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# ECONOMICS AND MARKETING

## Cotton Yield Response and Economic Implications to In-Row Subsoil Tillage and Sprinkler Irrigation

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### ABSTRACT

**Deep tillage at a 45° angle has been a recommended practice since the mid-1970s on most Mississippi Delta cotton soils. This practice disrupts hard pans and allows deeper wetting of the soil profile with winter rainfall. The newest deep tillage "subsoiler" designs (Paratill, low-till parabolic) have the shank extending through the soil at an angle, thereby reducing soil surface disturbance and allowing the subsoiler to run under the row in the direction of the row, without the shank passing directly through the drill. Both center pivot and furrow irrigation of cotton has expanded since the early 1980s. With intermittent rainfall, irrigation is supplemental and represents a type of insurance against yield uncertainty during extended periods of water deficit. The objective of this study was to determine the long-term effects of sprinkler irrigation and in-row subsoil tillage on cotton yield and economic return. Field experiments were conducted at Stoneville, MS on a silt loam soil from 1994 through 2001. In-row subsoil tillage was performed with a low-till parabolic subsoiler and irrigation was applied with an overhead lateral-move sprinkler irrigation system. Production costs were calculated for direct costs and total specified costs excluding land rent, general farm overhead and returns to management. Average net returns were calculated as the difference between income at the cotton loan rate of $1.15 per kg of lint and total specified costs. Returns were maximized with either the irrigated, non-subsoiled or the non-irrigated, subsoiled environments. Lower returns occurred in the irrigated, subsoiled environment due to the higher costs and lack of yield increase.**

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Deep tillage with a subsoiler at a 45° angle has been a recommended practice since the mid-1970s on most Delta cotton soils (Spurgeon et al., 1974). This practice disrupts hard pans and allows deeper wetting of the soil profile with winter rainfall (Tupper, 1977; Wesley and Smith, 1991). Deep tillage of sandy loam and silt loam soils increases cotton (*Gossypium hirsutum*, L.) yields of non-irrigated cotton in most years (Tupper, 1977; Tupper and Spurgeon, 1981; Spurgeon et al., 1978; Wooten et al., 1975; Grissom et al., 1955 and 1956; Tupper et al., 1987; Tupper et al., 1989; McConnell, 1997; Rester, 2001). More recently, deep tillage in the fall of a dry clayey soil increased cotton and soybean yields (Wesley et al., 2001; McConnell, 1997; Rester, 2001). Deep tillage in the fall is preferred since the soil is usually drier and should fracture better than in the spring. Tupper et al. (1989) found that annual deep tillage or deep tillage 2 out of 3 yr netted higher returns than deep tillage every other year in a 6-yr study with cotton grown on a silt loam soil. Yearly variation in total rainfall and rainfall distribution affected both the yield and the yield response from deep tillage during these studies.

Deep tillage "subsoiler" designs, such as the Paratill (Tye Company; Lockney, TX or Bingham Brothers, Inc.; Lubbock, TX) and the low-till parabolic subsoiler (Tupper, 1994), have the shank extending through the soil at an angle such that the foot can run under the drill or parallel to the row. These "subsoilers" were designed to reduce disturbance of the soil surface. Cotton producers are adopting this practice as they move towards reduced tillage where they can subsoil and form rows in one operation. This requires less time to prepare fields in the fall after cotton harvest when days fit for fieldwork may be limited (Spurlock et al., 1995; Zapata et al., 1997). Yields from subsoil tillage at a 45° angle to the direction of the row and from subsoil tillage in the direction of the row with either the Paratill or the low-till parabolic subsoiler were not different (Tupper and Pringle, 1997). Yield differences between the Paratill and the low-till parabolic subsoiler when tillage was in the row direction also were not different.

