall when the soil profile is dry disrupts the orientation of these blocks and reduces their size. The tillage operation also increases the volume of loose soil material between these blocks, and this improves infiltration by increasing the volume of macropores in the soil. Water moves more quickly through macropores than through the smaller pores in the soil blocks (17). Higher infiltration rates result in a larger volume of moistened soil following a rainfall event. Excess water is able to drain from the profile, and this improves the aeration of the soil and allows the soil to warm up more quickly in the spring for earlier planting. Surface runoff and soil erosion are also reduced.

The objectives of this study were to (1) determine the effect of irrigation and deep tillage on soybean yield in a controlled traffic production system and (2) determine the economic returns to irrigation and deep tillage.

Materials and Methods

General

Field studies were conducted from 1987 through 1991 near Stoneville, MS on a Tunica clay soil (clayey over loamy, montmorillonitic, nonacid, thermic Vertic Haplaquept). On Tunica clay, the surface layer of clay ranges from 18 to 30 inches thick and overlies a clay loam or a silty clay loam subsoil. The soil composition of the A horizon (upper 30 inches) at the test site was composed of 1% sand, 36% silt, and 63% clay, whereas the B horizon was composed of 2% sand, 70% silt, and 28% clay. The field area for this study had a bulk density of approximately 1.4 g/cm3 and had been continuously cropped in nonirrigated, conventional-tilled soybean.

The experiment included four tillage treatments in both an irrigated and nonirrigated environment. The experiment was conducted with irrigation treatments (main plots) and tillage treatments (subplots) in a splitplot arrangement in a randomized complete block design with four replicates each year. Subplots were 53.3 feet wide and 92 feet long. Traffic lanes were established on 80-inch centers and remained in the same location throughout the study period. A production zone was centered between each traffic lane and contained four rows of soybeans. The area was planted with an eight-row planter with a 26-inch space for the traffic lanes.

Tillage treatments were randomly assigned to the subplots at the beginning of the test period and remained in the same location for the 5-year test period. Tillage treatments included three deep tillage methods and a conventional (disked) check plot. Treatments are identified as follows: triplex subsoiler with one shank (DT1), parabolic subsoiler with two shanks (DT2), parabolic subsoiler with three shanks (DT3), and disked check (C). The DT1 unit consisted of a straight subsoiler shank with a 30-inch wide wing attached to the point of elevation to give additional soil fracture. The DT2 unit contained two parabolic shanks spaced 40 inches apart; the DT3 unit contained three parabolic shanks spaced 20 inches apart. All deep-tilled plots were subsoiled in the row direction to a depth of 16-20 inches each year, with the tillage implements centered in each respective production zone. The check plot was prepared in a conventional manner with the disk-harrow followed by a field cultivator. All tillage inputs occurred between October 1 and December 19 each year. All plots remained as tilled throughout the winter season.

Prior to planting soybeans each year, all winter vegetation was eliminated either by a broadcast application of paraquat or by tilling with a disk-harrow. All plots were then tilled with a field cultivator followed by a spike-tooth harrow to smooth out the rough areas in the deep tilled plots. These procedures provided suitable seedbeds for planting soybeans. Asgrow 5980 was planted all years except 1991. Because of a severe infestation of stem canker (Diaporthe phaseolorum var. caulivora) disease in 1990, a resistant soybean variety (Pioneer 9592) was planted in 1991. Planting occurred between May 8 and May 13 each year. All machinery traffic was confined to the established traffic lanes.

Metolachlor plus metribuzin herbicides were broadcast-applied at planting from 1987 through 1990 for grass and broadleaf weed control in all treatments. In 1990 a mixture of bentazon and acifluorfen was applied post-emergence. In 1991 soybeans were first planted on April 24, followed with a preemergence application of a metribuzin and chlorimuron mixture. However, because of excessive rainfall (13.2 inches) after planting that flooded all plots, soybeans were replanted on May 13, 1991, and a mixture of bentazon and acifluorfen was broadcast-applied postemergence on June 3, 1991.

