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ECONOMICS AND MARKETING

Yield and Economic Response of Cotton to In-Row Deep Tillage and Furrow Irrigation in a Corn/Cotton Rotation on a Silty Clay Loam Soil

H. C. Pringle, III*, M. W. Ebelhar and S. W. Martin

ABSTRACT

Increasing available soil water for a crop can be accomplished with both deep tillage and irrigation. Both have the potential to replace or complement the other due to their common function. The addition of a crop rotation may also enhance or diminish the response from irrigation and/or deep tillage. The major objective of this study was to determine long-term effects of different levels of furrow irrigation and in-row subsoil tillage on lint yield and economic returns for cotton grown on alluvial silty clay loam soils in a cotton/corn cropping sequence. A secondary objective was to determine the ability and efficiency of deep tillage and irrigation to replace and/or complement each other in the cropping system. Field experiments were conducted at Tribbett, MS on silty clay loam soils from 1999 through 2004. In-row subsoil tillage was performed with a low-till parabolic subsoiler. A roll-out pipe system was used to furrow water the irrigated plots. Production costs were calculated and include direct costs plus total specified costs excluding land rent, general farm overhead, and returns to management. Growing non-irrigated cotton without deep tillage in this cotton/corn sequence on these silty clay loam soils that were prone to backwater flooding gave the highest average net returns. It appears producers should neither subsoil, nor furrow irrigate and the two should never be combined, based on this study. These results emphasize the need for drainage and support the need for further research on these type soils in the absence of drainage problems

Deep subsoil tillage of alluvial sandy loam, silt loam, silty clay loam and some clay soils has been shown to increase non-irrigated cotton [*Gossypium hirsutum*, L.] yields economically in the Mississippi River Delta (Spurgeon et. al., 1978; Tupper et. al., 1981, 1987, 1989, 1997; McConnel et al., 1989; Phipps et al., 2000; Wesley et al., 2001; Pringle and Martin, 2003). Yearly variation in total rainfall and rainfall distribution affected both the total yield and the yield response from deep tillage during these reported studies.

Irrigation can generally be expected to increase cotton lint yields except in higher than normal rainfall growing seasons in the humid environment of the Mississippi River Delta. Sprinkler irrigation of deep tilled, alluvial silt loam soils has resulted in lint yield increases in five of eight yr (Pringle et. al., 2003). In Louisiana, furrow irrigation increased lint yields 18 of 28 yr on an alluvial sandy loam soil (Millhollon et al., 2000) while furrow irrigation increased yields seven of eight yr on a thin loessial silt loam soil (Hutchinson et al., 1985). Additionally, increased seed cotton yields were obtained with sprinkler irrigation on an alluvial silty clay soil in Arkansas in a 3 yr study (Vories et al., 1991).

Deep tillage has not consistently resulted in a yield increase or an economic benefit under irrigated conditions in the Mississippi Delta for cotton grown on alluvial silt loam soils (Pringle and Martin, 2003). Likewise, no positive yield responses for furrow-irrigated cotton were found in Arizona with deep tillage in a reduced tillage system on a Casa Grande silty loam soil (Typic Natrargids) (Coates, 2000). Mixed results were obtained in regard to the yield benefit of deep tillage and irrigation of corn in other areas of the United States (Cassel and Edwards, 1985; Camp et al., 1988; Ibrahim and Miller, 1989).

Crop rotations have long been supported and promoted for their benefits such as maintenance of crop yields; control of diseases, insects, and weeds; increases in residues and water infiltration; improved soil tilth and water holding capacity; and prevention of soil erosion. Researchers have discovered cotton yield enhancements following corn (Barker et al., 1984; Beatty and Eldridge, 1979; Ebelhar and Welch, 1989a; Harvey et al., 1961; Harvey et al.,

H. C. Pringle, III*, M. W. Ebelhar and S. W. Martin, Delta Research & Extension Center, P.O. Box 197, Stoneville, MS 38776
*Corresponding author: lpringle@drec.msstate.edu

1964; Hinkle, 1969; Spurgeon and Grissom, 1965a; Sturkie, 1966) in many areas and under various conditions. The exact cause of this enhancement is not totally understood. However, the effects of crop rotations on the physical and chemical properties of soil have been studied extensively (Ebelhar and Welch, 1989b; Page and Willard, 1947; Raney and Cooper, 1968; Spurgeon and Grissom, 1965b; Uhland, 1949; and Van Bavel and Schaller, 1950) with most researchers agreeing that the benefits are derived from a combination of effects. Increased aeration and water infiltration, improved tilth, and reduced compaction have all been proposed as benefits from crop rotation.

Increasing soil water for a crop can be accomplished with both deep tillage and irrigation. Soil water is increased with deep tillage by disrupting the soil profile (Hoeft et al., 2000) below 15 cm to increase the number and size of macrospores in the soil allowing deeper root penetration and wetting or recharge of the soil profile with rainfall and irrigation while these macrospores remain. The purpose of water added through irrigation during the growing season is to replenish soil water in a timely manner such that water does not become limiting in the development of the crop. Irrigation and deep tillage have the potential to replace or complement each other due to their common function. The addition of a crop rotation with possible benefits such as increased aeration and water infiltration, improved tilth and reduced compaction may affect the response obtained from irrigation and/or deep tillage.

Deep tillage of an alluvial silty clay loam soil increased non-irrigated cotton lint yield (Tupper and Pringle, 1997). These silty clay loam soils occupy about 12.3% of the total land area in the Yazoo - Mississippi Delta (Pettiet, 1974). Some of these soils have been identified as being present in a group of problem fields that are drought prone, low yielding areas in the Yazoo - Mississippi Delta with compaction and soil acidity restricting plant growth (Pettiet, 1973). Although deep tillage is not expected to be beneficial in the presence of infertile acidic subsoil (Adams, 1981), it is expected to be beneficial in the absence of acidic subsoils. With expanding corn acreage, the silty clay loam soils in the Mississippi Delta would be suitable for cotton/corn rotations production systems if the problems of drought and/or soil compaction could be resolved with irrigation and/or deep tillage.