Irrigation with both center pivot and with furrow systems has expanded since the early 1980s. Sprinkler irrigation of subsoiled, deep, silt loam soils has resulted in yield increases in years in which non-irrigated, subsoiled plots yielded 1008 kg per hectare or less (Pringle et al., 1990; Pringle et al., 1988). In a study with soybean, Wesley et al. (1994) did not find any positive increase in yield or returns with deep tillage preceding irrigated soybean on a clayey soil.

Both deep tillage and irrigation can increase soil water for the crop. Deep tillage, as mentioned above, does this by disrupting hard pans and allowing deeper rooting and wetting or recharge of the soil profile with winter rainfall. Irrigation adds water during the growing season to replenish soil water. The ability and efficiency of irrigation and deep tillage to replace or to complement each other is part of the objective of this study

This study was designed to determine whether or not cotton yields could be maintained with irrigation alone, when the soil was too wet to subsoil. Irrigation and subsoiling add cost but little research has been done on the cost effectiveness of doing both for cotton production. Obviously, different weather years have influenced the level of response from deep tillage and irrigation, thus establishing a need for a long-term study.

An objective of this study was to determine long-term effects of different levels of irrigation and in-row subsoil tillage on yield and economic returns for cotton grown on a field known to respond to deep tillage and irrigation. A second objective is to determine the ability and efficiency of deep tillage and irrigation to replace and/or complement each other.

## MATERIALS AND METHODS

**Cotton production.** An 8-yr field study was conducted from 1994 through 2001 on a field with variable soil series according to the soil survey of Washington County, Mississippi (USDA-SCS, 1961). A Bosket (fine-loamy, mixed, active, thermic Mollic Hapludalfs), deep sandy loam on the upper part of the study field was composed of 62% sand, 33% silt, and 5% clay to 91.4 cm depth. The middle of the field was classified as Dundee (fine, silty, mixed, active, thermic Typic Endoaqualfs) silt loam to loam soil overlying a sandy loam. Soil composition of the A horizon (upper 61 cm) was 41% sand, 51% silt, and 7% clay, whereas the B horizon was composed of 55% sand, 38% silt, and 7% clay. The soil at the lower end of the field was classified as Dowling (very-fine, smectitic, nonacid, thermic Vertic Endoaquepts) silt loam and was composed of 28% sand, 65% silt, and 8% clay. The study was designed so that soil variability occurred across and not within replications. This area had been continuously cropped with cotton for over 20 yr. Key production practice dates for each crop year are given in Table 1.

The study was conducted in a randomized complete block design with a factorial arrangement of treatments and five replicates each year. The tillage/

**Table 1. Dates of production practices and cotton cultivars grown in a deep tillage/irrigation study at the Delta Research and Extension Center, Stoneville, MS**

| Practice[z] | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 |
|---|---|---|---|---|---|---|---|---|
| Subsoiled | 3/24 | 3/20 | 10/30[y] | 3/12 | 2/15 | 10/27[y] | 10/28[y] | 2/7 |
| Planted | 4/22 | 4/19 | 5/2 | 5/8 | 4/24 | 5/3 | 4/26 | 4/27 |
| Cultivar | DES119 | DES119 | SG125 | SG125 | SG125 | SG125 | SG747 | SG747 |
| First irrigation | | | | | | | | |
| HL-NS, HL-S | 7/7 | 6/20 | 6/28 | 7/10 | 6/23 | 7/8 | 7/5 | 6/22 |
| LL-NS | 8/15 | 7/19 | 7/6 | 7/28 | 7/27 | 7/28 | 7/11 | 7/5 |
| LL-S | 8/19 | 7/28 | 7/20 | 7/28 | 7/27 | 7/28 | 7/25 | 7/5 |
| Last irrigation | 8/26 | 8/17 | 7/30 | 8/29 | 8/5 | 8/12 | 8/14 | 7/25 |
| Harvest 1st pick | 10/6 | 9/20 | 10/7 | 10/9 | 9/4 | 10/4 | 9/18 | 10/1 |
| Harvest 2nd pick | 11/1 | 10/2 | 10/17 | 10/22 | 9/29 | 10/22 | 9/28 | 10/23 |

[z] HL-NS – High-level irrigated, non-subsoiled treatment; HL-S – High-level irrigated, subsoiled treatment; LL-NS – Low-level irrigated, non-subsoiled treatment; LL-S – Low-level irrigated, subsoiled treatment.

