Bulletin 1117 **February 2002**

FALL TILLAGE FOR SOYBEAN GROWN ON DELTA CLAY SOILS

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The authors appreciate the expert technical assistance provided by Lawrence Ginn, Sandra Mosley, and Debbie Boykin; resources provided by the Delta Research and Extension Center; and supplemental funding provided by the United Soybean Board and the Mississippi Soybean Promotion Board. For more information, contact Dr. Heatherly by telephone at (662) 686-3128, by fax at (662) 686-5218, or by e-mail at lheatherly@ars.usda.gov. Bulletin 1117 was published by the Office of Agricultural Communication, a unit of the Division of Agriculture, Forestry, and Veterinary Medicine at Mississippi State University.

ABSTRACT

Conventional soybean production in the midsouthern United States has involved planting in a seedbed that had been shallow-tilled in the fall or spring just before planting. Moisture deficits that frequently occur during the growing season reduce yield of soybean in this traditional production system. Field experiments were conducted at Stoneville, Mississippi (lat. 33°26’N), on Tunica clay (clayey over loamy, smectitic, nonacid, thermic, Vertic Haplaquept) and Sharkey clay (very-fine, smectitic, thermic chromic Epiaquert) from 1993 through 2000. The objective was to compare yields and economic returns from plantings of MG IV and V soybean varieties grown on the two soils after shallow (ST) and deep (DT) fall tillage. Net returns were calculated as the difference between income and all direct and indirect costs excluding those for land, management, and general farm overhead. Costs for tillage in DT were $12 to $17 per acre greater than those for tillage in ST. Yields and net returns resulting from DT were greater than those from ST in all years on the Tunica soil. Yields and net returns from nonirrigated April/early May plantings after DT on Sharkey clay were significantly greater than those from ST in only 1 year out of 5. Yields and net returns from nonirrigated mid-May/early June plantings after DT were never significantly different from those of ST. The DT treatment followed by irrigation of the soybean crop the following year did not affect yield or net return. These results indicate that deep tillage of Tunica clay soil will result in significantly greater yield and net return, while deep tillage of Sharkey clay soil only has potential for increasing both when plantings are made in early April.

ABBREVIATIONS: DOP – date of planting; DT – deep fall tillage; FT – fall tillage; I – irrigated or irrigated environment; MG – maturity group; NI – nonirrigated or nonirrigated environment; ST – shallow fall tillage.

Fall Tillage for Soybean Grown on Delta Clay Soils

INTRODUCTION

Conventional soybean production in the midsouthern United States has involved planting in a seedbed that had been disk- or spring-tooth-harrowed in the fall and left untilled before planting, or harrowed in the spring just before planting. Use of this system has been associated with low average yield from nonirrigated (NI) plantings over the past two decades.

The frequency and severity of moisture deficits at Stoneville, Mississippi (lat. 33°26'N), typically increase from April through September (Boykin et al., 1995). Van Bavel (1959) calculated that the number of drought days (number of days in a period when potential evapotranspiration exceeds capacity of soil to supply that amount of water) in the middle Mississippi River Valley was near zero in April and May, but drought days climbed to 13, 14, and 15 days per month in June, July, and August, respectively. The effect of the drought days in July and August was compounded by previous periods with a high incidence of drought. Varieties planted in May or later typically flowered, set pods, and filled seeds during the hottest and driest portion of the growing season when moisture deficits were greatest (Boykin et al., 1995), and soil water normally was depleted. Thus, they were susceptible to yield limitations imposed by drought. Results from research at Stoneville revealed that May and June plantings of these cultivars were high-risk enterprises (Heatherly, 1998).

Clay soils occupy more than 9 million acres or about 50% of the land area in the lower Mississippi River alluvial flood plain in the midsouthern United States. Of these clay soils, Sharkey is the dominant series and comprises about 3 million acres in the Mississippi River flood plain regions of Arkansas, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee (Pettry and Switzer, 1996). Soils of the Sharkey series are clayey throughout the profile. Soils of the Tunica series occupy a much smaller percentage of the Delta area than do Sharkey soils. Tunica soils differ from Sharkey soils by having coarser textured materials at 20 to 30 inches below the clay surface layers. Soybean is planted on the majority of the cropped clay soils, and most of these plantings of soybean on clay are not irrigated. Thus, low-yield-potential, high-risk dryland production is the normal system (Heatherly, 1998a; Williams, 1998). Profitable production systems are needed for soybean on these nonirrigated sites.

If spring tillage is conducted, it almost always delays planting, and on poorly drained clay soils, that delay frequently becomes extended to weeks because of inconveniently timed spring rains. Heatherly (1981) measured almost identical yields where Sharkey clay was deep-tilled (subsoiled 15 to 18 inches deep) in the spring (March or April) when the soil was wet compared with shallow, disk-harrow spring tillage before May or later soybean planting. This lack of significant effect on soybean yield from deep tillage of wet clay in the spring recently has been confirmed (Popp et al., 2001).

