Fall Deep Tillage of Tunica and Sharkey Clay: Residual Effects on Soybean Yield and Net Return

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INTRODUCTION

In the Mississippi River alluvial flood plain in the southern United States, clayey soils occupy approximately 9.1 million acres or about 50% of the total land area. Sharkey clay is the dominant soil series in the region and comprises about 3 million acres *(10)*.

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 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.

Monocrop soybean is planted on the major portion of this acreage and is grown mainly in dryland production systems. Yields of monocrop soybean from conventional soybean production systems (CSPS) in dryland environments are typically low, ranging from 20-25 bushels per acre *(5)*, and are only marginally profitable *(12, 14, 15)*. In this production system, Maturity Group V (MG V) or later soybean cultivars are planted in May and June in a seedbed prepared by disking and/or harrowing either in the fall after harvest or in the spring before planting *(3)*. Moisture deficit and drought stress, which often occur in the region, coincide with the reproductive stage of soybean grown in this system, and thus reduce yield potential *(11)*.

The early soybean production system (ESPS) was developed to avoid the drought stress effects on soybean grown in the CSPS *(6)*. In this production system, the seedbed is prepared in the fall. Winter and spring vegetation are controlled by preplant, foliar application of herbicides in late March or early April. MG IV soybean crops are planted in April in a stale, untilled seedbed. The reproductive stage of these varieties occurs earlier in the year when rainfall and soil moisture levels are greater. Thus, most drought stress is avoided and yield potential of soybean is improved.

Deep tillage has been shown to be a practical method for increasing water intake rates and depth of profile wetting of slowly permeable structured clays *(9)*. Researchers found that deep tillage of clay soil when the upper profile was dry doubled the average water intake rate during the next crop season compared with conventional tillage *(7)*.

A recent study in Mississippi evaluated the effects of three deep tillage implements in a controlled traffic system on yield of MG V soybean grown with and without irrigation on a Tunica clay *(16,17)*. All deep tillage was done in the row direction in the fall when the soil profile was relatively dry. In a sprinkler-irrigated environment, soybean yields from the deep-till treatments and the conventional-disked treatment were similar and averaged 46 bushels per acre. Conversely, in a nonirrigated environment, all deep-till treatments produced an average of 43 bushels per acre, which was significantly greater than the 29 bushels per acre produced from the conventional-disked treatment. Over the 1986-1991 study period, deep tillage in the fall in a controlled traffic system increased average yield of nonirrigated soybeans by 48% (43 vs. 29 bushels per acre) above that produced from the conventional-disked treatment.

Data from the Mississippi study indicate soybean yield response to deep tillage in nonirrigated production systems was a function of growing-season precipitation. Rainfall at the test site for the May through September growing seasons averaged 17.5, 10.2, 28.2, 11.1, and 15.3 inches, respectively, for the 1987-1991 crop years. The response to deep tillage was greater in the drier growing seasons. Deep tillage in the fall of 1986 increased yields in 1987 by 78% (48 vs. 27 bushels per acre) when growing-season rainfall approximated the long-term average of 18.7 inches for the region. Conversely, deep tillage in the fall of 1987 increased yields in 1988 by 150% (43 vs. 17 bushels per acre) when rainfall was only 10.2 inches. In 1989, when May through September rainfall was 28.2 inches, yields from the deep-till treatments and the conventional treatment were similar. The yield increases in the drier years resulted from overall enhanced soil structure, increased water infiltration and storage, and improved water availability, movement, and drainage.

Deep tillage of Tunica clay in the fall significantly increased yield and net return from nonirrigated MG V soybeans grown in the CSPS. However, the effect of fall deep tillage on MG IV soybean grown in the ESPS on clayey soils was unknown. Therefore, two long-term field studies were conducted on nonirrigated Tunica and Sharkey clay soils to determine the annual and residual effects of fall deep tillage on yield and net return from MG IV soybean grown in the ESPS in the Mississippi River alluvial flood plain.

MATERIALS AND METHODS

Field studies were conducted from 1994 through 1998 on well-drained Tunica (clayey over loamy, montmorillonitic, nonacid, thermic, Vertic Halaquept) and Sharkey clay (very fine, montmorillonitic, nonacid, thermic, Vertic Halaquept) soils near Stoneville, Mississippi (33°26' N lat.). In general, the clay layer on Tunica ranges from 20 to 30 inches thick and overlies a clay loam or silty clay loam subsoil. The soil 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. Soil composition of the Sharkey clay soil was 3% sand, 32% silt, and 65% clay. Both study areas contained 2-3% organic matter and had been planted to monocrop soybean for the past 10 years.