[y] Subsoiling occurred in fall of previous year.

irrigation treatments were randomly assigned to the plots at the initiation of the study and remained in the same location for the duration. The study provided three water environments in both subsoiled and non-subsoiled treatments. The six treatments were as follows: 1) non-irrigated, non-subsoiled (NI-NS), 2) low-level irrigated, non-subsoiled (LL-NS), 3) high-level irrigated, non-subsoiled (HL-NS), 4) non-irrigated, subsoiled (NI-S), 5) low-level irrigated, subsoiled (LL-S), and 6) high-level irrigated, subsoiled (HL-S). Plots were 18.3 m wide and 20.4 m long to ensure uniformity of sprinkler irrigation of harvest rows. Cotton was planted on 1 m wide rows with a 6-row planter.

In-row subsoil tillage was performed with a four-shank, low-till parabolic subsoiler to a depth of 35 to 40 cm, in the subsoiled plots. Deep tillage occurred either in the fall after harvest or in late winter (Table 1). The entire study area was then bedded with a disk-hipper. After the 1995 harvest, a reduced-tillage approach was taken that excluded any disking or application of pre-plant incorporated herbicides. A burndown herbicide and/or re-bedding were used to manage winter weeds.

The HL-NS and HL-S were initiated and watered for a shallow-rooted system, while LL-NS and LL-S were initiated and watered for a deeper-rooted system. Soil water potential was monitored to determine when to initiate irrigations in LL-NS, LL-S, HL-NS, and HL-S. Soil water potential was monitored at the 15, 30, 46, 61, and 91 cm depths in five replicates of LL-NS and LL-S in 1994 through 1999. In 2000 and 2001, NI-NS, NI-S, LL-S, HL-NS, and HL-S were monitored every 15 cm to a 91 cm depth. Tensiometers 2725A (Soilmoisture Equipment Corp., Santa Barbara, CA) were used in 1994 through 1998 to determine soil water potential. An electrical resistance type sensor, Watermark Model 200SS (Irrometer Co., Riverside, CA), was used in 1999, 2000, and 2001. The HL-NS and HL-S were initiated when the easily 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 at the 30-cm depth (Table 1). The LL-NS and LL-S were initiated when the entire rooting profile was depleted of its easily available water as determined by soil water potential readings (Table 1). Rooting depths of 61 cm and 61 to 91 cm were used for LL-NS and LL-S, respectively. Irrigation was applied with an overhead, lateral-move sprinkler irrigation system. Once irrigations were initiated, they were continued every 4 to 5 d unless rainfall, equipment breakdowns, or scheduling problems delayed irrigation. Irrigation amounts were 1.3 to 3.3 cm per application. Total water received by each treatment from rainfall and sprinkler irrigation for each year is listed in Table 2.

Soil pH was slight to very slightly acid (6.0 to 7.0) for the duration of the study. Soil K (249 to 819 kg/a) was high throughout the study. Soil P (50 to 202 kg/a) initially was mostly in the high range with approximately half the plots dropping into the medium range near the end of the study, according to the Mississippi State Soil Testing Laboratory. Muriate of potash was applied to increase and maintain potassium levels at the high or high+ range in the surface layer for 6 of the 8 yr of the study. Potash was applied at 448 kg per ha (0-0-60) prior to planting in 1995 and 224 kg per ha prior to planting in the fall of 1995 through 2001, except for 1998. Nitrogen was applied at 135 kg per ha in a split application, with 90 kg per ha prior to or at planting and 45 kg per ha prior to first bloom in most years. In 1995 and 2000, 135 kg per ha of nitrogen was applied in one application prior to planting. Inadvertently in 2001, 112 kg per ha of nitrogen was applied twice