Wesley and Smith (1991) performed deep tillage on a Tunica clay in the fall after soybean harvest when the soil profile was dry because of growing season soil water depletion. They measured large, significant yield increases from soybean planted the following May during years when drought occurred during the growing season, and they determined that net return was greatly increased from this practice (Wesley et al., 1994). The increased production was associated with increased moisture content in the soil, presumably because of greater infiltration and storage resulting from the deep tillage. This work has been used to promote the deep tillage of all dry clay soils in the fall. Studies on Sharkey clay in Arkansas (36°N lat.; Popp et al., 2001) and Mississippi (Wesley et al., 2001) showed average increases in yield of 8.6 and 5.4 bushels per acre, respectively, and average increases in net return of $39 and $29 per acre, respectively, from DT. Yield levels (36 to 44 bushels per acre) in the Arkansas study indicated that summer drought was not severe. The

Mississippi study used estimated DT costs that were a low $7 to $8 per acre more than those for ST.

The objective of this work was to compare yields and economic returns from April and May or later plantings of Maturity Group (MG) IV and V soybean varieties grown with and without irrigation on clay soils after shallow and deep tillage in the fall when soil was dry. Economic analysis of 8 years of results was conducted to assess and compare the profitability of the two tillage systems.

MATERIALS AND METHODS

Field studies were conducted from 1993 through 2000 at the Delta Research and Extension Center (DREC) in Stoneville, Mississippi. MG IV and V soybean varieties (Table 1) were planted in stale seedbeds in 20-inch-wide rows on the dates shown in Table 1 after fall tillage of Tunica clay and Sharkey clay soils. Planting rate was 4.5 to 5 seed per foot of row to achieve a per-acre seeding rate of about 120,000 seed per acre. Seed were treated before planting with metalaxyl (Apron) in 1993-1996, with mefenoxam (Apron XL) in 1997, with mefenoxam plus carboxin plus thiram in 1998 and 1999, and with metalaxyl plus carboxin plus thiram in 2000 as a precaution against *Pythium* spp., *Rhizoctonia* spp., and seed-borne fungi.

Nonirrigated (NI) experiments (Experiments 1, 2, and 3) were conducted during all years, and irrigated (I) experiments (Experiment 3) were conducted in 1999 and 2000. Fall tillage (FT) treatments were either shallow tillage (ST) with a disk harrow and/or field cultivator, or deep tillage (DT) to a depth of 15 to 18 inches using a subsoiler with tines spaced 40 inches apart, followed by smoothing with a disk harrow and field cultivator. The number of tillage operations was generally two for ST and three for DT after subsoiling. In Experiment 1, a randomized complete block design was used. In Experiment 2 and Experiment 3, FT treatments were blocked in separate but adjacent areas. In Experiment 2, planting dates were randomized within

Table 1. Dates of fall deep tillage, rainfall before deep tillage, planting dates, varieties, and weed management inputs for nonirrigated and irrigated experiments conducted at Stoneville, Mississippi, 1993-2000.

Date tilled	Pretill rain [1]	Date planted	Irrigation [2]	Variety (MG)	Herbicides [3]
Experiment 1 — Tunica clay					
10/5/92	2.75	4/29/93	NI	RA 452 (IV)	PRE: Metribuzin and Metolachlor; POST: Bentazon
9/24/93	2.10	4/11/94	NI	RA 452	PRE: Metribuzin and Metolachlor; POST: Fomesafen and Fluazifop
9/12/94	0.45	4/17/95	NI	DP 3589 (V)	PRE: Metribuzin and Metolachlor; POST: Sethoxydim (FT) and 2,4-DB + Linuron
9/28/95	1.63	4/30/96	NI	DP 3589	PRE: Metribuzin and Metolachlor; POST: Sethoxydim and 2,4-DB + Linuron
9/25/96	1.81	4/8/97	NI	DP 3588 (V)	PRE: Metribuzin + Chlorimuron; POST: Fluazifop and 2,4-DB + Linuron
9/30/97	2.19	4/1/98	NI	DP 3588	PRE: Metribuzin + Chlorimuron; POST: Sethoxydim (FT) and 2,4-DB + Linuron
Experiment 2 — Sharkey clay [4]					
9/28/94	1.14	4/18/95	NI	DP 3478 (IV), Hutcheson (V)	PRE: Metribuzin and Metolachlor; POST: Fomesafen
		5/9/95	NI	DP 3478, Hutcheson	PRE: Metribuzin and Metolachlor; POST: Fomesafen and Bentazon + Acifluorfen
10/5/95	1.51	4/30/96	NI	DP 3478, Hutcheson	PRE: Metribuzin and Metolachlor; POST: 2,4-DB + Linuron
		5/15/96	NI	DP 3478, Hutcheson	PRE: Metribuzin and Metolachlor; POST: 2,4-DB + Linuron
10/5/97	2.11	4/9/98	NI	DP 3478, Hutcheson	PRE: Metribuzin + Chlorimuron; POST: Bentazon + Acifluorfen (ST); 2,4-DB + Linuron (DT)
		6/10/98	NI	DP 3478, Hutcheson	PRE: Metribuzin + Chlorimuron; POST: 2,4-DB + Linuron
9/23/98	2.90	5/4/99	NI	DP 3478, Hutcheson	PRE: Metribuzin + Chlorimuron; POST: 2,4-DB + Linuron
		5/24/99	NI	DP 3478, Hutcheson	PRE: Metribuzin + Chlorimuron; POST: 2,4-DB + Linuron
10/4/99	1.72	4/27/00	NI	DP 3478, Bolivar (V)	PRE: Metribuzin + Chlorimuron; POST: Bentazon + Acifluorfen
		5/17/00	NI	DP 3478, Bolivar [5]	PRE: Metribuzin + Chlorimuron; POST: Bentazon + Acifluorfen
Experiment 3 — Sharkey clay					
9/22/98	2.90	4/22/99	I	SG 468 (IV), AP 4880 (IV)	POST: Bentazon + Acifluorfen and Select (Conv.); Roundup Ultra twice (GR)
9/23/98	2.90	5/3/99	NI	SG 468, AP 4880	POST: Bentazon + Acifluorfen and Select (Conv.); Roundup Ultra twice (GR)
9/14/99	1.39	4/20/00	I	SG 498 (IV), AP 4882 (IV) [6]	POST: Bentazon + Acifluorfen and Sethoxydim (Conv.); Roundup Ultra twice (GR)
10/4/99	1.14	4/27/00	NI	SG 498, AP 4882	POST: Bentazon + Acifluorfen and Sethoxydim (Conv.); Roundup Ultra (GR)

