INITIATION OF FURROW IRRIGATION IN CORN ON A DUNDEE/FORESTDALE SILTY CLAY LOAM SOIL WITH AND WITHOUT DEEP TILLAGE

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ABSTRACT. *Improving corn (*Zea mays *L.) furrow irrigation efficiency with proper irrigation scheduling will help conserve dwindling ground water resources in the Mississippi Delta. The objective of this study was to develop irrigation initiation recommendations for corn grown on a deep silty clay loam (SiCL) soils with and without deep tillage. Studies were conducted during the 2009, 2010, 2011, and 2012 growing seasons on a Dundee (fine-silty, mixed, active, thermic Typic Endoaqualfs) /Forestdale (fine, smetitic, thermic Typic Endoaqualfs) silty clay loam in the Mississippi Delta. Furrow irrigation was initiated at multiple timings with corn yield and net returns being later determined. Soil water potential (SWP), soil water deficit (SWD), and growth stage were compared at these initiation timings to determine which parameter or combination of parameters consistently predicted the greatest yields and net returns. Deep tillage increased irrigated yield three out of four years with no interaction between the main effects of tillage and irrigation initiation indicating there was no justification for different irrigation scheduling recommendations with (DT) or without deep tillage (NDT). Irrigation that provided adequate moisture from tasseling to physiological maturity maximized yields and net returns all four years of the study. Results indicated furrow irrigations on this soil should be initiated at the V15-V16 growth stage (3-5 days before VT) or later, when SWP readings are -50 kPa or drier or when SWD estimates are 100 mm or lower and rainfall is not imminent. These results reinforce the sensitivity of corn to drought stress during tasseling, silking, and pollination, and the need to ensure that water is not limiting as the corn enters into this critical time period.*

Keywords. *Corn, Deep tillage, Furrow irrigation, Irrigation initiation, Irrigation scheduling, Soil water deficit, Soil water potential, Water conservation.*

Irrigation increases corn [*Zea mays L.*] yields most years on multiple soils types (sand, sandy loam, loamy sand, clay loam, silty clay, and clay soils) in the humid subtropical environment of the mid-southern United States (Cassel et al., 1985; Hook et al., 1985; Camp et al., 1988; Boquet et al., 1989; Thompson et al., 1991; Morris et al., 1993; Vories et al., 1993; Wagger and Cassel, 1993; Wesley et al., 1994a; Bruns et al., 2003). As a result, irrigated corn acreage in the Mississippi Delta is steadily increasing. However, as irrigated corn acreage is expanding, ground water resources are decreasing in the Mississippi Delta (YMD, 2006). Furrow irrigation is the most popular irrigation method in this region, yet is one of the least efficient application methods for row crops (Negri and Hanchar, 1989). Anecdotally, many corn producers in the region focus on irrigation strategies they believe will maximize yield, regardless of the quantity of water used. Continuation of furrow irrigation in this area will depend on improving furrow irrigation strategies that optimize yields while minimizing the amount of water applied.

Hiler and Howell (1983) summarized research stating that most non-forage row crops including corn are more sensitive to moisture deficits at certain growth stages than others, and that the extent of yield reduction depends not only on growth stage but also the magnitude of the water deficit. Rhoads and Bennett (1990) concluded that corn is more sensitive to water stress during anthesis (R1 growth stage) than during grain fill (R4-R5) and less sensitive to water stress during vegetative development (prior to VT) (Ritchie and Hanaway, 1989). Heatherly and Ray (2007) stated that large reductions in kernel number in corn resulted from water-deficit stress occurring between V15 and two weeks after R1. Water-deficit stress occurring during R2-R4 (blister to dough) resulted in unfilled or undersized kernels while water-deficit stress occurring during R4.7-R6 (beginning dent to physiological maturity) resulted in reductions in kernel weight. Heatherly and Ray (2007) also concluded that corn grown on sandy soils is more sensitive to water deficits during vegetative development than corn grown on finer textured soils. Given the importance of adequate water at certain corn developmental stages, one strategy that corn

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producers can employ to decide on irrigation initiation is "critical growth stage irrigation."