The two experiments were conducted in dryland environments and included selected tillage treatments in randomized complete block designs with four replicates. All treatment plots were 53 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 soybean spaced 18 inches apart.

Tillage treatments were randomly assigned to plots at the beginning of the test period and remained in the same location for the 5-year test period. Tillage treatments included selected deep-till (subsoiled) treatments performed at specified time intervals, a Paratill® subsoiler treatment, and a conventional disk check treatment (Table 1). The Tunica clay experiment included all treatments shown in Table 1, whereas the Sharkey clay experiment included only the DT1, DT5, PT1, and C treatments.

All tillage was performed in the row direction in the fall when the soil profile was relatively dry. All deep-till treatments (DT1-DT5) were subsoiled in the fall at the specified time intervals to a depth of 16 to 20 inches with a four-shank subsoiler with curved shanks spaced 40 inches apart. The paratill treatment (PT1) was tilled annually to a depth of 12 inches with a Paratill® plow equipped with four legs (shanks) spaced 40 inches apart and angled 45 degrees to the side to lift and fracture the soil. The conventional treatment (C) was prepared annually with a disk harrow and/or a field cultivator and tilled to a depth of 4 inches.

Maturity Group IV varieties were used in both experiments all years. In the Tunica clay experiment, RA 452 was

Table 1. Type and frequency of tillage for soybeans grown on clayey soils near Stoneville, Mississippi, 1994-1998.

Treatment [1]	Treatment description	Year applied [2]
DT1	fall deep tillage, annually	1993, 1994, 1995, 1996, 1997
DT2	fall deep tillage, once every 2 years	1993, 1995, 1997
DT3	fall deep tillage, once every 3 years	1993, 1996
DT4	fall deep tillage, once every 4 years	1993, 1997
DT5	fall deep tillage, once every 5 years	1993
PT1	fall paratill, annually	1993, 1994, 1995, 1996, 1997
C	fall conventional tillage, disk annually	1993, 1994, 1995, 1996, 1997

[1]Tillage applied as follows: DT1-DT5 – subsoiler with four curved tines spaced 40 inches apart and tilled to a depth of 16-20 inches; PT1 – paratill® plow with four shanks spaced 40 inches apart and tilled to a depth of 12 inches; and C – conventional disk harrow and/or field cultivator to a depth of 4 inches.
[2]All deep-till treatments received the same secondary (shallow) tillage as applied to C.

planted in 1994 and 1995, and DP 3478 in 1996, 1997, and 1998. Planting occurred between April 11 and April 23 each year. In the Sharkey clay experiment, RA 452 was planted in 1994 through 1997, whereas DP 3478 was planted in 1998, with planting occurring between April 7 and May 1 each year. Seeding rates were approximately five seeds per foot of row or about 45 pounds per acre in all years. Seeds were treated with metalaxyl fungicide as a precaution against *Pythium* spp.

The experiments were initiated in September 1993 after soybean harvest. All plots were tilled as specified between September 12 and September 24 each year and remained untouched throughout the winter. In March 1994, all treatment plots in each experiment were tilled with a field cultivator to prepare a suitable seedbed for planting and to eliminate winter vegetation. In subsequent years, all C plots and all plots that were deep-tilled in the fall were also smoothed in the fall with either a disk-harrow and/or a field cultivator to assure a stale seedbed for early planting the following year *(3,4)*. All other treatment plots remained untouched throughout the winter and were planted no-till in a stale seedbed the following year.

Production inputs from burndown to harvest were identical for all treatments within each experiment each year except in the Tunica clay experiment in 1998, when Select (clethodim) herbicide was applied postemergence to all DT5 plots for johnsongrass (*Sorghum halapense* [L.] Pers.) control. For crop years 1995 through 1998, all winter vegetation was eliminated by a broadcast application of Roundup (glyphosate) applied within 1 month of planting. A tank-mix application of Dual (metalachlor) plus Lexone (metribuzin) was applied to each experiment each year at planting for control of annual weeds. In the Tunica clay experiment, a tank-mix application of Reflex (fomesafen) plus Fusilade (fluazifop) was applied postemergence to all plots in 1994, 1995, and 1996, whereas an application of Poast Plus (sethoxydim) and a lay-by application of Lorox (linuron) plus Butyrac (2,4-DB) was applied in 1996, 1997, and 1998. In the Sharkey clay experiment, a postemergence application of Reflex was applied to all plots in 1995, and a lay-by application of Lorox plus Butyrac was applied to all plots in 1997 and 1998.