The overall study was designed to determine the necessity of deep tillage and/or irrigation in a cotton/corn cropping system for an alluvial silty clay loam soil. Investments in irrigation and deep tillage are substantial so there is a need to determine the cost effectiveness of both in a cotton/corn cropping system over an extended period. Weather influences the level of response from deep tillage and irrigation and can lead to adverse effects rather than economic advantage, thus there is a need for a long-term study.

This study focuses on the results of the cotton component. The major objective was to determine long-term effects of different levels of furrow irrigation and in-row subsoil tillage on lint yield and economic returns for cotton grown on an alluvial silty clay loam soil series in a cotton/corn rotational cropping sequence. A secondary objective was to determine the ability and efficiency of deep tillage and irrigation to replace and/or complement each other in the cropping system.

MATERIALS AND METHODS

Cotton production. A 6-yr field study was conducted from 1999 through 2004 on a 12.1 ha field containing poorly drained to somewhat-poorly drained alluvial silty clay loam soils according to the USDA-SCS-Soil Survey of Washington County, Mississippi (1961). A Dundee (Typic Endoaqualfs) silty clay loam on the upper part of the study field was composed of 17% sand, 52% silt, and 31% clay to a 91.4 cm depth. The middle of the field was classified as Dowling (Vertic Endoaquepts) soil. Textural composition at the surface (0-15.2 cm) was 21% sand, 49% silt, and 30% clay with the subsoil (15.2 - 91.4 cm) composed of 16% sand, 49% silt, and 35% clay. The soil at the lower end of the field was classified as Forestdale (Typic Endoaqualfs) silty clay loam and was composed of 23% sand, 50% silt, and 27% clay in the surface and 16% sand, 52% silt, and 32% clay in the subsoil. The entire field had been continuously cropped with cotton for many years and had a poor yield history and poor fertility. Since 1995, improvements to both surface drainage and fertility, along with the addition of irrigation capabilities have been made in an effort to stabilize yields and reduce year-to-year variability.

The field was divided in to two sections so cotton could be alternated with corn on each half, thus establishing a 1:1 cotton/corn rotation. Treatments consisted of strip plots 4.9 m wide and 198 m long. The tillage/irrigation treatments were randomly assigned to the plots at the initiation of the study in each field and remained in the same location for the study duration. The study contained three water management practices: 1) non-irrigated (NI-), 2) low-level irrigated (LL-), and 3) high-level irrigated (HL-) for all tillage practices. Tillage practices included four tillage regimes for all water management practices: 1) no deep tillage for the present cotton crop year and for the previous year's corn crop (NS-NS), 2) no deep tillage for the present cotton crop year and deep tillage for the previous year's corn crop (NS-S), 3) deep tillage for the present cotton crop year and no deep tillage for the previous year's corn crop (S-NS), and 4) deep tillage for the present cotton crop year and deep tillage for the previous year's corn crop (S-S). All twelve treatments are listed in Table 1. Both cotton and corn were planted with a 6-row planter on 81 cm wide rows. The study was established in a randomized complete block design with a factorial arrangement of treatments and five replications.

In-row subsoil tillage was performed to a depth of 35 to 40 cm with a 6-shank, low-till parabolic subsoiler designed and built by Mississippi State University (Tupper, 1995). Primary tillage occurred either in the fall after harvest or in late winter (Table 2). To reduce problems associated with heavy corn residue in the deep tillage operation the entire study area was disked and then bedded utilizing a John Deere 886 Row-Crop Cultivator™ to build ridges/beds prior to the deep tillage. After the deep tillage operation was completed, the study area was then re-bedded with the same apparatus. A burndown herbicide was used to manage winter weeds when deep tillage and bedding operations were completed in the fall.

Irrigations for all HL- (HL-NS-NS, HL-S-S, HL-NS-S, and HL-S-NS) treatments were initiated and watered for a shallow-rooted system, while all LL- (LL-NS-NS, LL-S-S, LL-NS-S, and LL-S-NS) were initiated and watered for a deeper-rooted system. Theoretically shallow- rooted crops under drought stress require supplemental water earlier and more often. While neither cotton nor corn would normally be considered as shallow-rooted, soil compaction impedes deep root development forcing these crops to behave like shallow-rooted crops. Soil water potential was monitored to determine when to initiate irrigations in HL-NS-S and LL-NS-S using a Watermark ™ Model 200SS (Irrometer Co., Riverside, CA) electrical resistance sensor. Soil water potential was monitored in row at the 15-, 30-, 46-, and 61-cm depths in all replicates each year. All HL- treatments were initiated when the readily available water was depleted from the top 30 cm of the soil profile, as determined when the soil water potential averaged –50 to –70 kPa

Table 1. List of tillage/irrigation treatments in a deep tillage/irrigation study at the Delta Research and Extension Center satellite farm, Tribbett, MS

Treatment	Irrigation	Deep Tillage	
		Present cotton crop year	Previous year's corn crop
NI-NS-NS	non-irrigated	non-subsoiled	non-subsoiled
NI-NS-S	non-irrigated	non-subsoiled	subsoiled
NI-S-NS	non-irrigated	subsoiled	non-subsoiled
NI-S-S	non-irrigated	subsoiled	subsoiled
LL-NS-NS	low-level irrigated	non-subsoiled	non-subsoiled
LL-NS-S	low-level irrigated	non-subsoiled	subsoiled
LL-S-NS	low-level irrigated	subsoiled	non-subsoiled
LL-S-S	low-level irrigated	subsoiled	subsoiled
HL-NS-NS	high-level irrigated	non-subsoiled	non-subsoiled
HL-NS-S	high-level irrigated	non-subsoiled	subsoiled
HL-S-NS	high-level irrigated	subsoiled	non-subsoiled
HL-S-S	high-level irrigated	subsoiled	subsoiled