[1] Rainfall during 30 days preceding deep tillage date.
[2] NI = not irrigated; I = irrigated.
[3] PRE = preemergent; POST = postemergent; Conv. = applied to conventional varieties; GR = applied to glyphosate-resistant varieties; FT = applied to fall deep tilled; ST = applied to fall shallow tilled.
[4] 1997 plantings are not included because wet soil in the fall of 1996 prevented subsoiling.
[5] Premature death caused by drought.
[6] SG 498 and SG 468 are glyphosate-resistant half-siblings; AP 4882 and AP 4880 are conventional half-siblings.

each FT area, and varieties were randomized within each planting date block. Four replicates were used in all experiments. Alleys in Experiments 1 and 2 were not tilled after planting so that water movement through the deep furrows created at planting of the soft Sharkey clay would be unrestricted from individual plots for the entire length of each field. All experimental units remained in the same location for the duration of the research.

All tillage operations were started immediately after harvest of soybean when soil was dry. Dates of subsoiling and rainfall for the 30-day period preceding it are shown in Table 1. Effective deep tillage could not be done in the fall of 1996 because of wet soil resulting from 8 inches of rain that fell from August 10 through September 30. Thus, results from 1997 Experiment 2 are not included. Deep tillage of the Tunica clay site was done in the direction of the row. On the Sharkey sites, DT was performed at a 45-degree angle to row direction to prevent the planting tractor from sinking in the subsoil slits. Weather data in Table 2 were collected by the NOAA Midsouth Agricultural Weather Service Center in 1993-1995 and by DREC personnel in 1996-2000.

Plantings were made into a stale seedbed on the dates shown in Table 1 after application of glyphosate (0.75 pound of active ingredient per acre) to kill weeds. After planting, weeds were managed every year with preemergent and/or postemergent herbicides (Table 1) applied at labeled rates so that weed competition was not a factor limiting crop production.

In irrigated Experiment 3, water was applied by the furrow method through gated polyvinyl pipe whenever soil water potential at the 12-inch depth, as measured by tensiometers, decreased to about -70 centibars. Irrigation was started near beginning bloom and was ended near or at full seed stage. Irrigation amounts were determined by the degree of cracking in this shrink-swell soil (cracks when dry, swells when wet), since water applied to it through surface irrigation flows downward to the depth of cracking and rises to the surface as the cracks fill (Mitchell and van Genuchten, 1993).

All production inputs within each year were recorded for all experiments. Estimates of total costs and returns were developed for each annual cycle of each experimental unit using the Mississippi State Budget Generator (Spurlock and Laughlin, 1992). Total specified expenses were calculated using actual inputs for each treatment of each study in each year and included all direct and fixed costs, but they excluded costs for land, management, and general farm overhead, which were assumed to be the same for all treatment combinations. Direct expenses included costs for herbicides, seed, gated polyvinyl pipe used in irrigation, and labor; costs for fuel, repair, and maintenance of machinery and irrigation systems; cost of hauling harvested seed; and interest on operating capital. Fixed expenses were ownership costs for tractors, self-propelled harvesters, implements, sprayers, and the irrigation system. Costs of variable inputs and machinery were based on prices paid by Mississippi

Table 2. Weather variables for indicated months and years at Stoneville, Mississippi.