**Table 2. Total water from rainfall and sprinkler irrigation during May to August period for cotton grown in a deep tillage/ irrigation study at the Delta Research and Extension Center, Stoneville, MS**

| Treatment | | Total water (cm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | Average |
| Non-subsoiled | Non-irrigated | 55.1 | 29.0 | 34.8 | 41.4 | 37.6 | 26.7 | 35.8 | 47.0 | 38.4 |
| | Low-level | 61.0 | 40.4 | 46.2 | 47.2 | 42.7 | 36.8 | 57.4 | 57.2 | 48.5 |
| | High-level | 65.3 | 44.2 | 50.0 | 51.1 | 50.3 | 43.2 | 60.7 | 60.7 | 53.1 |
| Subsoiled | Non-irrigated | 55.1 | 29.0 | 34.8 | 41.4 | 37.6 | 26.7 | 35.8 | 47.0 | 38.4 |
| | Low-level | 58.9 | 38.6 | 40.6 | 47.2 | 42.7 | 36.8 | 48.3 | 57.2 | 46.2 |
| | High-level | 65.3 | 44.2 | 50.0 | 51.1 | 50.3 | 43.2 | 60.7 | 60.7 | 53.1 |

before planting for a total of 224 kg per ha.

Immediately after rows were conditioned in mid-April to early May each year, Delta Experiment Station (DES) 119 (1994-1995), Sure-Grow (SG) 125 (1996-1999), or SG 747 (2000-2001) was planted at 14.8 to 16.4 seed per m of row (Table 1). Cotton cultivars were changed in 1996 due to the unavailability of DES 119 seed and again in 2000 due to the unavailability of SG 125 seed.

Fluometuron (Cotoran 4L; Novartis Crop Protection, Greensboro, NC) was banded alone or in combination with norflurazon (Zorial Rapid 80; Novartis Crop Protection, Greensboro, NC) or pendimethalin (Prowl 3.3 EC; American Cyanamid, Parsippany, NJ) at planting in all treatments for control of grass and broadleaf weeds. Two to three banded applications of 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 (prior to bloom) to control small, actively growing grasses and broadleaf weeds. In most years, diuron (Direx 4L; Griffin L.L.C., Valdosta, GA) was applied broadcast as a layby to control late-emerging annual grasses and small-seeded broadleaf weeds.

Insecticides were applied uniformly to the study site as recommended based on insect scouting data obtained from cotton in and around the study area. Specific insecticides and total number of applications (4 to 11 applications) varied each year depending on the species and recommended thresholds of each species of insects observed.

Cotton was harvested between 18 September and 1 November of each year (Table 1). The four center rows of each plot were harvested twice each year with a spindle picker modified for plot harvest. Representative samples of seed cotton were taken from each plot of each treatment at first and second harvest. Replications of each treatment were combined and ginned on a small-scale ginning system (20-saw gin stand) to determine lint percentage and lint yield. A standard recommended gin equipment sequence was used to gin all samples.

Monthly average maximum air temperatures from the National Weather Service, Cooperative Observer Network at Stoneville, Mississippi located within a half mile of the study and monthly rainfall received at the study site for each growing season are presented in Table 3.

Yearly yield data were subjected to analysis of variance and means were separated by least significant difference (LSD) procedure at the 5% level of significance. The LSD is a statistic that estimates the smallest difference necessary between two treatments due to something other than natural variation. 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. Thus, differences among treatment yields averaged across years were not statistically analyzed.