at the 30-cm depth (Table 2). All LL- treatments were initiated when the entire rooting profile was depleted of its readily available water as determined by soil water potential readings (Table 2). A roll-out pipe system (12-in diameter, poly-pipe, Delta Plastics, Stuttgart, AR) was used to furrow water the irrigated plots. Five middles (every-row) of the 6-row plots were watered, 1999-2001. Due to irrigation water advancing through the traffic middles too quickly, only three non-traffic middles (alternate-row) were watered in 2002-2004. Once irrigations were initiated, a schedule was developed to time irrigations every 8 to 10 d (every-row) or 6 to 8 d (alternate-row) unless rainfall, equipment breakdowns, or scheduling problems delayed irrigation. Irrigation water pumped ranged from 5.9 to 9.9 cm per application (every-row) and 1.9 to 4.7 cm per application (alternate-row). Less total water was pumped per application with alternate-row irrigation but was watered more frequently. Total water pumped for each treatment for each year and total rainfall is listed in Table 3 and 4, respectively.

Table 2. Dates of production practices and cotton cultivars grown in a deep tillage/irrigation study at the Delta Research and Extension Center satellite farm, Tribbett, MS

Practice[z]	1999	2000	2001	2002	2003	2004
Subsoiled	10/22 [y]	10/27 [y]	10/17[y]	10/24[y]	1/28	10/7[y]
Planted	4/22	4/19	4/27	4/19	4/30	4/20
Cultivar	STV474	SG747	SG747	SG747	PSC355	PSC355
First irrigation						
HL-	7/2	6/28	6/13	6/14	6/28	7/14
LL-	7/16	7/6	6/18	6/19	7/8	7/15
No. of irrigations						
HL-	4	4	5	6	8	5
LL-	3	3	3	4	5	3
Last irrigation						
HL-	7/29	7/25	7/24	8/6	8/16	8/16
LL-	8/4	7/25	7/24	8/6	8/16	8/10
Harvest 1st pick	9/24 & 9/27	9/19 & 10/12	10/3	9/9 & 11/18	9/17-18	9/29-30
Harvest 2nd pick	10/21					

[z] HL- includes HL-NS-NS - High-level irrigated, non-subsoiled for cotton and for previous year's corn crop; HL-S-S - High-level irrigated, subsoiled for cotton and for previous year's corn crop; HL-NS-S - High-level irrigated, non-subsoiled for cotton, subsoiled for previous year's corn crop; HL-S-NS – High-level irrigated, subsoiled for cotton, non-subsoiled previous year's corn crop.
LL- includes LL-NS-NS – Low-level irrigated, non-subsoiled for cotton and previous year's corn crop; LL-S-S – Low-level irrigated, subsoiled for cotton and previous year's corn crop; LL-NS-S – Low-level irrigated, non-subsoiled for cotton, subsoiled for previous year's corn crop; LL-S-NS – Low-level irrigated, subsoiled for cotton, non-subsoiled for previous year's corn crop.

[y] Subsoiling occurred in fall of previous year.

Table 3. Total water pumped from furrow irrigation during May-August period for cotton grown in a deep tillage/irrigation study at the Delta Research and Extension Center satellite farm, Tribbett, MS

Irrigation treatment [z]	Total water pumped (cm)						
	1999	2000	2001	2002	2003[y]	2004	Average
LL-	23.8	24.0	21.6	19.7	___	10.8	20.0
HL-	28.8	31.5	35.1	23.0	___	15.3	26.7

[z] HL- includes HL-NS-NS - High-level irrigated, non-subsoiled for cotton and for previous year's corn crop; HL-S-S - High-level irrigated, subsoiled for cotton and for previous year's corn crop; HL-NS-S - High-level irrigated, non-subsoiled for cotton, subsoiled for previous year's corn crop; HL-S-NS – High-level irrigated, subsoiled for cotton, non-subsoiled previous year's corn crop.
LL- includes LL-NS-NS – Low-level irrigated, non-subsoiled for cotton and previous year's corn crop; LL-S-S – Low-level irrigated, subsoiled for cotton and previous year's corn crop; LL-NS-S – Low-level irrigated, non-subsoiled for cotton, subsoiled for previous year's corn crop; LL-S-NS – Low-level irrigated, subsoiled for cotton, non-subsoiled for previous year's corn crop.

[y] Data were incomplete due to the flow meter malfunction during the irrigation season.

Table 4. Average maximum air temperature and rainfall by month for the growing season of cotton, Delta Research and Extension Center satellite farm, Tribbett, MS

Month	Average maximum air temperature (°C) [z]						30-yr normal[y]
	1999	2000	2001	2002	2003	2004	
May	29.1	29.4	29.9	28.1	29.0	28.5	28.4
June	31.8	32.0	31.4	31.8	30.3	30.6	32.3
July	34.1	34.6	33.5	33.8	33.0	32.3	33.6
August	35.7	36.7	32.6	33.6	34.1	31.9	33.2
	Rainfall (cm)						
January [z]	35.1	9.0	16.4	23.8	3.6	9.1	13.8
February [z]	3.3	4.1	21.9	9.4	19.4	20.9	11.3
March [z]	10.1	19.6	12.6	21.8	6.5	5.4	14.3
April [z]	16.1	28.2	10.1	8.3	9.6	10.5	13.8
May [x]	10.9	13.5	7.2	4.6	5.5	15.8	13.3
Total	79.0	78.4	73.8	70.4	45.5	64.3	66.6
June [x]	19.7	9.3	11.0	6.4	16.0	34.3	10.2
July [x]	1.5	0.8	11.7	13.0	2.5	8.8	9.8
August [x]	1.5	0.0	16.6	10.2	2.5	7.8	5.2
Total	22.7	10.1	39.3	29.6	21.0	50.9	25.2

[z] National Weather Service, Cooperative Weather Network, Stoneville, MS located 12.9 km northwest of study site.