Month	Avg. max. temperature	Total rainfall (R)	Total pan evaporation (PE)	Difference (R-PE)
	°F	*in*	*in*	*in*
		30-year normals [1]		
May	82	5.0	7.7	-2.7
June	90	3.7	8.5	-4.8
July	91	3.7	8.2	-4.5
Aug.	90	2.3	7.3	-5.0
		1993		
May	82	6.6	7.2	-0.6
June	91	3.8	8.3	-4.5
July	96	2.8	9.3	-6.5
Aug.	94	3.1	7.2	-4.1
		1994		
May	82	5.1	7.6	-2.5
June	92	2.0	7.8	-5.8
July	90	11.6	6.5	5.1
Aug.	91	0.4	6.9	-6.5
		1995		
May	86	3.1	8.0	-4.9
June	89	4.0	8.8	-4.8
July	91	5.8	8.4	-2.6
Aug.	95	1.4	8.6	-7.2
		1996		
May	88	2.4	10.6	-8.2
June	89	5.2	7.0	-1.8
July	91	3.3	7.9	-4.6
Aug.	89	4.3	6.4	-2.1
		1997		
May	80	5.8	7.8	-2.0
June	87	4.2	7.5	-3.3
July	94	2.9	8.0	-5.1
Aug.	89	2.8	7.3	-4.5
		1998		
May	87	4.6	8.2	-3.6
June	92	1.6	9.8	-8.2
July	94	5.7	7.8	-2.1
Aug.	94	0.7	7.6	-6.9
		1999		
May	84	5.7	8.5	-2.8
June	89	2.8	8.4	-5.6
July	93	1.0	7.8	-6.8
Aug.	96	0.2	9.2	-9.0
		2000		
May	85	6.9	8.0	-1.1
June	90	6.1	7.6	-1.5
July	94	0.6	8.6	-8.0
Aug.	98	0.0	8.7	-8.7

[1] 1964-1993 (Boykin et al., 1995).

farmers each year. Irrigation costs were based on a 160-acre irrigation setup and included an annualized cost for the engine, well, pump, gearhead, generator, fuel tank and lines, and land leveling. Total fixed costs of the irrigation system consisted of annual depreciation, interest on investment, and insurance. Machinery ownership cost was estimated by computing the annual capital recovery charge for each machine and applying its per-acre rate to each field operation.

Income from each experimental unit was calculated using the market-year average price for Mississippi of $6.53, $5.59, $6.76, $7.34, $6.90, and $5.63 per bushel for 1993 through 1998, respectively. The USDA loan rate for Mississippi of $5.35 per bushel was used for calculations of income from the 1999 and 2000 experiments. Yearly prices instead of an average long-term price were used to reflect the effect of market forces on income for each individual year. Net returns above total specified expenses were determined for each experimental unit each year.

Soybean plant height at maturity was recorded for each plot in each experiment (except 1993 to 1996 Experiment 1) just before harvest to determine the possible effect of FT on plant stature. A field combine modified for small plots was used to harvest the four center rows of each plot. Yields were adjusted to 13% moisture content. The MG V variety was not harvested in date of planting (DOP) 2 of Experiment 2 because of premature death caused by drought.

Analysis of variance (PROC MIXED; SAS Institute, 1996) was used to evaluate the significance of effects on plant height, seed yield, and net returns. For Experiment 1, analyses across years treated year as a fixed effect to determine interactions involving year. For Experiments 2 and 3, year and all factors were treated as fixed in across-years analysis. Separation of main effect means was achieved using F-test significance. Where significant interactions among factors occurred, mean separation was accomplished with an $LSD_{0.05}$.

RESULTS

Weather

In 1993, July and August average maximum temperatures were above normal, while July plus August rainfall was near normal (Table 2). This resulted in the July plus August moisture deficit (rainfall minus pan evaporation) being slightly more than normal. In 1994, average maximum temperatures were near normal, July rainfall was well above normal, and August rainfall was well below normal. In 1995, average maximum air temperatures were well above normal in May and August. Moisture deficits in 1995 were above normal in May and August, but below normal in July. The July 15 to August 31 period received only 1 inch of rain. Average maximum air temperatures in 1996 were near normal for most months. The months of June through August had near- or below-normal moisture deficits. In 1998, the May through August period was generally hotter than normal, and moisture deficits were above normal in all months except July. The July 15 to August 31 period received only 0.7 inch of rain. Both 1999 and 2000 had July and August temperatures that were well above normal and July and August rainfall amounts that were greatly below normal. In essence, all years had periods of low rainfall and high temperatures that resulted in drought stress conditions during some portion of the soybean growing season.