**Table 3. Average maximum air temperature and rainfall by month for the May to August growing season of cotton at the Delta Research and Extension Center, Stoneville, MS**

| Month | Average maximum air temperature (°C)[z] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 30-yr normal[y] |
| May | 27.8 | 30.0 | 31.1 | 26.7 | 30.6 | 28.9 | 29.4 | 30.0 | 27.8 |
| June | 33.3 | 31.7 | 31.7 | 30.6 | 33.3 | 31.7 | 32.2 | 31.1 | 32.2 |
| July | 32.2 | 32.8 | 32.8 | 34.4 | 34.4 | 33.9 | 34.4 | 33.3 | 32.8 |
| August | 32.8 | 35.0 | 31.7 | 31.7 | 34.4 | 35.6 | 36.7 | 32.8 | 32.2 |
| | Rainfall (cm)[z] | | | | | | | | |
| May | 13.0 | 7.9 | 6.4 | 16.3 | 10.2 | 8.9 | 17.3 | 10.7 | 12.7 |
| June | 9.1 | 7.1 | 11.2 | 10.9 | 6.1 | 14.0 | 17.0 | 5.6 | 9.4 |
| July | 32.0 | 12.4 | 6.1 | 6.4 | 18.3 | 3.0 | 1.5 | 7.6 | 9.4 |
| August | 1.0 | 1.5 | 11.2 | 7.9 | 3.0 | 0.8 | 0.0 | 23.1 | 5.8 |

[z] National Weather Service, Cooperative Weather Network, Stoneville, MS.

[y] Average air temperature and rainfall for 1964 to 1993 (Boykin et al., 1995).

**Economic analysis.** Production costs were calculated for direct costs and for total specified costs based on 2001 input prices using the Mississippi State Budget Generator (MSBG) (Laughlin and Spurlock, 2002). 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 8-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, pivot maintenance, and trips across the field.

The MSBG enterprise budgets include costs for ginning and hauling. Thus, for treatments where yield was increased, these costs are increased as well. Additionally, irrigation may increase insecticide costs (Andrews, et. al., 2002); thus, 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 per kg of lint. Returns from cottonseed were included and were valued at $0.11 per kg and calculated as 155% of lint yield (Laughlin and Spurlock, 2002). The economic decision, then, is to maximize average returns above specified costs.

Standard deviations are reported for the cost per kg of lint and for the net returns per hectare for each treatment. The standard deviation allows for some comparison of the variability of cost and returns over the 8-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:

$$\frac{[C_1 - SeedValue_1) - (C_2 - SeedValue_2)]}{(Y_1 - Y_2)}$$

where C is the total specified cost of the respective treatment, seed value is the value of the respective treatment's seed yield and Y is the respective treatments 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.** The growing seasons in 1994 and 1995 were characterized by July being wetter than normal followed by August being drier than normal (Table 3). In 1994 and 1995, all of the treatments provided ample soil water to increase yields over NI-NS except for LL-NS in 1994 (Table 4). The LL-S and HL-S were similar in yield to NI-S or LL-NS and HL-NS indicating that the additional water resulting from the combination of deep tillage and irrigation did not influence yield.

It is not obvious from the monthly rainfall records for June and July of 1996 (Table 3), but there was a month-long drought that occurred during a critical reproductive period from late June to late July, when less than 2.5 cm of rainfall was measured. The NI-S produced more lint than NI-NS, but did not provide enough water to maximize yield, because all of the irrigated treatments produced higher lint yields (Table 4).

**Table 4. Lint yield of cotton grown in a deep tillage/irrigation study at the Delta Research and Extension Center, Stoneville, MS**

| Treatment | | Lint yield (kg/ha) | | | | | | | | | Standard deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | Average | |
| Non-subsoiled | Non-irrigated | 887 | 644 | 381 | 1294 | 885 | 548 | 682 | 881 | 775 | 277 |
| | Low-level | 1014 | 875 | 953 | 1230 | 1004 | 840 | 1186 | 668 | 971 | 183 |
| | High-level | 1049 | 911 | 1048 | 1231 | 858 | 970 | 1228 | 627 | 990 | 199 |
| Subsoiled | Non-irrigated | 1126 | 832 | 648 | 1348 | 981 | 676 | 839 | 883 | 916 | 233 |
| | Low-level | 1048 | 927 | 851 | 1179 | 945 | 875 | 995 | 745 | 945 | 132 |
| | High-level | 1053 | 899 | 1021 | 1129 | 821 | 974 | 1266 | 595 | 970 | 204 |
| LSD ($P$ = 0.05) | | 128 | 113 | 203 | 133 | NS | 100 | 127 | 146 | | |