Each year all treatments in the irrigated environment were sprinkler-irrigated from a lateral-move system. Irrigation was initiated when soil water potential, as determined by tensiometers located at the 12-inch depth in three replicates of the check plots, averaged between -50 and -70 centibars.

The combine used for harvesting had 80-inch wheel spacings; therefore, harvest traffic was also confined to the established traffic lanes. The plot combine's cutter bar was also 80 inches wide and harvested a complete production zone with each pass. Three production zones were harvested from each subplot for yield determinations. Seed moisture was corrected to 13% dry basis. Harvest dates occurred between September 27 and October 13 each year.

Economic Analysis

Incomes and expenses were estimated annually for each treatment in the irrigated and nonirrigated environments. Application rates for all the variable inputs were those used for crop production in this study. Crop prices used in the budgets were the seasonal average prices received for the year as reported by the Mississippi Agricultural Statistics Service, 1987-91. Gross income was calculated annually as the product of treatment yields and seasonal average price.

Variable costs were the actual prices paid by farmers each year and include the cost of herbicide, seed, labor, fuel, repair and maintenance of equipment, and interest on operating capital. Fixed costs include annual ownership costs of tractors and other self-propelled equipment, implements, and the irrigation system. Total specified costs include both variable and fixed costs.

Net returns per acre were calculated as the difference between gross income and total specified costs.

Average net returns were calculated as the mean of the annual net returns over the study period. Expense estimates did not include charges for land, management, or overhead. Performance rates on all field operations were based on using eight-row equipment with associated power units.

Irrigation costs were based on a quarter-mile center pivot system capable of irrigating 130 acres from one pivot point. Investment costs include the cost of an engine, well, pump, gearhead, generator, fuel tank and fuel lines, and the pivot system. Total fixed costs consist of annual depreciation, interest on investment, and insurance. Annual depreciation was calculated using the straight-line method with zero salvage value. Annual interest charges were based on one-half of the original investment times an appropriate interest rate for each year of the study. Insurance was estimated at 1% of the original investment. Operating or direct costs include fuel, oil, labor, and engine repair. Fuel requirements were determined from engineering formulas (21).

Results and Discussion

Precipitation received at the test site and supplemental water provided by irrigation during the May-September growing season each year are presented in Table 1. Production input dates, yields, gross income, specified costs of production, and net returns above specified costs for each treatment in the irrigated and nonirrigated environments are presented in Tables 2-6, respectively. A summary of these data is presented in Table 7.

Table 1. Total precipitation and supplemental water from irrigation during the May-September period for soybeans grown near Stoneville, MS 1987-1991[1]

Source	Crop Year				
	1987	1988	1989	1990	1991
	---------- inches ----------				
Rainfall	17.5	10.2	28.2	11.1	15.3
Irrigation	12.1	14.5	4.5	7.8	8.1
Total Water	29.6	24.7	32.7	18.9	23.4

[1]The long-term (50-year) average rainfall for the region during the May-September period is 18.7 inches.

Seed Yield

Yields from all tillage treatments in the irrigated environment were similar in all years except 1989 (Table 3), when yields from DT2 were lower than all other irrigated treatments. Precipitation and supplemental water from the sprinkler irrigation system (Table 1) provided adequate soil moisture in all treatment plots throughout each production season, thereby over- shadowing any positive effects of deep tillage on soybean yields.

In the nonirrigated environment, yields from all deep-tilled treatments were similar all years except 1988 and higher than yields from the check treatment all years except 1989, when all yields were similar (Table 3). Adequate and timely rainfall was also received during the reproductive period of 1989 (Table 1) and thus alleviated all visible evidence of drought stress.

The low yields in all irrigated treatments and all deep-tilled treatments in the nonirrigated environment in 1990 were attributed to the severe infestation of stem canker in the Asgrow 5980 cultivar. The extremely low yield of the nonirrigated check treatment in 1990 (14 bushels/acre) was attributed to both stem canker and moisture stress.