A modified combine used to harvest all plots had 80-inch wheel spacings and an 80-inch-wide cutter bar that harvested four planted rows with each pass. Three passes (subsamples) were harvested from each plot for yield determination. Seed weights were adjusted to 13% moisture content, dry basis. Two 100-seed samples were collected from each plot for determination of seed weight. Harvest occurred between August 31 and September 19 each year.

All production inputs within each year were recorded for all treatments. Estimates of costs and returns were developed for each annual cycle of each experimental unit. Total specified expenses were calculated using actual inputs for each treatment in each year of the experiment and included all direct and fixed costs. However, total specified expenses excluded costs of land, management, and general farm overhead, which were assumed to be the same for all treatment combinations. Direct expenses included costs of pesticides, seed, and labor; costs for fuel, repair, and maintenance of machinery; cost of hauling harvested seed; and interest on operating capital. Fixed expenses were ownership costs of tractors, self-propelled harvesters, implements, and sprayers. Costs of variable inputs and machinery were based on prices paid by Mississippi farmers each year (i.e., machinery costs varied each year). 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.

Performance rates on all field operations were based on the use of 12-row equipment with associated power units. The power complement included one 100-horsepower (HP) tractor, one 145-HP tractor, one 180-HP tractor, one self-propelled combine with a 25-foot header width, and one 40-foot-wide, high-clearance sprayer. The equipment complement included a subsoiler unit equipped with four shanks, a Paratill® plow with four shanks, disk harrow, field cultivator, section harrow, 12-row planter, cultipacker, and a tractor-mounted sprayer.

Estimated costs of preplant tillage operations were determined each year for each treatment within each experiment. In each experiment, all deep-tilled treatments received the same secondary (shallow) tillage as applied to the C treatment. The estimated costs for specific operations were identical in both experiments each year. Estimated costs for fall deep tillage of the DT1-DT5 treatments ranged from $7.28 per acre in the fall of 1993 to $8.26 per acre in the fall of 1997. Estimated costs of deep tillage with the paraplow ranged from $5.53 per acre in 1993 to $6.27 per acre in 1997. Estimated costs for conventional disking (once-over) ranged from $3.73 per acre in 1993 to $4.23 per acre in 1997, whereas the estimated costs of a field cultivator was $4.59 per acre in 1993. A spike-tooth harrow was used in both experiments in the fall of 1996 and 1997 and was budgeted at $2.03 per acre and $2.06 per acre, respectively. Fall tillage costs for the DT2, DT3, DT4, and DT5 treatments in the Tunica clay experiment and the DT5 treatment in the Sharkey clay experiment were prorated on an annual basis over subsequent years in which tillage was omitted. This type of allocation over time spreads the tillage costs incurred one year over all years that received benefits from deep tillage.

Gross return from each experimental unit was calculated annually by multiplying the Mississippi market-year average price by the yield. Yearly prices, instead of an average long-term price, were used to reflect the effect of market forces on income for each individual year. The Mississippi market-year soybean price was $5.59 per bushel in 1994, $6.76 in 1995, $7.34 in 1996, $6.90 in 1997, and $6.05 in 1998. Net returns above total specified expenses were determined annually for each experimental unit.

An analysis of variance for a randomized complete block design [PROC MIXED]*(13)* was used annually and across years to evaluate the significance of treatment effects on soybean yield, seed weight, and net return. In the analyses combining data over years, year, and year×treatment were treated as fixed effects, whereas replication×year was treated as a random effect. In the Tunica clay experiment, spatial variability existed because yield consistently increased easterly across the plots. Data were adjusted to account for this spatial trend by using plot location as a covariate in the model and least squares estimates of adjusted treatment means. This spatial pattern was not present in the Sharkey clay experiment. Treatment means were evaluated using an LSD value at alpha ≤ 0.05.

RESULTS AND DISCUSSION

Weather

Growing-season precipitation was slightly above normal in 1994, 1995, and 1996; near normal in 1997; and considerably less than normal in 1998 (Table 2). However, seasonal distribution of precipitation was erratic most years. In 1994, record rainfall received in a 10-day period in July exceeded the long-term average by 7.9 inches, whereas rainfall received during April, June, and August the same year was 5.5 inches less than the long-term average. Rainfall received in April 1995 totaled 9.6 inches and exceeded the long-term average by 4.2 inches. A major portion (7.4 inches) of the April 1995 total of 9.6 inches was received in a 4-day period immediately after planting. Rainfall received in August of 1994, 1995, and 1998 was considerably less than the long-term average. In fact, rainfall received in 1998 was less than normal all months except July, when rainfall exceeded the normal by 1 inch.