Another method available to corn producers to optimize corn yield while reducing irrigation water use involves the utilization of soil moisture sensors. A popular type of soil moisture sensor is a granular matrix sensor (Watermark™, Irrometer Co., Riverside, Calif.). Granular matrix sensors measure the negative pressure, soil water potential (SWP) the plant has to exert to remove water from the soil and indirectly indicate the moisture content of the surrounding soil. Field capacity is the moisture content of the soil after all free water has drained away due to gravity and occurs around -10 kPa for sandy soils and -30 kPa for clayey soils (Martin et al., 1990). Wilting point refers to there being no more available water in the soil. This generally occurs around -1500 kPa for most crops (Martin et al., 1990). Granular matrix sensors have a limited range of 0 to -200 kPa, but most of the readily available soil moisture is removed by the crop within this range. These sensors are placed at several depths in the soil throughout the rooting zone and are used to monitor SWP and whether roots are active at each depth. Determining specific SWP values to trigger irrigation initiation will aid corn producers in making optimal irrigation initiation timings in the Mississippi Delta.

Another tool that can be used to schedule irrigation is the determination of soil water deficit (SWD) using a checkbook method. This method is a soil water balance model that takes into account deposits (effective rainfall, P_e; effective irrigation, I_e) and withdrawals (crop water use, or evapotranspiration, ET_c) to determine the soil water deficit (Martin et al., 1990). With this method, estimates are made of effective rainfall and irrigation knowing the total amounts of rainfall occurring and irrigation water applied, respectively. Weather parameters are used to estimate reference crop evapotranspiration, ET_o, which then can be adjusted to ET_c using crop coefficients, K_c (Allen et al., 1998). Allowable soil water deficits need to be determined for Mississippi Delta soils and crops/growth stages to conserve water while maintaining or maximizing yields and net returns.

When considering irrigation strategies, corn producers must also take into account other agronomic practices that can affect both irrigation and corn yield. One of these practices is deep tillage. Deep tillage has been a recommended practice since the mid-1970s on most Mississippi Delta soils (Spurgeon et al., 1974). This practice disrupts the soil profile at depths greater than 30.5 cm (*ASAE Standards*, 2005) allowing root exploration and water penetration into a larger soil volume (Bowen, 1981; Unger et al., 1981) provided there are no chemical barriers (acid subsoils) to root penetration and development (Adams, 1981). This increased root proliferation and increased soil water availability improves nutrient supply and uptake (Sumner and Boswell, 1981). Deep tillage also can improve aeration and may reduce the incidence of some diseases (Cannell and Jackson, 1981; Lyda, 1981).

Deep subsoil tillage of sandy loam and loamy sands containing tillage pans found in the south and southeast has been shown to increase non-irrigated (NI) corn yields in most years (Chancy and Kamprath, 1982; Rich et al., 1985; Ewing et al., 1991; Reeves et al., 1992; Wagger et al., 1992; Hunt et al., 2004; Raper et al., 2005). Deep tillage of alluvial sandy loam, silt loam, silty clay loam, and some clay soils has been shown to increase NI cotton (*Gossypium hirsutum* L.) yield economically in the Mississippi River Delta (Spurgeon et al., 1978; Tupper and Spurgeon, 1981; Tupper et al., 1987, 1989; McConnell et al., 1989; Tupper and Pringle, 1997; Phipps et al., 2000; Wesley et al., 2001; Pringle and Martin, 2003). Yearly variation in total rainfall and rainfall distribution affected both the yield and the yield response from deep tillage during these studies. Generally, positive yield responses from deep tillage of NI crops are reduced when there is ample rainfall during the growing season.

Deep tillage plus sprinkler irrigation has increased yield of corn on loamy sands in the mid-southern United States (Wright et al., 1984; Cassel and Edwards, 1985; Camp et al., 1988) but the response to deep tillage under these irrigated conditions was much smaller than the response to deep tillage without irrigation. Benefits from deep tillage were found to be relatively unimportant for irrigated corn on some sand or loam soils in the northwest (Ibrahim and Miller, 1989). Deep tillage has not consistently shown a yield increase or economic benefit under irrigated conditions in the Mississippi Delta for cotton grown on alluvial silt loam soils (Pringle and Martin, 2003) or for soybean [*Glycine max (*L.*) Merr*] grown on coastal plain soils in the southeastern United States (Frederick et al., 2001; Camp and Sadler, 2002). Likewise, no positive yield responses for furrow irrigated cotton were found in Arizona with deep tillage in a reduced tillage system on a silt loam soil (Coates, 2000). Wesley et al. (1994b) did not find a positive increase in soybean yield or returns to investment with deep tillage preceding irrigated soybean production on an alluvial clay soil. Deep tillage ahead of corn in an irrigated environment needs to be examined on silty clay loam soils in the Mississippi Delta.