In 1997, yields from NI-NS and NI-S were high (Table 4), because of adequate and uniformly distributed rainfall plus favorable temperatures during the reproductive period (Table 3). The 41 cm of precipitation were sufficient for NI-NS and NI-S to produce yields equal to or greater than the other treatments. The HL-S yielded less than NI-NS and NI-S, indicating that yields were not maximized due to excessive water from rainfall, irrigation, and additional stored water resulting from deep tillage.

The 1998 growing season (May-August) was one of the warmest on record (Table 3), and the cotton matured early. Yields among treatments were not different (Table 4). Potential positive responses to irrigation were offset by 15 cm of rainfall, which fell over a 4-d period in mid-July.

During the drier- and warmer-than-normal July and August of 1999 and 2000 (Table 3), both the non-subsoiled and subsoiled environments responded to irrigation, but not all irrigated treatments produced similar yields (Table 4). The lower yields produced in the low level of irrigation in the subsoiled and non-subsoiled treatments in 1999 and 2000, respectively, than the high levels of irrigation were attributed to insufficient water to maximize yields. This insufficient water was due to the lack of stored soil water and too little irrigation applied to LL-NS in 1999 and too little irrigation water applied in LL-S in 2000.

Rainfall in August 2001 totaled 23 cm (Table 3). A double rate of nitrogen was inadvertently applied that year, and this exacerbated the effect of the high rainfall in August. The taller and denser-canopied irrigated cotton (LL-NS, HL-NS, LL-S, and HL-S) was not as mature as non-irrigated cotton (NI-NS and NI-S) when the rains began. Lower bolls on the full-canopied irrigated cotton were just beginning to open and were more susceptible to boll rot under the wet, overcast conditions. Yields from LL-NS, HL-NS, and HL-S were lower than those from NI-NS and NI-S (Table 4).

Over the 8-yr study, subsoil tillage increased yields in the non-irrigated treatments compared with the irrigated treatments in 1994, 1995, 1996, 1999, and 2000 (Table 4). The additional water stored in the soil profile due to the fracturing of the soil with subsoil tillage was beneficial in most years.

In the non-subsoiled treatments, irrigated yields (LL-NS and HL-NS) were similar in 1997 and 1998, lower in 2001, and higher than non-irrigated yields (NI-NS) the other five years (Table 4). Rain was insufficient in most years to provide adequate soil water in the non-subsoiled environment. Yields in the non-subsoiled irrigated treatments (LL-NS and HL-NS) were similar except in 1999. The LL-NS, with its delayed irrigation initiation and less total water provided sufficient soil water so that there were no differences among LL-NS and HL-NS in most years.

Yields between the subsoiled irrigated treatments (LL-S and HL-S) were similar except in 2000 and 2001 (Table 4). In the subsoiled environment, yields in both irrigated treatments were greater than yields from the non-irrigated treatment in 1999 and 2000, similar in 1994, 1995, and 1998, and lower in 1997. In 1996 and 2001, LL-S yields were similar to those from NI-S, while HL-S yielded more in 1996 and less in 2001 than NI-S. In drier years, irrigating subsoiled plots was necessary to provide adequate soil water to maximize yields, but in most years irrigation was not necessary and in 2 yr was detrimental. Difference in the supplemental water supplied by HL-S and LL-S was not enough to result in yield differences in most years.

Yields from all irrigated treatments (LL-NS, HL-NS, LL-S, and HL-S) in both the non-subsoiled and subsoiled environments were similar in most years, except in 1999, 2000 and 2001 (Table 4). Irrigation of non-subsoil treatments (LL-NS and HL-NS) was equally as effective as the irrigation of subsoil treatments (LL-S and HL-S) at providing adequate soil water to the crop.