Costs

Costs within a planting date and/or irrigation treatment within each year and experiment were essentially the same, except for the difference in cost between DT and ST. Estimated costs associated with DT ranged from $12 to $17 per acre more than those for ST. This resulted from an estimated subsoiling cost of $9 to $12 per acre and an extra disking or spring-tooth harrowing in DT that cost an estimated $3 to $5 per acre. This extra estimated expense that was associated with the DT treatment in our study was similar to the additional $18 per acre estimated extra expense for subsoiling of Sharkey clay in a recent Arkansas study (Popp et al., 2001). Studies conducted by Wesley et al. (2001) estimated additional costs for DT treatments as only $7 to $8 per acre, since tillage after DT in their study was identical to that used in an ST treatment.

Experiment 1

The MG V variety grown in 1995 through 1998 averaged 35 and 29 inches tall in DT and ST treatments, respectively (Table 3). Subsoiling Tunica clay before April planting resulted in increased yield and net return in all years of the experiment. A significant interaction between year and FT for both seed yield and net return occurred because the magnitude of difference between ST and DT values ranged from 7.1 to 27.8 bushels per acre and from $28 to $144 per acre. Across the 6 years, average yield and net return were 17.3 bushels per acre and $87 per acre greater because of DT. Thus, deep tillage of the Tunica clay at this site resulted in profitable yield increases over the term of this experiment. These results are almost identical to those of Wesley et al. (2001), who reported a 5-year average yield increase of 15.1 bushels per acre and a 5-year average increase in net return of $87 per acre from DT during the same years of this study on nonirrigated Tunica soil.

Table 3. Seed yield and net return from nonirrigated MG IV and MG V varieties grown on Tunica clay after fall deep tillage (DT) or shallow tillage (ST) at Stoneville, Mississippi, 1993-1998. (Experiment 1).

Planting date	Variety (MG)	Seed yield		Net return	
		DT	ST	DT	ST
		bu/A	*bu/A*	*$/A*	*$/A*
4/29/93	RA 452 (MG IV)	24.7	17.6	10	-18
4/11/94	RA 452	53.5	35.9	138	61
4/17/95	DP 3589 (MG V)	41.3	13.5	108	-36
4/30/96	DP 3589	59.5	43.1	279	187
4/8/97	DP 3588 (MG V)	60.7	45.4	266	175
4/1/98	DP 3588	43.1	23.0	98	10
Avg.		47.1 A[1]	29.8 B	150 A	63 B

[1] Differences between average values for each trait significant at $p \le 0.05$.

Experiment 2

General

Analysis of variance revealed that interactions between year and all other factors were significant for seed yield and net return (Table 4). Therefore, results are presented on an individual year basis. No significant or meaningful interactions involving FT, DOP, or variety occurred for plant height. Since there are no results from DOP 2 for the MG V variety in 2000, a long-term mean for the later planting of the MG V cultivar to compare with the 1995 through 2000 average for the MG IV cultivar was not calculated in Table 4.

1995

The deep tillage treatment resulted in an average plant height of 25 inches vs. an average of 22 inches for plants in ST, and plants in DOP 2 were 4 inches taller than those in DOP 1. Average yields of 34.3 and 32.4 bushels per acre from DT and ST, respectively, were not significantly different (Table 4). Average yield of 37.8 bushels per acre from DOP 1 was greater than the 29 bushels per acre average yield from DOP 2. The slightly higher (1.9 bushels per acre) average yield from DT was sufficient to offset the higher costs associated with DT; thus, resultant average net returns from ST and DT were nearly identical at $103 per acre and $100 per acre, respectively (Table 4). Net return of $142 per acre from DOP 1 was greater than the $62 per acre from DOP 2.

1996

Plants in DT averaged 27 inches in height compared with 25 inches for those in ST, but the difference was not significant. Plants in DOP 2 were 5 inches taller than those in DOP 1. Average yield (38 bushels per acre for DT and 33.2 bushels per acre for ST) and average net return ($148 per acre for DT vs. $127 per acre for ST) were not significantly different between DT and ST (Table 4). Average DOP 1 yield (37.7 bushels per acre) and net return ($142 per acre) were greater than those from DOP 2 (29 bushels per acre and $62 per acre).

1998

The 25-inch average height of DT plants was significantly greater than the 20-inch average height of ST plants. Plants in DOP 2 were 13 inches taller than plants in DOP1. Yield and net return were significantly affected by the FT x DOP interaction (Table 4). In DOP 1, average yield of 31.8 bushels per acre after DT was significantly greater than the average ST yield of 22.4 bushels per acre, while in DOP 2, the difference between the 13.4 bushels per acre from DT and the ST average of 11.6 bushels per acre was not significant. Differences in net returns followed the same pattern; i.e., net returns from DOP 1 DT were greater than those from DOP 1 ST, but DT and ST net returns in DOP 2 were not different. All net returns from DOP 2 treatment combinations were negative.