Therefore, the first objective of this work was to compare yields and economic returns of corn with and without deep tillage while at multiple furrow irrigation initiation timings on a silty clay loam soil. The second objective was to compare irrigation initiation on critical growth stage determination, SWP value and calculated SWD value. The third objective of this study was to develop an irrigation initiation recommendation for furrow irrigated corn grown on silty clay loam soils in the Mississippi Delta.

MATERIALS AND METHODS

Field studies were established at the Mississippi State University Delta Research and Extension Center satellite farm near Tribbett, Mississippi (36-m elev., 33° 21' N, 90° 48' W) during a four-year period from 2009-2012. Corn was in an annual rotation (1:1) with cotton on two adjacent fields and had been in this rotation since 1999. The study was conducted in a randomized complete block design with a 6 × 2 factorial arrangement of treatments in four replicates. The first factor was irrigation strategy which included five irrigation initiation timings and a non-irrigated (NI) treatment. The second factor was tillage practice which included deep tillage (DT) and no deep tillage (NDT).

The soils were composed of a Dundee/Forestdale complex. The Dundee (Fine-silty, mixed, active, thermic Typic Endoaqualfs) silty clay loam consists of very deep, somewhat poorly drained soils that formed in loamy alluvium (USDA NRCS OSD, n.d.) and belongs to a 0.3 intake family with a maximum rooting depth of 1.2 m (USDA/SCS, 1974). The Forestdale series (Fine, smetitic, thermic Typic Endoaqualfs) consists of very deep, poorly drained, very slowly permeable soils that formed in clayey and silty alluvium (USDA NRCS OSD, n.d.) and belongs to a 0.2 intake family with a maximum rooting depth of 1.2 m (USDA/SCS, 1974). Both soils tend to form a fairly impermeable crust following a rain or irrigation event.

Deep tillage on assigned DT plots was performed in-row to a depth of 35.6 cm with a 4-shank, low-till parabolic subsoiler designed and built by Mississippi State University (Tupper, 1995; Tupper and Pringle, 1997). In this corn/cotton rotation on the two adjacent fields, plots that were DT ahead of corn were NDT for cotton the next year and plots that were NDT ahead of corn were DT for cotton the next year. This primary tillage occurred either in the fall after harvest or in late winter depending on weather conditions. Disking was performed prior to deep tillage if weeds became a problem such that it would interfere with DT operations. The field was bedded utilizing a John Deere 886 Row-Crop Cultivator (John Deere Co., Moline, Ill.). Plots consisted of 6 rows spaced 1.0 m apart and 198 m long. Nitrogen (urea-ammonium nitrate, 32% N) was applied as a split application with 112 kg N ha^{-1} at planting followed by 157 kg N ha^{-1} applied as a sidedress application at V5-V6. Both applications were made with a “knife” applicator equipped with a knife on each side of the planted row (25 cm from row). All studies were maintained weed-free throughout the growing season using combinations of pre and post-emergence herbicides.

Immediately after rows were conditioned in late-March to mid-April, Pioneer 31P42 (DuPont-Pioneer, Johnston, Iowa) corn was seeded at 77,500 kernels ha^{-1} at a depth of 5 cm. This hybrid has a relative maturity of 119 days. A water furrow was cultivated in between rows ahead of irrigation to help control weeds and to facilitate water flow down the intended row-middles.

Watermark™ Model 200SS soil water potential sensors (Irrometer Co., Riverside, Calif.) were prepared in accordance with the manufacturer’s recommendations prior to installation. A 2.2 cm diameter soil probe was used to core out the soil down to the desired installation depth. A soil and water slurry was added to the hole to ensure proper sensor-to-soil contact. A length of PVC was attached to the sensor and used to push the sensor down to the desired depth, and then soil was backfilled around the access hole. The sensors were installed in two irrigated plots, one DT and one NDT plot, in each replicate of the study. The sensors were installed in the predominant soil (Dundee) in the upper third of the field at three depths (23, 46, and 69 cm) below the soil surface, which represented the majority of the rooting zone for corn grown in this soil type. Each site was instrumented with inexpensive, open-source non-commercial dataloggers (Fisher, 2007) and set to read and store data every 2 h.