Rainfall before fall deep tillage was 3.1 inches in August and 1.9 inches in September of 1993. However, only 2.3 inches fell after August 6, 1993. Rainfall in the fall of 1994 was only 0.4 inch in August and 0.6 inch in September. In August 1996, 1.4 inches of rain fell; in September 1996, 1.2 inches. Thus, fall deep tillage was performed in a relatively dry soil in 1993, 1994, and 1995. Conversely, rainfall was 4.3 inches in August and the first half of September of 1996, and 2.8 inches in August and 1.1 inches in September of 1997. Rainfall in August and September of 1996 and 1997 wet the soil profile before fall tillage. Thus, all deep tillage was performed in a relatively wet soil.

Table 2. Monthly precipitation for 1994 through 1998 growing seasons at Stoneville, Mississippi.

Month	Crop year					30-year normals [1]
	1994	1995	1996	1997	1998	
	in	*in*	*in*	*in*	*in*	*in*
April	3.5	9.6	5.9	4.5	4.4	5.4
May	5.1	3.1	2.4	5.8	4.6	5.0
June	2.0	4.0	5.2	4.2	1.6	3.7
July	11.6	5.8	3.3	2.9	4.7	3.7
August	0.4	1.4	4.3	2.8	0.7	2.3
Total	22.6	23.9	21.1	20.2	16.0	20.1

[1]Boykin et al. 1995.

Table 3. Yield of soybean grown in deep-till production systems on Tunica clay near Stoneville, Mississippi, 1994-1998.

Treatment [1]	Crop year					Overall average
	1994	1995	1996	1997	1998	
	bu/A	*bu/A*	*bu/A*	*bu/A*	*bu/A*	*bu/A*
DT1	54.7	38.5	54.6	64.2	44.8	51.4
DT2	46.7	38.1	53.5	59.0	45.2	48.5
DT3	52.2	37.4	47.7	64.6	40.1	48.4
DT4	52.2	37.2	48.2	54.5	42.9	47.0
DT5	47.8	37.8	46.8	51.7	26.9	42.2
PT1	49.6	36.4	50.5	62.7	42.0	48.2
C	37.7	22.0	37.6	51.3	32.6	36.3
LSD(0.05)[2] min.	11.8	4.5	6.6	6.3	7.3	4.3
LSD(0.05)[2] max.	12.4	4.7	6.9	6.6	7.7	4.5

[1]DT1, deep-till annually; DT2, deep-till once every 2 years; DT3, deep-till once every 3 years; DT4, deep-till once every 4 years; DT5, deep-till once every 5 years; PT1, paratill annually; and C, conventional tillage – disk annually.
[2]The LSD values were not the same for all mean comparisons due to use of plot location as a covariate in the analysis of variance.

Agronomic Performance

Tunica Clay

In 1994, seed yields (Table 3) from all deep-till treatments were statistically similar and ranged from 46.7 to 54.7 bushels per acre. The similarity of these treatments was expected because the DT1-DT5 and PT1 treatments were initially deep-tilled in the fall of 1993. The lower yield from the C treatment (37.7 bushels per acre) was attributed to the plant's inability to set and adequately fill all pods due to insufficient water available during seed fill *(2)*. The analysis indicated yields from all deep-till treatments were significantly greater than yield from the C treatment. However, yields from DT2 and DT5 were significantly greater than the yield from C at $P = 0.12$ and $P = 0.09$ levels, respectively; the other deep-till treatments were greater at the $P \leq 0.05$ level. Seed weights (not shown) indicated seed from all deep-till treatments were significantly heavier than seed from C.

After harvest in 1994, only DT1 and PT1 were deep-tilled. Two days later, all DT1, PT1, and C plots were disked in a conventional manner. All DT2-DT5 plots remained as harvested and were planted in stubble the following year. In 1995, yields and seed weights from all treatments that were deep-tilled in the fall of 1993 and/or 1994 were statistically similar, and all were greater than the 22 bushels per acre yield from C. Yield from DT1 that was deep-tilled in 1993 and 1994 averaged highest (38.5 bushels per acre). However, the average yields from the DT2-DT5 treatments that were deep-tilled only in 1993 averaged 37.6 bushels per acre – only 2% less than yield from DT1. Yields from the deep-till treatments ranged from 36.4 to 38.5 bushels per acre, despite the severe moisture deficits that occurred from late July through August and the higher-than-normal temperatures (not shown) in April, May, and August.