In 1991 yields from all nonirrigated treatments were high due to timely rainfall received during the reproductive period (Table 1). However, yields from the deep tilled treatments averaged 27% higher (12 bushels/acre) than the check plot yields. Irrigation improved the check plot yield by 22% (10 bushels/acre). The 15.3 inches of precipitation received was sufficient for the nonirrigated deep tilled plots to produce yields similar to the irrigated plots.

Table 2. Production input dates for deep tillage-controlled traffic study near Stonevill, MS. 1987-1991

Subsoil	Production Input Dates	
	Plant	Harvest
10-01-86	05-19-87	10-09-87
10-19-87	05-16-88	10-13-88
12-19-88	05-12-89	10-06-89
10-11-89	05-08-90	09-27-90
10-01-90	05-13-91[1]	10-07-91

[1]Initial planting on 04-24-91 was flooded by excessive rainfall; replanted on 05-13-91.

Over the 5-year study, average soybean yields from all irrigated treatments were similar (Table 3). Yields from the deep-tilled treatments in the nonirrigated environment averaged 92% as high as yields from comparable treatments in the irrigated environment. The similarity of these yields indicates deep tillage in the fall, when the profile was dry, provided basically the same benefits as irrigation of soybeans during the reproductive period. However, yields from the irrigated check treatment averaged 55% higher than the yield of the nonirrigated check treatment. This comparison points out the positive benefits of irrigation to soybeans grown in conventional (disked) production systems. In the nonirrigated environment, yield data also indicate the average yield from the deep-tilled treatments averaged 46% higher than the average yield of the check treatment. Thus, deep tillage of Tunica clay in the fall when the soil profile is dry significantly enhanced yield potential over that provided by a conventional disk harrow for seedbed preparation.

Table 3. Yield of soybeans grown in deep tillage-controlled traffic study with and without irrigation near Stoneville, MS. 1987-1991.

Irrigation Treatment	Tillage Treatment [1]	Crop Year					
		1987	1988	1989	1990	1991	Avg.
		---------------------------------- bu/acre --					
Irrigated	DT1	55	53	35	32	57	46
	DT2	57	52	32	30	57	46
	DT3	57	50	35	29	57	46
	C	55	50	36	28	55	45
	Avg	56	51	35	30	57	46
Nonirrigated	DT1	48	41	42	26	56	43
	DT2	48	43	42	25	57	43
	DT3	44	36	41	25	58	41
	C	27	17	40	14	45	29
	Avg	42	34	41	23	54	39
LSD (0.05)[2]							
Compare treatments within irrigation levels		5	5	3	5	5	5
Compare treatments across irrigation levels		6	9	3	5	8	5
Compare irrigation levels		5	8	3	3	7	4

DT1 = triplex subsoiler with 1

[1]Tillage treatements:	shank
	DT2 = parabolic subsoiler with 2 shanks
	DT3 = parabolic subsoiler with 3 shanks
	C = disked check plot

[2] Significant differences occur at the 0.05 probability level when differences in treatment means equal or exceed the LSD values shown.

Economic Returns

Gross incomes (Table 4) from all irrigated treatments were virtually the same for each year because all treatment yields were statistically similar each year. However, gross income across years varied considerably because of year-to-year yield differences and differences in the seasonal average prices. In the nonirrigated environment, gross income to all deep-tilled treatments was considerably higher than from the check treatment all years except 1989, when yields were similar. Over the 5-year experiment, average gross income to the nonirrigated deep-tilled treatments ($258/acre) averaged 50% higher ($86/acre) than from the nonirrigated check treatment ($172/acre) and 91% as high as the average gross income to all irrigated treatments ($282/acre).

Specified costs of production (Table 5) for all irrigated deep-tilled treatments were virtually identical each year and over the 5-year study averaged $204/acre, which was $9/acre higher than the specified costs of production of the irrigated check treatment ($195/acre). In the nonirrigated environment, specified costs of production were considerably less; however, similar relationships were established between treatments. Specified costs for all nonirrigated deep-tilled treatments averaged $12/acre higher than the check treatment ($136 vs $124/acre).