Soil samples (0-76 cm) were taken in 2004 in the vicinity of the placement of Watermark sensors in this study and were used to create a soil water retention curve. Saxton’s model (Saxton et al., 1986), which developed soil water characteristics equations for multiple soil textures from a USDA soil database using soil texture and organic matter content, was used to calculate soil water characteristics for these samples. This model combined developed relationships for soil matrix potentials and conductivities, and the effects of density, gravel, and salinity. The model was used to construct the soil water retention curve. Ten sites were sampled at 0-15, 15-30, 30-46, 46-61, and 61-76 cm depths and averaged over all depths and sample sites. The soil was predominately a silty clay loam with an average of 17% sand, 52% silt, 31% clay, and 0.8% organic matter (OM). These values were entered into Saxton’s model, leaving the salinity and gravel parameters at the default values of 0. Soil compaction measurements were not taken, so the soil compaction factor was left at the default value of normal. The resulting estimated soil water retention curve is shown in figure 1. From this curve, a water potential value of -159 kPa would indicate when 50% of the available water has been removed, a value commonly used in irrigation scheduling. The resulting value of 61 mm of soil water depletion was then obtained by subtracting the soil water content (SWC) value at 50% available water (27.35%) from the SWC at field capacity (35.2%) and multiplying by the depth of the majority of the root zone (76.2 cm).

A roll-out pipe system (Delta Plastics, Little Rock, Ark.) was used to furrow irrigate the irrigated plots by providing water to the five middles of the 6-row plots. The first irrigation initiation treatment of the study commenced when soil water potential (SWP) readings averaged over all three depths were in the range from -30 to -40 kPa, independent of growth stage. Once the first irrigation initiation treatment began, subsequent initiation treatments were initiated 3 to 5 d apart except when a rain event occurred. Subsequent irrigations for each initiation treatment were applied on a 7 to 10 d interval. If rain occurred during that time interval, subsequent irrigations would be delayed to allow for the estimated effective rainfall to be utilized by the crop. Irrigations were terminated within the 7 to 10 d prior to the occurrence of physiological maturity (R6). The volume of irrigation water applied was determined from a propeller type flow meter (McCrometer, Hemet, California) along with the area of the plots being irrigated and used to calculate the total irrigation

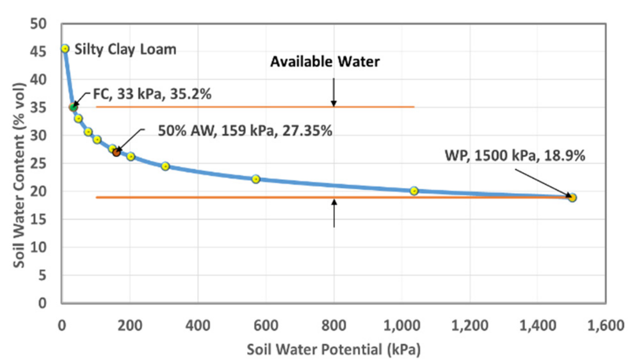

Figure 1. Estimated soil water retention curve for Dundee SiCL soil, Tribbett, Mississippi, including estimates of field capacity (FC), 50% available water (AW), and wilting point (WP).

water applied on an area basis for each irrigation. Total water applied for each treatment was then summed over each irrigation. The seasonal irrigation water use efficiency (SIWUE), defined as the mean yield increase due to an irrigation initiation treatment above the mean yield from the NI treatment divided by the total irrigation water applied, was determined for each irrigation initiation treatment.

Corn growth stage was recorded weekly, and growth stage at irrigation initiation was estimated from these records. We considered the VT growth stage to be when the tassels emerged and started extending above the leaves. This was used as a reference point such that the number of days before or after VT could then be determined for each irrigation initiation timing.

Soil water deficit (SWD) during the growing season was calculated using the checkbook method. ET_c was calculated based on the FAO-56 Penman-Monteith method using a single crop coefficient (Allen et al., 1998) as:

$$ETc = Kc * ETo \quad (1)$$

Weather data from an automated weather station (Campbell Scientific, Logan, Utah) on site was used in the calculation of ET_o (Allen et al., 1998). The crop coefficient (K_c) curve for corn (fig. 2) was derived using local observations for lengths of growth periods (initial, 31 d; development, 19 d; mid, 58 d; late, 19 d) and using local weather conditions to make adjustments to the magnitude of each K_c value (K_c initial 0.4; K_c mid, 1.2, K_c end, 0.35) for each growth period based on FAO-56 methodology (Allen et al., 1998). Measurements of rainfall were input to the Curve Number Method along with soil, cultural practice, and residue conditions (HSG Group B, Ag row crop, straight rows + crop residue cover-good condition, adjust for antecedent moisture condition) to predict runoff (USDA, 1986) and from that, estimate P_e.