After soybean harvest in all plots in September 1995, all DT1, DT2, and PT1 plots were deep-tilled the following day. All DT1, DT2, PT1, and C plots were promptly disked in a conventional manner. All DT3-DT5 plots remained as harvested and were planted in stubble in 1996. Production inputs were identical for all treatments in 1996. For the third consecutive year, yields from all deep-till treatments were significantly greater than yield from C. The three highest yields were produced by DT1 (54.6 bushels per acre), DT2 (53.5 bushels), and PT1 (50.5 bushels) – treatments that were deep-tilled the previous fall. Yields from DT3, DT4, and DT5 treatments, which had not been deep-tilled since the fall of 1993, were similar and averaged 47.6 bushels per acre. That yield was 6.5 bushels per acre (12%) less than the average yield from DT1 and DT2 (54.1 bushels). Seed from all deep-till treatments were significantly heavier than seed from C.

On September 12, 1996, all DT1, DT3, and PT1 plots were deep-tilled, while all C plots were disked. On October 8, 1996, all DT1, DT3, and PT1 plots were disked once. A field cultivator was used the same day to smooth all DT1, DT3, PT1, and C plots. All DT2, DT4, and DT5 plots remained as harvested and were planted in stubble in 1997.

Growing-season precipitation during the 1997 crop year was near normal each month, whereas temperatures (not shown) were slightly cooler than long-term normals. Yields from DT1, DT2, DT3, and PT1 were similar, and all were significantly greater than yield from C (51.3 bushels per acre). Yields from DT4 and DT5 were similar to yield from C. Again, as in the previous 2 years, treatments that had been deep-tilled the previous fall (DT1, DT3, and PT1) produced the highest yields, ranging from 62.7 to 64.6 bushels per acre. Yields from DT1, DT2, and DT3, which had been deep-tilled at least once in the previous 3 years, averaged 62.6 bushels per acre. Conversely, yields from DT4 and DT5, which were deep-tilled only in 1993, averaged 53.1 bushels per acre – 9.5 bushels (15%) less than the 62.6-bushel average yield from DT1, DT2, and DT3.

In the fall of 1997, all DT1, DT2, DT4, and PT1 treatment plots were deep-tilled. These plots, along with all C plots, were disk-harrowed once and then smoothed by one pass with a field cultivator. All DT3 and DT5 plots remained as harvested and were planted in stubble in 1998. During the 1998 growing season, production inputs to all treatments were identical except that DT5 received an additional postemergence application of herbicide for a severe infestation of rhizome johnsongrass. The lack of tillage in DT5 the previous 4 years allowed this perennial weed to build up to troublesome levels that adversely affected yields.

The 1998 growing season was hot and dry. Maximum air temperatures (not shown) averaged above the long-term normals from May through August, while rainfall was less than long-term normals in all months except July. In 1998, yields from DT1, DT2, DT3, DT4, and PT1 were statistically similar and greater than yields from DT5 and C. As in past years, treatments that were deep-tilled the previous fall (DT1, DT2, DT4, and PT1) and/or in the fall of 1996 (DT1, DT3, and PT1) produced the highest yields – 40.1 to 45.2 bushels per acre. Yields from the DT1-DT4 treatments averaged 43.3 bushels per acre. Conversely, yield from DT5, which was deep-tilled only in the fall of 1993, averaged 26.9 bushels per acre, or 16.4 bushels per acre (38%) less than the 43.3 bushels per acre average yield from the DT1-DT4 treatments. Yield from DT5 – adversely affected by the severe infestation of johnsongrass – was statistically similar to the 32.6-bushel yield from C. As in all past years, seed from all deep-till treatments were significantly heavier than seed from C.

When averaged across the 5-year study, yields from all deep-till treatments ranged from 42.2 to 51.4 bushels per acre and were significantly greater than the 36.3-bushel average yield from C. However, average yields from DT1, DT2, DT3, DT4, and PT1 were also significantly greater than average yield from DT5 (42.2 bushels per acre). Yields from DT1 (51.4 bushels per acre) averaged highest. However, yields from DT2, DT3, and PT1 averaged 48.4 bushels per acre, or 3 bushels (6%) less than the average yield from DT1. Yield from DT4 averaged 47 bushels per acre, or 4.4 bushels (9%) less than yield from DT1; DT5 averaged 42.2 bushels, 9.2 bushels (18%) less than DT1. Seed weight data indicate that all deep-till treatments produced seed that were significantly heavier than seed from C.