[y] NOAA/NESDIS/NCDC. 2002. Monthly station normals of temperature, precipitation, and heating and cooling degree days 1971-2000 (22 Mississippi). Climatography of the United States No. 81. Asheville, North Carolina. pp26.

[x] Rain gage located at study site, Tribbett, MS.

In 1998, soil pH was found to be moderately to very slightly acidic (5.4 to 6.9). Soil potassium (K) ranged from 264 to 722 kg K ha^{-1} and soil phosphorus (P) ranged from 45 to 300 kg P ha^{-1}. Based on Mississippi State Soil Testing and Plant Analysis Laboratory, 84% of the 131 grid-sampled sites (30.5 x 30.5 m grid) required at least a maintenance rate of K for cotton. Only 17% of samples indicated a need for any additional P. Lime was not recommended for the field as a whole. Muriate of potash (0-0-60) was applied uniformly to increase and maintain K levels at the high or high+ range in the surface layer five of the six yr of the study. Muriate of potash was applied at 224 kg ha^{-1} (0-0-60) prior to planting in the fall of 1999 through 2004, except for 2000. Nitrogen was applied at an average total rate of 146 kg N ha^{-1} in a single application as a urea-ammonium nitrate solution (32% N) prior to or at planting each year.

Immediately after rows were conditioned in mid-April to early May, ‘STV 474’ (1999, Stoneville Pedigreed Seed Co.), ‘SG 747’ (2000-2002, Sure Grow Seed Co.), or ‘PSC 355’ (2003-2004, PhytoGen Seed Co.) cotton seed was planted. Cotton cultivars were changed in 2000 due to the unavailability of STV 474 seed and again in 2003 due to the unavailability of SG 747 seed. Seeding rates ranged from 10.8 - 12.0 seed m^{-1} of row in 1999-2001 and then reduced to 8.6 - 8.9 seed m^{-1} of row in 2002-2004.

Fluometuron (Cotoran 4L; Novartis Crop Protection, Greensboro, NC) was usually banded in combination with either S-metolachlor (Dual Magnum, Syngenta, Greensboro, NC), pyrithiobac sodium (Staple, Dupont, Wilmington, DE), cyanazine (Bladex, Dupont, Wilmington, DE), or pendimethalin (Prowl 3.3 EC; American Cyanamid, Parsippany, NJ) at planting in all treatments for control of grass and broadleaf weeds. Generally, one to two banded applications of monosodium methanearsonate acid (MSMA) in combination with either cyanazine (Bladex 4L; Dupont Agricultural Products, Wilmington, DE), fluometuron (Cotoran 4L), or lactofen (Cobra; Valent USA, Walnut Creek, CA) were applied postemergence directed (prior to bloom) to control small, actively growing grasses and broadleaf weeds. In some years pyrithiobac sodium was banded over the top for hard to control broadleaf weeds and clethodim (Select 2 EC, Valent, Walnut Creek, CA) was spot sprayed over the top to control grasses. All herbicides were applied to the study site at labeled rates. A water furrow was cultivated in between rows ahead of irrigation to help control weeds and insure water flowed down the intended middles. In all but one year no layby applications were made.

An in-furrow application of aldicarb (Temik 15G, Bayer Crop Science, Research Triangle Park, NC) was applied at planting for control of thrips all years except for 1999. Insecticides were applied uniformly to the study site as recommended from insect scouting data obtained from cotton in and around the study area. Specific insecticides and total number of applications (three to seven applications) varied each year depending on the species and recommended thresholds of each species of insects observed.

Cotton was harvested between mid-September and mid-November of each year (Table 2) following a uniform defoliation across all irrigated and tillage combinations. The two center rows of each plot were harvested twice in 1999 and once in 2000-2002 with a spindle picker modified for plot harvest with bags collected and weighed individually. Three rows of each plot were harvested in 2003 and 2004 with a commercial spindle picker and bulk weighed. An instrumented "boll buggy" was used to weigh these harvest plots. Representative samples of seed cotton were taken from each plot at first and second harvest. These samples were ginned on a small-scale ginning system (20-saw gin stand) to determine lint percent and lint yield. A standard recommended gin equipment sequence was used to gin all samples and all samples were treated the same.

Monthly average maximum air temperatures from the National Weather Service, Cooperative Observer Network at Stoneville, Mississippi located 12.9 km northwest of the study and monthly rainfall received at the study site for each growing season are presented in Table 4.

Data were analyzed using SAS (Statistical Analysis System). Yearly yield data were subjected to analysis of variance and means were separated by Fisher's Protected Least Significant Difference (LSD) and by Waller-Duncan K-ratio t-tests procedure at the 5% level of significance. The magnitude and direction of the treatment yield response was highly influenced by the weather conditions for a given year, resulting in a significant treatment by year interaction. Due to year by treatment interactions, data were analyzed for each year separately.

Economic analysis. Production costs were calculated for direct costs and for total specified costs based on 2005 input prices using the Mississippi State Budget Generator (MSBG) (Laughlin and Spurlock, 2006). The MSBG calculates enterprise budgets for all specified costs. Land rent, general farm overhead, and returns to management were not included. Costs were calculated for each treatment within each year as well as for the 6-yr average. For irrigated and subsoiled treatments, fixed costs associated with wells and deep tillage are included, as well as direct costs associated with pumping water, and trips across the field.

The framework for this analysis is reported as a comparison of average returns above total specified costs for each treatment. Average net returns were calculated at the cotton loan rate of $1.15 kg^{-1} of lint (USDA, 2007). Returns from cottonseed were not included and were assumed to cover hauling and ginning costs. The economic decision, then, is to maximize average returns above specified costs.