Prior to harvest, 20 ear samples were collected from a row adjacent to the harvest rows of each plot to determine average number of kernels ear^{-1}. The middle two rows of each plot were harvested with a Gleaner K2 combine, and the kernels were then transferred to a weigh cart to measure yield. A sample was taken to measure harvest moisture content, test weight, and seed weight. Yields were later adjusted to 15.5% moisture content.

An economic analysis for this field study was performed based on partial budgeting of net returns above irrigation and hauling costs since all other production factors were held constant among all treatments. Irrigation cost estimates were based on yearly Mississippi State University budgets for furrow irrigation of a 64.8-ha tract using roll-out pipe (MSU, 2009-2012). Deep tillage cost estimates were based on yearly MSU budgets for a 6-shank low-till subsoiler. The average reported corn price for the week including the harvest date in the Mississippi Delta area (USDA AMS, n.d.) was used to set the corn price in the analysis.

Data were subjected to ANOVA using the PROC MIXED procedure in SAS (SAS Institute, Cary, N.C.). Differences in planting date, soil moisture, and weather conditions resulted in different irrigations among years, so data were analyzed by year. Within each year, tillage, initiation, and the tillage × initiation were considered fixed effects, while replication was considered a random effect. Least square means were calculated and separated by Fisher's Protected LSD procedure at the 5% level of significance.

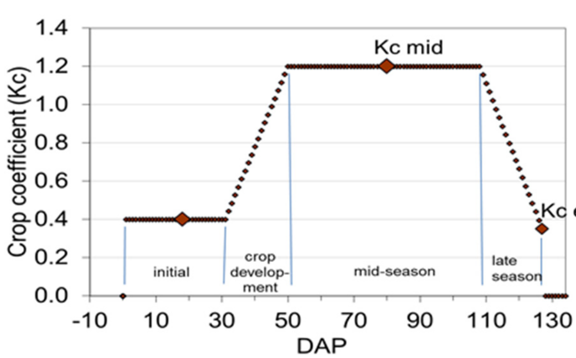

Figure 2. Crop coefficient curve for corn adjusted for local conditions.

RESULTS AND DISCUSSION

WEATHER

Table 1 summarizes rainfall and air temperatures during select periods of the crop year at Tribbett, Mississippi. Winter rainfall for each year is defined as the total rainfall collected between 1 November of the previous year and 31 March of the crop year. In 2009, 2010, and 2012, winter rainfall was 80%, 67%, and 58% lower than the historical average of the nearby Stoneville weather station (Pringle and Ebelhar, 2009; Unpublished Stoneville historical weather data), respectively. In 2009, rainfall at the Tribbett site in April and May was 81 mm higher than the historical average while it was 102 mm below average in 2012. Rainfall in June and July, which coincided with corn reproductive growth, was 63 and 114 mm below average in 2010 and 2011, respectively, while 2009 and 2012 were 33 and 43 mm above average, respectively.

Average maximum and minimum air temperatures in April and May at the Tribbett site were found to be higher than the Stoneville historical average in 2010, 2011, and 2012, while the maximum air temperature for this period in 2009 was lower than average (table 1). From June through July, average maximum air temperatures were above average in 2010 and 2011 along with above average minimum air temperatures as compared to 2009 and 2012. Maximum and minimum air temperatures are shown in table 1 for a period of one week starting at tasseling (VT) since some varieties are sensitive to heat during pollination. 2009 and 2011

Table 1. Rainfall and air temperature for select periods of the crop year at Tribbett, Mississippi.

Time Period	2009[a]	2010[a]	2011[a]	2012[a]	Historical[b]
	Rainfall (mm)				
Nov.-March	505	422	366	627	630
April-May	333	231	234	150	252
June-July	221	125	74	231	188
	Average Max/Min Air Temperature (°C)				
April-May	25/14.4	28.3/16.1	27.8/14.4	28.3/16.1	26.1/13.3
June-July	32.8/21.1	34.4/23.3	35/22.8	33.3/21.1	32.8/21.7
Week of pollination	35.6/22.8	33.9/22.8	35.6/21.1	30/19.4	

[a] Pringle and Ebelhar, 2009.
[b] Unpublished historical average for Stoneville, Mississippi (rainfall, 99 years; air temperature, 84 years) located eight miles NNE of Tribbett, Mississippi.

were more stressful during pollination since they had the highest average maximum and minimum air temperatures, while 2012 had the lowest.