Table 4. Yield of soybean grown in deep-till production systems on Sharkey clay near Stoneville, Mississippi, 1994-1998.

Treatment [1]	Crop year					Overall average
	1994	1995	1996	1997	1998	
	bu/A	*bu/A*	*bu/A*	*bu/A*	*bu/A*	*bu/A*
DT1	42.1	27.5	36.7	28.4	31.0	33.1
DT5	42.2	22.4	32.2	27.7	25.7	30.0
PT1	43.2	24.5	30.7	25.0	29.0	30.5
C	39.1	15.1	31.0	28.6	24.9	27.7
LSD (0.05)	3.8	3.8	3.8	3.8	3.8	2.9

[1]DT1, deep-till annually; DT5, deep-till once every 5 years; PT1, paratill annually; and C, conventional tillage – disk annually.

Sharkey Clay

In 1994, yields from all deep-till treatments were similar and ranged from 42.1 to 43.2 bushels per acre (Table 4). Yields from DT1 and DT5 were virtually the same because both treatments were deep-tilled with the same implement in the fall of 1993. Yield from PT1 (43.2 bushels per acre) was significantly greater than yield from C (39.1 bushels). The lower yield from C is related to its lighter seed (not shown). Yields from all treatments in 1994 were the highest recorded during the 5-year study. Above-normal rainfall (11.6 inches) in July provided adequate moisture during the seed fill period, which accounted for these high yields.

The 1995 crop year began with above-average rainfall (7.4 inches) received over a 4-day period immediately after planting on April 17. All C plots developed a hard soil crust that measured approximately 1 inch thick. This condition adversely affected emergence and resulted in an unacceptable plant population in all C plots. Therefore, all C plots were replanted on May 8, 1995. Plant populations of all deep-till treatments were acceptable.

Yields from all treatments in 1995 were the lowest recorded during the 5-year study. Yields from DT1 and PT1, which were deep-tilled the previous fall, were similar and the highest. Yield from DT5, which was deep-tilled in the fall of 1993, was numerically lower but statistically similar to yield from PT1. Yield from C, which was replanted 21 days later than all deep-till treatments, averaged 15.1 bushels per acre and was significantly lower than yield from all deep-till treatments. The later planting date of all C plots caused the seed fill period *(2)* to coincide with the severe moisture deficits that occurred in July and August of 1995 (Table 2). All but 1.2 inches of the total July rainfall (5.8 inches) was received before July 6, while rainfall the remainder of July and all of August totaled only 2.6 inches. This drought stress resulted in lighter-than-normal seed from all treatments. However, seed from all deep-till treatments were significantly heavier than seed from C.

In 1996, yields from all treatments were greater than the long-term average for the region. Above-average rainfall during seed fill and cooler-than-normal temperatures in most months encourage good yields. Yield from DT1 (36.7 bushels per acre) was significantly greater than yields from all other treatments. Yields from DT5 and PT1 averaged 32.2 and 30.7 bushels per acre, respectively, and were similar to yield from C (31 bushels).

In the fall of 1995, a total of 1.9 inches of rain fell in August and September before deep tillage of DT1 and PT1 plots. This rainfall wet the upper portion (8 inches) of the soil profile. The lower yield from PT1 relative to DT1 in crop year 1996 could have been caused by the wet profile minimizing the degree of soil fracture when plots were tilled to a depth of 12 inches by the paratill plow. DT1 was tilled deeper (16 to 20 inches), which fractured and shattered the deeper and drier portion of the soil profile, and this may have resulted in the increased yield from DT1 in 1996.

In August and September 1996 – before deep tillage was performed – rainfall totaled 5.4 inches. This quantity of rainfall wet the entire soil profile and prevented the deep-till implements from fracturing and shattering the soil profile in all DT1 and PT1 treatment plots. During the 1997 growing season, rainfall was near normal each month and temperatures were slightly cooler than the long-term average. As a result of these conditions, yields from all treatments in 1997 were similar and ranged from 25 to 28.6 bushels per acre. The similarity of these yields indicates that the residual effect of annual deep tillage of the DT1 and PT1 treatments was insignificant and thus failed to increase yields of DT1 and PT1 above the C treatment yield in 1997.

In 1998, yield from DT1 (31 bushels per acre) was similar to yield from PT1 (29 bushels) and was significantly greater than the yields from DT5 (25.7 bushels) and C (24.9 bushels). Yield from DT5 was statistically similar to yields from PT1 and C.