1999

Plants in DT averaged 29 inches tall compared with 23-inch-tall plants in ST, and plants in DOP 1 were 25 inches tall compared with 26-inch-tall plants in DOP 2. In this extremely dry year, all FT differences in yield and net return were nonsignificant (Table 4). All yields were less than 17 bushels per acre, and all net returns were negative.

2000

Plants in DT were a significant 4 inches taller than those in ST (34 vs. 30 inches). As mentioned earlier, the MG V variety in DOP 2 was not harvested. In DOP 1, average yield of 16.4 bushels per acre from DT was significantly greater than the 11.4 bushels per acre average yield from ST, but average net return from DT was not significantly different from average net return from ST, and both were negative (Table 4).

Overall

Across all years of the study, plants in DT DOP 1 were an average 3 inches or more taller than plants in ST. Over the 5 years of this study, increases in yield and net return from DT were significant only in DOP 1 in 1998. Fall subsoiling gave a 5-year average yield increase of 5.3 bushels per acre from the DOP 1 MG IV variety and 4.6 bushels per acre for the DOP 1 MG V variety in the April plantings. The increases in net returns to subsoiling in the early planting averaged $17 per acre for the MG IV variety and $14 per acre for the MG V variety. Thus, yield increases to subsoiling preceding the early planting in this experiment were not sufficient to result in large increases in profit. Average yield increase to subsoiling in the later plantings was only 1.7 bushels per acre for the MG IV variety, and the very small difference in net return between DT DOP 2 and ST DOP 2 was not significant.

These results are somewhat different from those of Popp et al. (2001) from Arkansas and Wesley et al. (2001) from Mississippi for Sharkey soil. They showed both increased yield and net return resulting from DT of Sharkey clay over the period of their studies. The Arkansas results were based on 1995-1997, when yield levels were moderately high for NI soybean (36 bushels per acre for ST and 44 bushels per acre for DT). This may have allowed effects of DT to be significantly expressed in the absence of severe drought such as occurred at Stoneville in 1999 and 2000. The Mississippi results (1994-1998) showed the same average yield response (5.4 bushels per acre) from a MG IV variety after DT as we did over the 1995-2000 period, but their lower estimated cost for DT may have contributed to their net return differences being significant and ours not. The Mississippi studies were planted from April 7 to May 1 each year, and 2 years out of the 5 had nonsignificant yield and net return responses to DT.

Table 4. Seed yield and net return from nonirrigated DP 3478 (MG IV) and Hutcheson (MG V) varieties grown on Sharkey clay after fall deep tillage (DT) or shallow tillage (ST) at Stoneville, Mississippi, 1995-2000 (Experiment 2).

Fall tillage (FT)	Date of planting (DOP)	Yield			Net return		
		3478	Hutcheson[1]	Avg.	3478	Hutcheson[1]	Avg.
		bu/A	*bu/A*	*bu/A*	*$/A*	*$/A*	*$/A*
DT	4/18/95	43.2	35.7	39.4	166	124	145
	5/9/95	30.3	28.0	29.2	60	51	56
	Avg.	36.8	31.8	34.3 A[2]	113	88	100 A
ST	4/18/95	38.2	33.9	36.0	150	127	138
	5/9/95	29.3	28.4	28.8	68	68	68
	Avg.	33.8	31.2	32.4 A	109	98	103 A
DT	4/30/96	32.3	45.2	38.8	112	209	160
	5/15/96	29.0	45.2	37.1	76	196	136
	Avg.	30.7	41.2	38.0 A	94	202	148 A
ST	4/30/96	29.2	37.2	33.2	101	164	132
	5/15/96	25.1	41.4	33.2	62	182	122
	Avg.	27.2	39.3	33.2 A	82	173	127 A
DT	4/9/98	37.9	25.8	31.8 a	83	21	52 a
	6/10/98	12.0	14.7	13.4 c	-78	-58	-68 c
	Avg.	25.0	20.2	22.6	2	-18	- 8
ST	4/9/98	26.0	18.7	22.4 b	33	- 3	15 b
	6/10/98	12.1	11.2	11.6 c	-63	-64	-64 c
	Avg.	19.0	15.0	17.0	-15	-34	-24
DT	5/4/99	15.3	14.9	15.1	-40	-43	-42
	5/24/99	13.2	16.6	14.9	-62	-44	-53
	Avg.	14.2	15.8	15.0 A	-51	-44	-48 A
ST	5/4/99	13.7	14.2	14.0	-37	-34	-36
	5/24/99	12.6	13.9	13.2	-53	-46	-50
	Avg.	13.2	14.0	13.6 A	-45	-40	-43 A
DT	4/27/00	19.4	13.3	16.4 A	-29	-54	-42 A
	5/17/00	10.7			-74		
ST	4/27/00	14.5	8.2	11.4 B	-37	-63	-50 A
	5/17/00	7.4			-73		
DT DOP 1 avg.		29.6	27.0	28.3	58	51	55
ST DOP 1 avg.		24.3	22.4	23.4	42	38	40
DT DOP 2 avg.		19.0			-16		
ST DOP 2 avg.		17.3			-12		

[1] Bolivar replaced Hutcheson in 2000.