Standard deviations (SD) are reported for the cost kg^{-1} of lint and for the net returns hectare^{-1} for each treatment. The standard deviation allows for some comparison of the variability of cost and returns over the 6-yr period and may provide a method of separating treatments with similar costs/returns. Additionally, a cross break-even analysis was conducted for treatments that appeared to have similar returns. The cross break-even analysis was calculated as:

$$\frac{(C_1 - C_2)}{(Y_1 - Y_2)}$$

Where C is the total specified cost of the respective treatment Y is the respective treatment's lint yield. The lint price resulting from the above equation will give a cotton lint price that makes the two treatments equal. If the actual lint price is above the breakeven value then treatment 2 will have larger returns. If the actual lint price is below the breakeven price then, treatment 1 will have larger returns. The cross break-even price would not be a break-even price in the sense of "profit" versus "loss", but provides a lint price for which a respective treatment would be preferred to another treatment. In essence, the break-even price is a method of ranking the treatments.

RESULTS AND DISCUSSION

Lint yield. Lint yields for all years and treatment averages are presented in Table 5. A summary of lint yield interaction means is found in Table 6 and a summary of lint yield main effect means can be found in Table 7.

July and August of 1999 and 2000 were both hotter and drier than the 30-yr average (Table 4) with 2000 being the hottest and driest year. In 1999 and 2000, cotton lint yields (Table 7) were increased with irrigation. Additional irrigation water with the HL- treatments reduced yield as compared to the LL- treatments, in the presence or absence of deep tillage for the present cotton crop year, and may have been excessive for these growing seasons. Plant growth in irrigated treatments was excessive in both years and no plant growth regulators were included that might confound the other data. Average lint yield response to irrigation was lower in 2000 (151 kg ha^{-1}) than in 1999 (358 kg ha^{-1}). Yields in 2000 were lower overall, which may reflect the hotter environment in 2000 (maximum air temperature ≥ to 35˚C, 15 days in a row in mid-July). No yield differences were found when averaged across tillage treatments (Table 7); however, NI- treatments with deep tillage for cotton (NI-S-S, NI-S-NS) increased non-irrigated yields in 1999 (Table 5).

Rainfall was slightly higher than normal in June and July of 2001 and much higher than normal (11.4 cm) in August (Table 4). Monthly air temperature was near normal during the growing season. Thus, the year 2001 was a less demanding environment than 1999 or 2000 which should have reduced the need for irrigation. The yield results support this observation as irrigation did not increase lint yields in 2001 (Table 7). The NI- treatments (NI-NS-NS, NI-S-S, NI-NS-S, and NI-S-NS) were not different than the HL- treatments but the LL- treatments yielded 51 kg ha^{-1} less than the average NI- and 33 kg ha^{-1} less than the average HL- treatments. There was no conclusive explanation as to why the LL- treatments, that received less irrigation water than the HL- treatments, yielded less than either the NI- treatments that received no irrigation or the HL- treatments this year. One possible explanation would be that the three irrigations in June which were applied during the longest dry period (3 weeks) of the growing season were beneficial for the HL- treatments but the one irrigation initiated later for the LL- treatments during this dry period may not

Table 5. Lint yield of cotton grown in a deep tillage/furrow irrigation study on a silty clay loam soil at the Delta Research and Extension Center satellite farm, Tribbett, MS

Treatment [z]	Lint yield (kg ha^{-1})							Standard deviation
	1999	2000	2001	2002	2003	2004	Average	
NI-NS-NS	689	635	983	1213	1037	1661	1036	376
NI-NS-S	624	670	947	1265	1122	1575	1034	364
NI-S-NS	729	683	887	1347	1126	1475	1041	328
NI-S-S	732	681	897	1306	1120	1361	1016	290
LL-NS-NS	1129	845	894	1150	1572	1511	1183	304
LL-NS-S	1105	847	915	1204	1497	1377	1158	254
LL-S-NS	1087	867	869	1169	1515	1341	1141	258
LL-S-S	1072	835	834	1197	1370	1160	1078	212
HL-NS-NS	1016	776	927	1222	1562	1522	1171	322
HL-NS-S	992	766	918	1171	1492	1360	1116	276
HL-S-NS	1039	796	894	1153	1532	1325	1123	274
HL-S-S	979	809	903	1105	1429	1218	1074	226
MSD (Kratio=100)	83	54	64	109	82	93		
LSD (*P*=0.05)	93	59	59	103	92	102		
Prob. > F	0.0001	0.0001	0.0021	0.0009	0.0001	0.0001		
C.V. (%)	7.8	6.0	5.1	6.7	5.3	5.7		

[z] NI (non-irrigated); LL (low-level irrigated); HL (high-level irrigated); NS (non-subsoiled) or S (subsoiled) for present cotton crop year and previous year's corn crop, respectively.

have been enough to benefit reproductive growth. Deep tillage of cotton (NI-S-S, NI-S-NS, LL-S-S, LL-S-NS, HL-S-S, and HL-S-NS) in 2001 reduced cotton lint yields by 50 kg ha^{-1} whereas deep tillage for corn the previous crop year (NI-S-S, NI-NS-S, LL-S-S, LL-NS-S, HL-S-S, and HL-NS-S) had no effect (Table 7). Again, plant vegetative growth was observed to be excessive. Rainfall and cool, cloudy weather during initial boll opening appeared to favor the incidence of boll rot, particularly in the irrigated and/or deep tilled plots.