Over the 5-year study, yields from DT1 (33.1 bushels per acre) averaged highest and were significantly greater than yields from DT5 (30 bushels) and C (27.7 bushels). Yields from PT1 averaged 2.6 bushels per acre (8%) less than yield from DT1. Yield from DT5 averaged 3.1 bushels per acre (9%) less than yields from DT1; C averaged 5.4 bushels (16%) less than DT1. Yields from DT5 and PT1 were in the intermediate range, but they were similar to yield from C. Seed weights from DT1, DT5, and PT1 were similar and were significantly greater than weight of seed from C.

Tunica Clay

Net returns above specified production costs (Table 5) from all deep-till treatments exceeded those from conventional treatment throughout the 5-year study. The only exception was in 1998 when net return from DT5 was lower because of the lower yield caused by the severe johnsongrass infestation.

In 1994, net return from the C treatment was $57 per acre. However, net returns from all deep-till treatments ranged from $110 to $145 per acre. In 1995, net return from the C treatment was low ($11 per acre) because of low yield and was not sufficient to cover basic land rental charges *(8)*. However, all deep-till treatments produced similar net returns, ranging from $98 to $117 per acre. In 1996, net returns from all deep-till treatments were similar and ranged from $185 to $224 per acre. Net return from C averaged $112 per acre, which was attributed to an above-average yield of 37.6 bushels per acre and a market price of $7.34 per bushel.

The relatively high yield of 51.3 bushels per acre from C in 1997 combined with a respectable price of $6.90 per bushel resulted in a net return of $211 per acre. However, as in all previous years, yields from all deep-till treatments averaged higher than yield from C and thus resulted in higher net returns. Net returns from DT1, DT2, DT3, and PT1 ranged from $262 to $300 per acre and were significantly greater than net return from C. Net returns from DT4 and DT5 were similar to net return from C. Net return from C in 1998 averaged $53 per acre, which was the second lowest during the 5-year study. Net returns from DT1, DT2, DT3, DT4, and PT1 were similar, ranging from $100 to $125 per acre – 89% to 136% greater than net return from C. Net return of $10 per acre from DT5 was similar to net return from C.

Over the 5-year study, net returns from all deep-till treatments ranged from $130 to $176 per acre and were significantly higher than average net return of $89 per acre from C. Average net return of $176 per acre from DT1 was the greatest; this return averaged $87 per acre (98%) greater than average net return from C. Net returns from DT2 and DT3 averaged $168 per acre – only 4% less than the average net return from DT1. Net returns from DT4 and PT1 averaged $160 per acre, which was 9% less than returns from DT1. Average net return from DT5 of $130 per acre was 26% less than net return from DT1.

Table 5. Net returns above specified production costs from soybean grown in deep-till production systems on Tunica clay near Stoneville, Mississippi, 1994-1998.

Treatment [1]	Crop year					Overall average
	1994	1995	1996	1997	1998	
	$/A	*$/A*	*$/A*	*$/A*	*$/A*	*$/A*
DT1	145	110	224	288	115	176
DT2	110	113	224	262	125	167
DT3	142	112	189	300	100	169
DT4	144	112	194	236	115	160
DT5	120	117	185	218	10	130
PT1	115	98	207	280	102	160
C	57	11	112	211	53	89
LSD (0.05)[2] min.	64	30	47	42	43	28
LSD (0.05)[2] max.	67	31	49	44	45	29

[1]DT1, deep-till annually; DT2, deep-till once every 2 years; DT3, deep-till once every 3 years; DT4, deep-till once every 4 years; DT5, deep-till once every 5 years; PT1, paratill annually; and C, conventional tillage – disk annually.
[2]The LSD values were not the same for all comparisons due to use of plot location as a covariate in the analysis of variance.

Table 6. Net returns above specified production costs from soybean grown in deep-till production systems on Sharkey clay near Stoneville, Mississippi, 1994-1998.

Treatment [1]	Crop year					Overall average
	1994	1995	1996	1997	1998	
	$/A	*$/A*	*$/A*	*$/A*	*$/A*	*$/A*
DT1	121	54	167	79	62	96
DT5	136	31	150	87	36	88
PT1	133	36	132	59	52	83
C	113	-37	136	90	36	67
LSD (0.05)	23	23	23	23	23	19

[1]DT1, deep-till annually; DT5, deep-till once every 5 years; PT1, paratill annually; and C, conventional tillage – disk annually.