[2] FT means in individual columns within year followed by a different upper-case letter, or FT x DOP means in individual columns within year followed by a different lower-case letter, are significantly different at $p \leq 0.05$.

Experiment 3

Significant interactions between year and FT or between year and variety occurred (Table 5). Therefore, analyses were conducted and results are presented by year. Plants in DT were always taller than those in ST. In 1999, NI plants in DT were an average 40 inches tall vs. 34 inches tall in ST. Plants in I DT averaged 36 inches tall compared with 30 inches tall for plants in I ST. In 2000, NI DT plants were 32 inches tall compared with 30 inches tall for NI ST plants, while I DT plants were 34 inches tall vs. 31 inches for I ST plants. In NI, severe drought in 1999 and 2000 resulted in extremely low yields and negative net returns. Fall tillage treatment had no significant affect on either variable in either year. In irrigated plantings, differences between DT and ST yields and net returns were not significant in either year. Irrigated yields averaged 64.3 and 62.5 bushels per acre for DT and ST, respectively. These irrigated test results indicate that fall deep tillage of Sharkey clay that will be cropped to irrigated soybean the following year is not feasible. The NI findings from the dry 1999 and 2000 are identical to those from the 1999 and 2000 studies of Experiment 2.

Table 5. Seed yield and net return from nonirrigated and irrigated glyphosate-resistant (GR) and conventional (C) MG IV varieties grown on Sharkey clay after fall deep tillage (DT) or shallow tillage (ST) at Stoneville, Mississippi, in 1999 and 2000 (Experiment 3).

Year	Variety	Yield			Net return		
		DT	ST	Avg.	DT	ST	Avg.
		bu/A	*bu/A*	*bu/A*	*$/A*	*$/A*	*$/A*
		Nonirrigated					
1999	SG 468 (GR)	11.6	14.8	13.2	-54	-26	-40
	AP 4880 (C)	12.0	8.4	10.2	-50	-56	-53
1999 avg.		11.8 A[1]	11.6 A		-52 A	-41 A	
2000	SG 498 (GR)	14.3	12.0	13.1	-32	-27	-30
	AP 4882 (C)	16.8	15.8	16.3	-35	-23	-29
2000 avg.		15.6 A	13.9 A		-34 A	-25 A	
Across year average		13.7	12.8		-43	-33	
		Irrigated					
1999	SG 468	56.3	57.2	56.7	125	147	136
	AP 4880	65.3	60.4	62.8	173	160	167
1999 avg.		60.8 A	58.8 A		149 A	153 A	
2000	SG 498	64.5	64.5	64.5	159	177	168
	AP 4882	71.0	68.0	69.5	191	189	190
2000 avg.		67.7 A	66.2 A		175 A	183 A	
Across year average		64.3	62.5		162	168	

[1] Tillage averages within year followed by different letters are significantly different at $p \le 0.05$ (according to F test).

DISCUSSION AND CONCLUSIONS

These results indicate that fall subsoiling of dry Sharkey clay will be a breakeven proposition in the worst-case scenario, and it will increase net returns in April but not May plantings in the best-case scenario. Fall subsoiling was especially beneficial for the early-April planting of 1998 in Experiment 2, when extreme drought occurred during the growing season. The extreme drought of 1999 and 2000 precluded any appreciable effect from subsoiling in NI when DOP 1 was in late April/early May. In those 2 years, all NI yields were low and all net returns were negative. Yields after DT of the Sharkey soil in NI did not approach the high yield and net return levels obtained from irrigated plantings of these (Table 5) and other varieties (Heatherly and Spurlock, 1999) at this location.

These yield and net return responses achieved as a result of DT of Sharkey clay are not of the magnitude of those achieved on Tunica clay by Wesley and Smith (1991), Wesley et al. (1994, 2001), or our Experiment 1. Presumably, the improved soil moisture status resulting from deep tillage that was measured by Wesley and Smith (1991) was not as effective for soybean grown on Sharkey clay in this study, even though moisture deficits were experienced in all years. Rainfall amounts between fall DT dates and planting dates in Experiment 1 were 24.5 inches in 1992-93, 27 inches in 1993-94, 36.6 inches in 1994-95, 28.2 inches in 1995-96, 39.4 inches in 1996-97, and 29.1 inches in 1997-98. For Experiment 2, rainfall amounts between the earliest DT and the earliest planting were 35.6 inches in 1994-95, 27.6 inches in

1995-96, 30 inches in 1997-98, 37.3 inches in 1998-99, and 33.4 inches in 1999-00. For Experiment 3, rainfall amounts between DT and planting were 37.3 and 33.4 inches for 1998-99 and 1999-00, respectively. These amounts were distributed over the approximately 6-month period between FT and planting dates in a manner that would have allowed a fully recharged soil profile at the beginning of each growing season.