**Economic Analysis.** Direct and total specified costs with standard deviations for each treatment for each year are presented in Tables 5 and 6, respectively. Irrigated treatments incurred higher production costs (Tables 5 and 6). 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 treatments, but are apparent when comparing NI-NS to NI-S. Average cost to produce a kg of lint per treatment is shown in Table 7. The NI-NS had the highest cost of production per kg. The LL-NS, HL-NS and NI-S have the lowest cost per kg of lint and provided positive returns over specified costs when lint price was at least $1.32 per kg of lint. The LL-S and HL-S 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.

**Table 5. Direct costs of cotton grown in a deep tillage/irrigation study at the Delta Research and Extension Center, Stoneville, MS**

| Treatment | | Direct costs ($/ha)[z] | | | | | | | | | Standard deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | Average | |
| Non-subsoiled | Non-irrigated | 971 | 922 | 818 | 1021 | 929 | 855 | 880 | 907 | 912 | 64 |
| | Low-level | 1016 | 1006 | 979 | 1023 | 971 | 951 | 1055 | 919 | 991 | 43 |
| | High-level | 1035 | 1026 | 1013 | 1035 | 961 | 998 | 1075 | 890 | 1003 | 57 |
| Subsoiled | Non-irrigated | 1035 | 976 | 892 | 1045 | 964 | 897 | 927 | 919 | 956 | 59 |
| | Low-level | 1030 | 1026 | 954 | 1026 | 971 | 971 | 998 | 919 | 986 | 40 |
| | High-level | 1050 | 1035 | 1018 | 1026 | 966 | 1013 | 1095 | 897 | 1013 | 59 |

[z] Direct costs include fertilizer, seed, chemicals, boll weevil eradication fees, labor, fuel, hauling and ginning.

**Table 6. Total specified costs for cotton grown in a deep tillage/irrigation study at the Delta Research and Extension Center, Stoneville, MS**

| Treatment | | Total specific costs ($/ha)[z] | | | | | | | | | Standard deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | Average | |
| Non-subsoiled | Non-irrigated | 1231 | 1184 | 1063 | 1265 | 1174 | 1100 | 1119 | 1147 | 1159 | 67 |
| | Low-level | 1334 | 1329 | 1285 | 1329 | 1278 | 1255 | 1357 | 1166 | 1292 | 61 |
| | High-level | 1357 | 1349 | 1317 | 1339 | 1268 | 1302 | 1376 | 1191 | 1312 | 60 |
| Subsoiled | Non-irrigated | 1302 | 1248 | 1144 | 1297 | 1218 | 1149 | 1176 | 1166 | 1213 | 64 |
| | Low-level | 1359 | 1359 | 1268 | 1339 | 1285 | 1285 | 1307 | 1228 | 1305 | 46 |
| | High-level | 1379 | 1369 | 1332 | 1339 | 1280 | 1327 | 1406 | 1206 | 1329 | 63 |

[z] 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 returns to management.

**Table 7. Cost of production per kg of lint for cotton grown in a deep tillage/irrigation study at the Delta Research and Extension Center, Stoneville, MS**

| Subsoil Treatment | Irrigation treatment | Cost[z] |
|---|---|---|
| Non-subsoiled | Non-irrigated | $1.50 |
| | Low-level | $1.33 |
| | High-level | $1.33 |
| Subsoiled | Non-irrigated | $1.32 |
| | Low-level | $1.38 |
| | High-level | $1.37 |

[z] Cost of production based on total specified costs.

Returns above total specified costs were calculated for each treatment using the cotton loan rate of $1.15 per kg of lint, average total specified costs for each treatment over the 8-yr period, and each treatment's respective 8-yr average lint yield (Table 8). The standard deviations of net returns for each treatment over the 8-yr period are also reported. When lint prices are at the loan rate of $1.15 per kg of lint, NI-S provides the most economical choice (i.e., smallest loss). The HL-NS treatment provides similar returns and has a lower standard deviation. The LL-NS treatment provides slightly lower returns and has a lower standard deviation.