Excellent overall lint yields were measured in the first two replications of the study harvested on September 19, 2002, and averaged 1626 kg ha^{-1}. Excessive rainfall and subsequent delays in harvest reduced yields down to an average of 930 kg ha^{-1} for an average loss of 43% by the time the last three replications were harvested on November 18. The yield reductions are similar to those reported by Freeland et al., 2004 for the same area. Excellent yields prior to the harvest delay indicate that 2002 was a good weather year for cotton until harvest time. Again, monthly average air temperatures were near the 30-yr average (Table 4). Rainfall was below normal in April, May, and June when crop water use was low and greater than normal in July and August when crop water use was high. A significant interaction effect between irrigation levels and deep tillage of cotton in the 2002 crop year (Table 6) was present. Irrigation with deep tillage for cotton (HL-S-S, HL-S-NS, LL-S-S, and LL-S-NS) reduced lint yields as compared to NI- with deep tillage for cotton in 2002 but irrigation without deep tillage of cotton (HL-NS-NS, HL-NS-S, LL-NS-NS, and LL-NS-S) did not affect yields as compared to NI- without deep tillage of cotton (NI-NS-NS and NI-NS-S). Deep tillage for cotton increased yield under non-irrigated conditions but had no effect under irrigated conditions.

In 2003, air temperature was again near the monthly 30-yr normal for May, July and August (Table 4). Rainfall from January through May was well below the normal. Rainfall during the growing season was similar to crop years 1999 and 2000; such that June had more than normal rainfall whereas July and August were well below the norm but not as dry as 1999 and 2000. A significant interaction between irrigation level and deep tillage of cotton in 2003 and a significant interaction between irrigation

Table 6. Summary of interactions of cotton lint yields in a deep tillage/furrow irrigation study on a silty clay loam soil at the Delta Research and Extension Center satellite farm, Tribbett, MS

Interaction means		Lint yield (kg ha^{-1})							Standard deviation
Irrigation x fall deep tillage present cotton crop year [z]		1999	2000	2001	2002	2003	2004	Average	
NI	NS	657	652	965	1239	1079	1618	1035	353
LL	NS	1117	846	905	1177	1534	1444	1171	267
HL	NS	1004	771	923	1196	1527	1441	1144	287
NI	S	731	682	892	1327	1123	1418	1029	296
LL	S	1079	851	851	1183	1442	1251	1110	228
HL	S	1009	802	899	1129	1480	1272	1099	241
LSD (P=0.05)		65	41	41	73	65	72		
Prob. > F		0.0586	0.6031	0.2600	0.0150	0.0151	0.8215		
Irrigation x deep tillage previous year's corn crop [z]									
NI	NS	709	659	935	1280	1081	1568	1039	336
LL	NS	1108	856	881	1159	1543	1426	1162	269
HL	NS	1027	786	911	1187	1547	1424	1147	286
NI	S	678	675	922	1285	1121	1468	1025	314
LL	S	1089	841	874	1201	1433	1269	1118	227
HL	S	986	787	910	1138	1460	1289	1095	242
LSD (P=0.05)		65	41	41	73	65	72		
Prob. > F		0.8905	0.5630	0.9103	0.2129	0.0038	0.5281		

[z] NI (non-irrigated); LL (low-level irrigated); HL (high-level irrigated); NS (non-subsoiled); S (subsoiled).

level and deep tillage in the previous year's corn crop were present (Table 6). Irrigation increased lint yields over all NI- treatments an average of 395 kg ha^{-1}. Below average rainfall in January through May as well as July and August contributed to this large yield response. The interaction occurred in the response to deep tillage within irrigation levels. Under non-irrigated conditions the treatment without deep tillage for cotton or for the previous year's corn crop (NI-NS-NS) reduced yields (Table 5). In the HL- treatments, the HL-S-S treatment yielded less than the HL-NS-NS and HL-S-NS (Table 5). The LL-S-S treatment reduced yields in the LL- treatments (Table 5).

The key weather factor of 2004 was the excessive rainfall in June (Table 4). The inability of the main drainage system of the area to adequately remove the excess water in the watershed in a timely manner resulted in backwater flooding in most of the study field for several days. This was also the coolest crop year with June, July, and August below normal. Rainfall in July was near normal and above normal in August. Under flooded conditions, denitrification and other transformations can occur, leading to reductions in plant available N along with poor aeration in the root zone. Cotton was visibly stunted on the low end of the field where it was flooded for the longest period supporting the occurrence of N loss and poor aeration. Disrupting the soil profile below 15 cm to increase the number and size of macrospores in the soil and to allow deeper root penetration and recharge of the soil profile with deep tillage will saturate the soil profile deeper after several days of flooding than without deep tillage. Thus, with deep tillage the soil will be recharged with more water and be saturated longer. Visually, leaf color of the deep tilled treatments was a lighter green than in the absence of deep tillage. This leaf color difference supports the deep tilled characteristics of more water being recharged deeper into the root zone and being saturated longer in this flood event which would result in a longer time period for poor aeration conditions to exist and N losses to occur. Also, this was the only year of the study that, visibly, the deep tilled treatments for cotton were not taller than the treatments without deep tillage. These assertions are supported by the cotton lint yield responses (Table 7). Deep tilled treatments reduced lint yields by 187 kg ha^{-1} with deep tillage of cotton and by 131 kg ha^{-1} with deep tillage of corn in the previous crop year. Irrigation treatments reduced lint yields by an average of 166 kg ha^{-1}. These observations and yield measurements indicate that the treatments without deep tillage survived this occurrence of flooding better than those with deep tillage.

Over the 6-yr study, NI- with deep tillage for cotton increased lint yields in 1999 and 2002 but decreased yields in 2001 and 2004 (Table 5). The negative yield response in 2004 with deep tillage under non-irrigated conditions was 112 kg ha^{-1} larger than the largest positive yield response in 2002. Pringle and Martin (2003) reported increased yield with deep tillage under non-irrigated conditions in a mono-crop cotton production system on silt loam soil as did Tupper and Pringle (1997), on a nearby Forestdale silty clay loam soil.

Irrigated treatments with deep tillage of cotton decreased cotton lint yields in the wetter years of 2001 and 2004 (Table 5), otherwise they did not increase yields over treatments without deep tillage. Pringle and Martin (2003) reported similar results under irrigated conditions in a mono-crop cotton production system on silt loam soil.