Using a $5-per-bushel price for soybean, a 2.4- to 3.4-bushel-per-acre yield increase would be required to break even using the $12- to $17-per-acre higher tillage cost associated with DT in these studies. Thus, with low commodity prices, significant profitability from deep tillage of these clay soils in the fall will require consistently larger yield increases than those obtained in this study. The significant yield increase of 11.9 bushels per acre obtained from the April planting of DP 3478 in 1998 of Experiment 3 provides a more positive outlook for increased profits if prices are higher than those used here. Thus, the use of DT on this soil should be based on anticipated early-April planting and expected commodity price because significant economical yield increases were not consistently achieved.

The importance of the increased plant height resulting from DT indicates that plants in DT had more available soil water for growth, as measured by Wesley et al. (1991). This increased growth was achieved during the vegetative growth period (April, May, and early June) of each season, and it should have provided a positive effect on weed control, especially considering the short stature of some of the early-planted cultivars. The taller stature of plants after DT did not translate to greater yields in NI because drought during the reproductive portion (mid-June through mid-August) of each growing season restricted seed formation and seed filling.

Before deciding whether to undertake fall subsoiling, a producer should evaluate its potential net economic benefits. Additional crop revenue could arise if the yield impact is positive, while additional costs will be incurred to acquire the needed machinery and perform the tillage operation. Assuming the producer owns a subsoiler, its initial purchase price must be prorated over its expected useful life in order to estimate accurately its ownership cost on an annual basis. Performing the tillage operation will generate other expenses such as fuel, operator labor, interest on operating expenses, and repairs and maintenance on the implement and tractor. The total cost of subsoiling would be the sum of the ownership and operating costs of the tractor and implement.

A variety of types and sizes of deep tillage implements is available. In this study, a three-shank parabolic subsoiler pulled by a 225-horsepower track tractor was assumed to be in use. The list price of the subsoiler (new in 2000) was about $3,200. A larger or more specialized new tillage tool would be more expensive, while a used implement would be less expensive. The annual ownership cost for a subsoiler, plus its expected per-acre repair and maintenance expenses, would usually be much lower than these expenses for the tractor. Thus, the costs attributed to the subsoiler are relatively small compared with those related to the tractor. Operator labor and fuel expenses would normally account for the majority of the expected operating costs of the subsoiling operation.

Once the producer has purchased a subsoiler, the decision to subsoil in a given year depends only on whether the potential revenue gain will be greater than the additional operating cost — not the additional total cost. In this case, the producer should not be concerned with covering both the operating cost and the annualized ownership cost because the ownership cost will remain constant regardless of whether subsoiling is performed; that is, the ownership cost is fixed in the short term. The only relevant cost to consider when making a short-term decision is the operating cost. On the other hand, a producer who has not purchased a subsoiler yet should consider returns above total costs before making the purchase; that is, the long-term decision should be to purchase the subsoiler only if the additional revenue can cover both operation and ownership costs. In this study, we have computed returns above total costs. Thus, producers who already own a subsoiler (and are evaluating the short-term decision of whether to subsoil) should attempt to estimate the likely returns above their own operating costs.

If equipment for deep tillage is on hand (fixed cost incurred), the occasional response of early-planted cultivars to DT of Sharkey clay indicates that over the long term, net return will be increased from DT. If equipment is not on hand, these results do not support the investment required to obtain the necessary equipment. In no case should this practice be used for May and later plantings, or to replace existing irrigation capability.

These results further confirm the importance of April planting of soybean cropped on nonirrigated clay sites in the midsouthern United States, regardless of fall tillage input. Yields and net returns from the early plantings were consistently greater than those from the later plantings were. Deep tillage in the fall erratically complemented this system on Sharkey clay. Thus, the advantage from using deep tillage was not as consistent or pronounced as was the advantage from using early planting. An artifact of the deep tillage of the Sharkey sites was that planting in April was often delayed past the intended early part of the month because of extremely soft soil resulting from fall subsoiling.

From these results, and from those of previous studies (cited earlier) conducted at this location, it appears that soil series plays an integral part in the response of dryland soybeans to subsoiling of clay soils. More specifically, the Tunica clay showed a consistently large response to fall subsoiling, while the Sharkey clay showed a smaller and less consistent response.

Results from agronomic research rarely are devoid of effects of years or interactions between or among years and experimental variables. Thus, the above conclusions are based on results across years, because, in reality, producers must make decisions based on multiyear results regardless of the presence or absence of interactions. Fuel and commodity prices must be considered before deciding to deep-till the clay soils represented in these studies. For instance, higher fuel prices and low commodity prices in 2000 combined to greatly affect the net return response compared with the yield response vs. previous years. Also, if the normal two fall tillage operations (disk harrow followed by disk harrow or field cultivator) used in ST in these studies are replaced by no-till systems, the resulting cost savings of $7 to $10 per acre will provide even more impetus to exclude DT from consideration.

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