Sharkey Clay

In 1994, net returns from all treatments were similar and ranged from a low of $113 per acre from C to a high of $136 per acre from DT5 (Table 6). Yield from PT1 was significantly greater than yield from C (Table 4); however, because of the higher production costs of PT1 due to deep tillage, the increase in yield was not great enough to produce a significantly greater net return.

Net returns from all treatments in 1995 were extremely low. However, net returns from DT1, DT5, and PT1 were similar and significantly greater than net return from C. Net return from DT1 averaged $54 per acre and provided some return to land and management. However, net returns of $31 per acre from DT5 and $36 per acre from PT1 were not sufficient to cover basic land rental values of $40 per acre *(8)*. Net return from C was negative (-$37 per acre), and was attributed to the higher production costs and the low yield associated with replanting on May 8.

In 1996, net return of $167 per acre from DT1 was the highest and was significantly greater than net returns of $132 per acre from PT1 and $136 per acre from C. In 1996, yield from DT1 was significantly greater than yields from all other treatments (Table 4). However, net returns from DT1 and DT5 were similar. Thus, the significantly higher yield from DT1 was not sufficient to offset the higher specified production costs for DT1 and thus increase net return above the net return from DT5.

Net returns from DT1, DT5, and C were similar in 1997. Net returns from DT5 and C were significantly greater than net return from PT1 because of the lower specified costs of production for DT5 and C. Net returns from DT1 and PT1 were similar because of the similarity of yields and the minor difference in specified costs of production.

In 1998, net return of $62 per acre from DT1 was the highest. This return was similar to net return of $52 per acre from PT1, and it was significantly greater than the $36 per acre net returns from DT5 and C. In this instance, the higher yield from DT1 in 1998 was sufficient to offset the higher specified costs of production for DT1 and to significantly increase net return above the net returns from DT5 and C. Net return from PT1 was only marginally profitable, whereas net returns from DT5 and C were not sufficient to cover land rental values.

Over the 5-year study, average net return of $96 per acre from DT1 was the highest. Net returns from DT5 and PT1 averaged $88 and $83 per acre, respectively, and were statistically similar to return from DT1. Net returns from DT1 and DT5 were significantly greater ($P \leq 0.05$) than net return of $67 per acre from C, whereas average net return from PT1 was greater than net return from C at $P = 0.10$.

SUMMARY

In dryland production systems, fall deep tillage of Tunica and Sharkey clay soils significantly increased yields and net returns above those produced by a conventional soybean production system. However, the annual and residual response to fall deep tillage was greater on the Tunica soil.

On Tunica clay, fall deep tillage performed annually (DT1) produced the highest average yield of 51.4 bushels per acre and net return of $176 per acre. Conversely, yield and net return from the conventional production system (C) averaged 36.3 bushels per acre and $89 per acre, respectively. Treatments in which fall deep tillage was performed once every 2 years (DT2) or once every 3 years (DT3) produced yields averaging 48.4 bushels per acre – 3 bushels (6%) less than yield from DT1. Net returns from these two treatments averaged $168 per acre, which was $8 (5%) less than net return from DT1. Yields from PT1 and DT4 averaged 48.2 and 47 bushels per acre, respectively, whereas net returns from each averaged $160 per acre – 9% less than net return from DT1. Yield from DT5 averaged 42.2 bushels per acre, which was 9.2 bushels (18%) less than yield from DT1. Net return from DT5 averaged $130 per acre – $46 (26%) less than from DT1. These data indicate fall deep tillage should be performed to a depth of 16-20 inches at least once every 3 years to maximize and sustain higher soybean yields and net returns on nonirrigated Tunica clay.

On Sharkey clay, fall deep tillage performed annually (DT1) produced the highest average yield of 33.1 bushels per acre and net return of $96 per acre. Lowest average yield and net return were from C: 27.7 bushels and $67 per acre. Yield from DT1 was similar to the 30.5-bushel-per-acre yield from PT1 and was significantly greater than the average yield of 30 bushels from DT5 and 27.7 bushels from C. Net returns from DT1 ($96 per acre), DT5 ($88), and PT1 ($83) were similar. However, only net returns from DT1 and DT5 were significantly greater than the $67 per acre return from C. These data indicate fall deep tillage should be performed annually on Sharkey clay to significantly increase soybean yield and net return above those produced from conventional tillage. Data are inconclusive relative to the residual effects of deep tillage on soybean yield. However, net return from fall deep tillage performed once every 5 years (DT5) was significantly greater than net return from C because of the lower tillage costs associated with DT5.

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