The graph of mean-variance of the treatments reveals that NI-NS and HL-S are not on the efficient frontier, and that LL-NS, HL-NS, and NI-S are very similar in terms of mean net revenue and variance (risk) (Figure 1). Producer preference between these treatments is somewhat a matter of choice depending on their risk preference. Cotton price, which is exogenous to the producer, plays a role in the sense that different treatments have higher mean net revenues depending on cotton lint prices. These three treatments would be difficult to separate depending on whether the choice was the highest average return or the less risky return (i.e., lower standard deviation). If these treatments are analyzed using the cross break-even analysis method presented previously, HL-NS would have larger returns than LL-NS at lint prices above $0.91 per kg of lint and higher returns than NI-S when lint prices are above $1.18 per kg of lint. Thus, it could be said that when cot-

**Table 8. Average net returns per hectare for cotton grown in a deep tillage/irrigation study at the Delta Research and Extension Center, Stoneville, MS**

| Treatment | | Average net returns ($/ha)[z] | | | | | | | | | Standard deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | Average | |
| Non-subsoiled | Non-irrigated | -58 | -334 | -559 | 444 | -5 | -376 | -219 | 17 | -136 | 308 |
| | Low-level | 4 | -175 | -26 | 295 | 48 | -146 | 210 | -284 | -9 | 195 |
| | High-level | 29 | -146 | 67 | 288 | -135 | -21 | 245 | -363 | -5 | 213 |
| Subsoiled | Non-irrigated | 184 | -148 | -288 | 483 | 77 | -256 | -68 | 0 | -2 | 253 |
| | Low-level | 25 | -133 | -144 | 218 | -37 | -129 | 7 | -244 | -55 | 142 |
| | High-level | 12 | -181 | 16 | 152 | -196 | -41 | 266 | -420 | -49 | 215 |

[z] Based on cotton prices at loan rate of $1.15 per kg of lint.

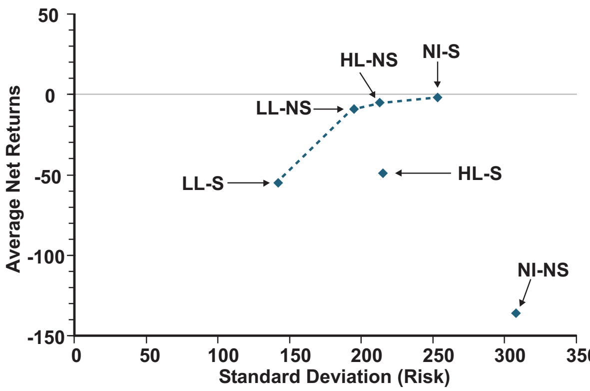


**Figure 1. Average net returns and standard deviation (risk) comparison for cotton grown with or without deep tillage and three levels of irrigation; NI-NS = non-irrigated, non-subsoiled, LL-NS = low-level irrigated, non-subsoiled, HL-NS = high-level irrigated, non-subsoiled, NI-S = non-irrigated, subsoiled, LL-S = low-level irrigated, subsoiled, HL-S = high-level irrigated, subsoiled.**

ton prices are above the loan rate, HL-NS would provide the highest economic returns on average and would be one of the less risky choices.

The NI-S treatment had the lowest cost per kg of lint, but the increased yield associated with HL-NS provided higher returns if lint prices are equal to $1.18 per kg or above (Table 7). Cotton lint prices have been depressed for several years. The cotton loan rate puts a "floor" under prices at $1.15 per kg, so producers often make decisions based on prices at or above the loan rate. If prices remained under the loan rate for extended periods, NI-S might be preferred.

Based on this study, it appears producers should either subsoil or irrigate, but not both. For producers with the ability to irrigate, deep tillage is not necessary.

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