Net returns to all irrigated treatments were approximately the same in a given year but exhibited year-to-year variability (Table 6). The highest net returns were recorded in 1988 and were attributed to a high yield (Table 3) and a seasonal price of $7.50/bushel. The lowest net returns were recorded in 1990 and were attributed to the lower than normal yield levels caused by the severe infestation with stem canker disease. Low yields in 1990, combined with above-average specified costs of production, resulted in negative net returns to all irrigated treatments that ranged from $-31 to $-45/acre. In 1991 exceptionally high yields were recorded. However, net returns were only slightly above average for the 5-year period because of the additional costs associated with replanting and postemergence herbicides. Over the 5-year experiment, the average net returns to all irrigated treatments ranged from $79 to $83/acre.

In the nonirrigated environment, net returns to all deep-tilled treatments greatly exceeded net returns from the check treatment all years except 1989. These higher returns are directly related to the significantly higher yields produced by the deep-tilled treatments. In 1989 yields from all treatments were similar and thus resulted in net returns that were virtually identical. In 1990, when yields of all treatments were reduced by stem canker, yields from all deep-tilled treatments were sufficient to virtually offset specified costs of production, whereas yields of the check treatment were so low that sizeable negative net returns (-$59/acre) resulted. Over the 5-year experiment, average net returns above specified costs for all deep-tilled treatments ($122/acre) were 155% higher than average net returns from the check treatment ($48/acre).

Table 4. Gross income from soybeans grown in deep tillage-controlled traffic study with and without irrigation near Stonevill, MS. 1987-1991[1]

Irrigation Treatment	Tillage Treatment [2]	Crop Year					
		1987	1988	1989	1990	1991	Avg.
		---------- $/acre ----------					
Irrigated	DT1	323	395	206	187	323	287

	DT2	332	392	188	178	322	282
	DT3	332	378	204	173	327	283
	C	323	377	214	163	313	278
Nonirrigated	DT1	278	306	245	154	322	261
	DT2	284	322	246	148	326	265
	DT3	260	268	241	145	330	249
	C	158	129	234	83	257	172

[1]Gross income was calculated annually as the product of treatment yield and seasonal average price. Seasonal average prices for soybeans for 1987-1991 were $5.84, $7.50, $5.90, $5.90, and $5.70 per bushel respectively.

[2]Tillage treatements:
DT1 = triplex subsoiler with 1 shank
DT2 = parabolic subsoiler with 2 shanks
DT3 = parabolic subsoiler with 3 shanks
C = disked check plot

Table 5. Specified costs of production for soybeans grown in deep tillage-controlled traffic study with and without irrigation near Stoneville, MS. 1987-1991.

Irrigation Treatment	Tillage Treatment [1]	Crop Year					
		1987	1988	1989	1990	1991	Avg
		---------------------------------- $/acre ---------------------------------------					
Irrigated	DT1	202	200	171	218	228	204
	DT2	202	200	171	218	228	204
	DT3	202	200	172	218	229	204
	C	194	191	163	208	218	195
Nonirrigated	DT1	129	124	109	152	164	136
	DT2	129	125	109	153	164	136
	DT3	129	124	109	153	165	136
	C	117	112	99	142	152	124

[1]Tillage treatements:
DT1 = triplex subsoiler with 1 shank
DT2 = parabolic subsoiler with 2 shanks
DT3 = parabolic subsoiler with 3 shanks
C = disked check plot

Table 6. Net returns above specified costs for soybeans grown in deep tillage-controlled traffic study with and without irrigation near Stoneville, MS. 1987-1991.