Deep tillage for the previous year's corn crop decreased cotton lint yields in the NI- and irrigated treatments in 2004 and the irrigated treatments in 2003 (Table 5). In all other years, deep tillage the previous year for corn had no effect on lint yields. Benefits of deep tillage in the previous year's corn crop for present year cotton are non-existent.

The additional water stored in the soil profile due to the mechanical fracturing of the soil with deep tillage of cotton was not beneficial in most years on this silty clay loam soil. This field has been prone to backwater flooding in wetter-than-normal years when the drainage system is full. This appears to be a reason for decreased lint yields with deep tillage in some years as previously discussed. Also, saturated conditions can lead to poor soil aeration in the root zone thus reducing root activity and subsequently, nutrient uptake. Cotton lint yield results with deep tillage indicate that no consistent positive benefit was obtained with deep tillage of cotton and/or with deep tillage in the previous year's corn crop (Table 7). Therefore, deep tillage in this cropping system would not be recommended for the cotton component. Deep tillage for the previous year's corn crop should only be considered if it is beneficial for the corn grown that season.

When in-season rainfall (June – August) was greater than the 30-yr average (Table 4), irrigation with and without deep tillage of cotton did not increase yield and in some cases decreased cotton lint yields (Table 7). Irrigation increased lint yield with and without deep tillage when in-season rainfall was below normal. The yield response in 2000 to irrigation was lower than in 1999 and 2003, due partly to the higher than normal maximum air temperature in July and August. Irrigation without deep tillage of cotton resulted in the highest average yield for the 6-yr study (Table 5).

The main differences between the HL- and LL-treatments were that during the three years irrigation increased yields (Table 7), two of those the LL- treatments yielded better than the HL-treatments, indicating that a later irrigation initiation date and less total water applied was more appropriate for this silty clay loam soil. This effect did not occur in the third year. There irrigation increased yields but there was an interaction effect in which the LL- treatments with deep tillage of cotton yielded less than the average of the LL- and HL- treatments without deep tillage of cotton (Table 6). In the wetter years of 2002 and 2004, there was no difference among the HL- and LL- treatments. In 2001 the LL- treatments yielded less than the HL- treatments. Thus, there is no clear advantage among the HL- and LL- treatments.

In 2004, several days of backwater flooding had a negative effect on lint yield response to deep tillage and to irrigation. If 2004 data were excluded from the analysis of the data, irrigation in the presence or absence of deep tillage of cotton on the average would have had a greater average yield response over similar NI- treatments. This positive response would be in line with the expected outcome. On average, effects of deep tillage of cotton would switch from slightly negative to a more positive effect under non-irrigated conditions; however, the difference would not be large enough magnitude to be significant. This data would still not agree with data from a similar soil nearby that showed deep tillage increased yields in a non-irrigated environment (Tupper and Pringle, 1997). Average yields for irrigation with deep tillage of cotton would increase but would not be better than irrigation alone. After excluding 2004 data which had several days of backwater flooding, yield responses to deep tillage and irrigation are less than previously reported (Pringle and Martin, 2003; Tupper and Pringle, 1997). Reduced response levels may be explained by soil types, by benefits of the crop sequence masking the benefits from deep tillage and irrigation, or by other years in the study having short term floods due to slow watershed drainage.

Table 7. Summary of main effects of cotton lint yields in a deep tillage/furrow irrigation study on a silty clay loam soil at the Delta Research and Extension Center satellite farm, Tribbett, MS

Deep tillage system means [z]	Lint yield (kg ha^{-1})							Standard deviation
	1999	2000	2001	2002	2003	2004	Average	
Present cotton crop year								
NS	926	756	931	1204	1380	1501	1116	302
S	940	778	881	1213	1349	1314	1079	252
LSD (P=0.05)	38	24	24	42	37	42		
Prob. > F	0.4658	0.0681	0.0001	0.6723	0.0951	0.0001		
Previous year's corn crop								
NS	948	767	909	1209	1391	1473	1116	295
S	917	768	902	1208	1338	1342	1079	259
LSD (P=0.05)	38	24	24	42	37	42		
Prob. > F	0.1118	0.9228	0.5796	0.9758	0.0074	0.0001		
Irrigation system means [z]								
NI	694	667	929	1283	1101	1518	1032	318
LL	1098	848	878	1180	1488	1347	1121	260
HL	1006	787	911	1163	1504	1356	1140	245
LSD (P=0.05)	46	29	29	52	46	52		
Prob. > F	.0001	.0001	.0042	.0001	.0001	.0001		

[z] NI (non-irrigated); LL (low-level irrigated); HL (high-level irrigated); NS (non-subsoiled); S (subsoiled).

Table 8. Total specified costs for cotton grown in a deep tillage/irrigation study at the Delta Research and Extension Center satellite farm, Tribbett, MS

Irrigation x deep tillage present cotton crop year [z]		Total specified costs ($ ha^{-1})[y]							Standard deviation
		1999	2000	2001	2002	2003	2004	Average	
NI	NS	1062	963	1136	1270	1082	1116	1105	101
LL	NS	1230	1131	1304	1451	1276	1284	1279	104
HL	NS	1243	1144	1331	1505	1263	1298	1297	120
NI	S	1090	991	1164	1298	1110	1144	1133	101
LL	S	1258	1159	1332	1479	1304	1312	1307	104
HL	S	1271	1172	1526	1506	1304	1326	1351	138

[z] NI (non-irrigated); LL (low-level irrigated); HL (high-level irrigated); NS (non-subsoiled); S (subsoiled).

[y] Total specified costs include direct costs plus the additional fixed costs of machinery and equipment ownership. Total specified costs exclude land rent, general farm overhead and return to management.

Economic Analysis. Total specified costs and respective SD for each irrigation x fall deep tillage treatment, for each year are presented in Table 8. Deep tillage for the previous year's corn crop was charged to that crop in that year. Irrigated treatments incurred higher production costs. These costs were influenced by the fixed costs of a well plus direct costs, which varied from year to year across treatments according to the number of irrigations. Costs associated with deep tillage are not as apparent across irrigated treatments, but are apparent when comparing NI- treatments with and without deep tillage of cotton. Average cost to produce a kg of lint per irrigation x deep tillage treatment is shown in Table 9. The NI- treatments without deep tillage had the lowest cost of production per kg. All treatments without deep tillage and the NI- treatments with deep tillage had lower cost per kg of lint and provided positive returns (Table 10) over specified costs when lint price was at least $1.15 kg^{-1} of lint (loan rate). The irrigated treatments with deep tillage had similar costs of production and net returns per hectare. The added cost of deep tillage and irrigation increased production costs and reduced net returns for both treatments.

Returns above total specified costs were calculated for each treatment using the cotton loan rate of $1.15 kg^{-1} of lint, average total specified costs for each treatment over the 6-yr period, and each treatment's respective 6-yr average lint yield (Table 10). The SD of net returns for each treatment over the 6-yr period is also reported. When lint prices are at the loan rate of $1.15 kg^{-1} of lint, NI-NS-NS provides the most economical choice. The NI-NS-S provides similar returns and has a lower standard deviation. The LL-NS-NS treatment provides slightly lower returns and has a lower standard deviation.

Table 9. Cost of production kg^{-1} of lint for cotton grown in a deep tillage/irrigation study at the Delta Research and Extension Center satellite farm, Tribbett, MS

Irrigation x fall deep tillage present cotton crop year [z]		Cost ($ kg^{-1})[y]
NI	NS	1.06
LL	NS	1.09
HL	NS	1.13
NI	S	1.10
LL	S	1.17
HL	S	1.22

[z] NI (non-irrigated); LL (low-level irrigated); HL (high-level irrigated); NS (non-subsoiled); S (subsoiled).

[y] Cost of production based on total specified cost.

Treatments without deep tillage provide higher returns for the associated higher risk when prices are at or below the loan rate (Figure 1). However, the LL-NS-NS treatment would have larger returns than NI-NS-NS when lint prices are above $1.28 kg^{-1} of lint based on the cross break-even analysis. Thus, when cotton prices are "high", the LL-NS-NS treatment would provide the highest economic returns on average and with less risk.

Conventional wisdom would suggest that irrigated production would be less risky, and this is confirmed in Figure 1 (i.e., the irrigated treatments in general had lower SD). Figure 1 also reveals that on average, treatments without deep tillage provided the highest returns when calculated at the loan rate. Thus, higher yields associated with irrigation, even with less risk, would likely not be preferred by profit maximizing producers. Cotton price, which is exogenous to the producer, can have significant affects on profitability of tillage and/or irrigation.

Table 10. Average net returns per hectare for cotton grown in a deep tillage/irrigation study at the Delta Research and Extension Center satellite farm, Tribbett, MS

Treatment	Average net returns ($ha^{-1})^z							Standard deviation
	1999	2000	2001	2002	2003	2004	Average	
NI-NS-NS	-270	-232	-6	125	110	793	87	384
NI-NS-S	-345	-204	-46	183	208	694	82	369
NI-S-NS	-252	-220	-145	251	185	551	62	320
NI-S-S	-249	-209	-133	204	178	420	35	270
LL-NS-NS	68	-198	-276	-130	530	453	74	343
LL-NS-S	40	-152	-252	-67	443	300	52	269
LL-S-NS	-9	-200	-334	-135	436	231	-2	288
LL-S-S	-25	-181	-373	-103	271	21	-65	215
HL-NS-NS	-75	-253	-265	-100	533	452	49	353
HL-NS-S	-104	-261	-276	-160	452	266	-14	301
HL-S-NS	-78	-243	-499	-181	457	198	-58	339
HL-S-S	-146	-252	-489	-236	338	76	-118	288

^{z} Based on cotton prices at loan rate of $1.15 per kg of lint.

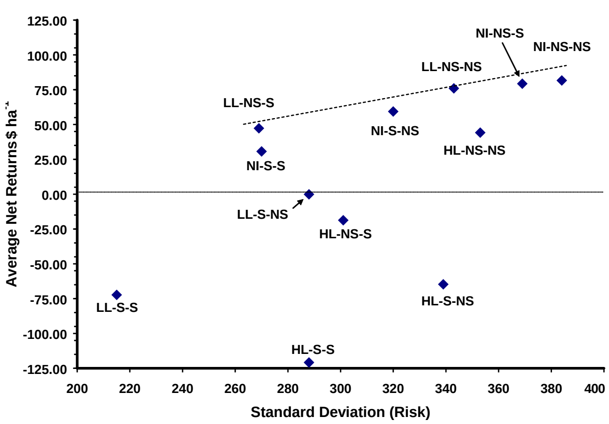

Figure 1. Average Net Returns and Standard Deviation (risk) comparison for cotton grown in a deep tillage/irrigation study at the Delta Research and Extension Center satellite farm, Tribbett, MS: NI (non-irrigated); LL (low-level irrigated); HL (high-level irrigated); NS (non-subsoiled) or S (subsoiled) for cotton and for previous year's corn crop.

On silty clay loam soils that were prone to backwater flooding, growing non-irrigated cotton without deep tillage in a cotton/corn sequence provided the highest net return. It appears that producers should neither deep till nor irrigate and specifically should not deep till and irrigate, based on this study. These results were influenced heavily by the 2004 data where backwater flooding occurred for an extended period of time due to the poor watershed drainage from the area. Economically, if 2004 data were excluded, irrigation without deep tillage would give the highest net returns followed by NI- with or without deep tillage. The combination of irrigation and deep tillage would not be economical due to added costs associated with both practices without additional yield. These results emphasize the need for drainage and support the need for further research on these type soils in the absence of surface drainage problems. The overall reduced levels of yield response to deep tillage and irrigation supports the need for further research to determine if benefits from a cotton/corn rotation could be masking the possible benefits obtained from deep tillage and irrigation.

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