Irrigation Treatment	Tillage Treatment [1]	Crop Year					
		1987	1988	1989	1990	1991	Avg

		$/acre					
Irrigated	DT1	121	195	35	-31	95	83
	DT2	130	192	17	-40	94	79
	DT3	130	178	32	-45	98	79
	C	129	186	51	-45	95	83
Nonirrigated	DT1	149	182	136	2	158	125
	DT2	155	197	137	-5	162	129
	DT3	131	144	132	-8	165	113
	C	41	17	135	-59	105	48

[1]Tillage treatements:

DT1 = triplex subsoiler with 1 shank

DT2 = parabolic subsoiler with 2 shanks

DT3 = parabolic subsoiler with 3 shanks

C = disked check plot

Summary

A comparative summary of the data for the conventional check treatment (C) and the deep-tilled treatment with two subsoiler shanks (DT2) is presented in Table 7. Conventional production practices for soybeans in the Midsouth include land preparation with a disk-harrow, field cultivator, and/or spring-tooth harrow. Soybeans are then planted in the prepared seedbed and grown with or without irrigation during the reproductive period. In most instances, soybeans are grown in nonirrigated environments. This production system corresponds to the nonirrigated conventional treatment, where the net returns averaged $48/acre over the 5-year study.

When supplemental irrigation is utilized in conventional production systems, net returns would be typical of the returns from the irrigated conventional treatment that averaged $83/acre. These higher returns were a direct result of supplemental irrigation that increased yields 16 bushels/acre. Thus, in conventional production systems, irrigation increased the average net returns to soybeans by 73% ($35/acre).

In nonirrigated production systems on Tunica clay that included deep tillage (subsoiling) in the fall in lieu of supplemental irrigation during the crop's reproductive period, net returns to the deep-tilled treatment averaged $129/acre and were 169% higher than the net returns from nonirrigated conventional production systems ($48/acre). These highly favorable net returns to deep tillage are attributed to the significantly higher yields of the deep-tilled treatment (43 vs 29 bushels/acre). The higher yields of the deep-tilled treatment increased gross income $93/acre ($265 vs $172/acre), while the specified costs of production with deep tillage increased only $12/acre ($136 vs $124/acre).

The average net returns to the nonirrigated deep-tilled treatment were 55% higher than returns to the irrigated conventional treatment ($129 vs $83/acre). Yields and gross income of these treatments were similar. However, the specified costs of production of the irrigated conventional treatment exceeded the cost of the nonirrigated deep-tilled treatment by $59/acre. These higher costs were attributed to the irrigation equipment and associated expenses and significantly reduced the net returns to the irrigated conventional treatment.

The average net returns to the nonirrigated deep-tilled treatment averaged 63% higher than returns to the irrigated deep-tilled treatment ($129 vs $79/acre). Yields and gross income were similar; however, the additional costs associated with irrigation ($68/acre) significantly reduced net returns of the irrigated treatment. Irrigation during the reproductive season failed to increase yields over those attained by deep tillage in the fall without irrigation.

Table 7. Summary of soybean yield, gross income, specified costs, and net returns for the conventional check and a deep-tilled treatment with and without irrigation on Tunica clay, near Stoneville, MS. 1987-1991.

Irrigation Treatment[1]	Tillage Treatment[2]	Soybean Yield	Gross Income	Specified Costs	Net Return
		bu/acre	$/acre	$/acre	$/acre
NI	C	29	172	124	48
I	C	45	278	195	83
NI	DT2	43	265	136	129
I	DT2	46	282	204	79

[1]Irrigation treatments are NI (nonirrigated) and I (irrigated).

[2]Tillage treatments are C (conventional disked check) and DT2 (deep tilled with a parabolic subsoiler with 2 shanks).

Conclusion

Production of soybeans in a nonirrigated environment with deep tillage in the fall in lieu of supplemental irrigation during the reproductive period (1) produced yields similar to those produced in conventional production systems with irrigation, (2) produced significantly higher yields than those produced in conventional production systems without irrigation, and (3) produced net returns that greatly exceeded net returns from conventional production systems with and without irrigation. In light of these results, tillage recommendations for clay soil should reflect potential benefits from subsoiling when the soil is relatively dry.

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