Yield and Economic Analysis

Irrigation initiation affected yield, kernel weight, and net returns in all years of the study (table 2). It affected kernel number in all years except 2012. Tillage affected yield and net returns in 2009, 2010, and 2011, but not 2012. It affected kernel number in 2009 and 2010 but did not affect kernel weight in any year of the study. An irrigation initiation × tillage interaction was not observed for any response variables in any year of this study. The non-significant interaction indicated that the irrigation initiation was not influenced by tillage and responded independent of tillage system. Likewise, tillage was not directly influenced by the irrigation initiation timing.

Estimates of variable and fixed irrigation costs for furrow irrigation, additional fixed and variable costs of water lifting, hauling costs, and deep tillage costs obtained from yearly Mississippi State University Department of Agricultural Economics Budget Report (MSU, 2009-2012) varied by year and are given in table 3. Irrigation cost excluding water lifting increased dramatically in 2012 due to an increase in capital recovery costs for land leveling. Fuel prices increased over the years causing all cost categories to increase slightly. Concurrent with the increase in irrigation costs excluding water lifting was a rise in corn price between 2009 and 2012.

2009

Corn was visibly stunted and had a light green color after excessive rainfall (206 mm; 1 May to 12 May) prior to V6 in NDT treatments as compared to DT treatments in 2009. DT increased corn yields and net returns by an average of 1.07 Mg ha^{-1} and \$111 ha^{-1} (table 4), respectively, potentially, attributed to better internal drainage, less de-nitrification, or less total saturation in the root zone in these soils during early vegetative growth (Larson, 2009). The 9 June (71 DAP), 15 June (77 DAP), 19 June (81 DAP), and 24 June (86 DAP) irrigation initiations occurring at VT or earlier had greater average yields, ranging from 8.34 to 11.4 Mg ha^{-1} compared to 6.40 Mg ha^{-1} for NI corn and 6.90 Mg ha^{-1} for the 27 June (89 DAP), R2 growth stage initiation treatment. The greatest average yield (11.2 Mg ha^{-1}) and net returns (\$1198 ha^{-1}) were found among the earliest three irrigation treatments initiated at 9 June (71 DAP), V11; 15 June (77 DAP), V15; and 19 June (81 DAP), V17 growth stages. These greater yields and net returns were due to increased kernel weight and kernel ear^{-1} as compared to the 27 June (89 DAP)), R2 initiation and NI corn. One irrigation (69 to 76 mm of water) was saved when delaying initiation to 15 June or 19 June which also recorded the greatest SIWUE of 2.02 kg m^{-3} and 1.98 kg m^{-3} of water, respectively. The 19 June (81 DAP), V17 initiation occurred at the beginning of a 10-day period during which maximum air temperatures averaged 35.6°C, the first extended heat period >35°C that occurred this growing season which continued through silking and pollination (table 1). There was a reduction in irrigated yields and net returns for the 24 June (86 DAP), VT and 27 June (89 DAP), R2 initiation treatments as compared to earlier initiations, showing the sensitivity of the variety, to the greater maximum air temperatures which occurred during tasseling and pollination when soil moisture was not adequate soon enough.

Table 2. Analysis of variance (p<0.05) of irrigation initiation timing (Init)and tillage (Till) effects on corn yield, yield components, and net returns during each year of field studies on a Dundee/Forestdale SiCL soil, Tribbett, Mississippi.

	Effect	2009	2010	2011	2012
Yield	Init	0.0001	0.0001	0.0001	0.0001
	Till	0.0001	0.0001	0.0001	0.444
	Init × Till	0.517	0.714	0.268	0.651
Kernel no.	Init	0.0001	0.0002	0.0001	0.864
	Till	0.045	0.036	0.638	0.783
	Init × Till	0.261	0.284	0.698	0.234
Kernel wt.	Init	0.0001	0.0001	0.0001	0.0001
	Till	0.849	0.325	0.151	0.749
	Init × Till	0.683	0.672	0.239	0.950
Net returns	Init	0.0001	0.0001	0.0001	0.0007
	Till	0.0004	0.0001	0.0006	0.795
	Init × Till	0.494	0.707	0.278	0.658

Table 3. Estimated irrigation, deep tillage, and hauling cost and corn price for each year.

	2009 (\$)	2010 (\$)	2011 (\$)	2012 (\$)
Irrigation cost per ha excluding water lifting (\$ ha^{-1})[a]	102.87	106.75	113.74	169.81
Water lifting cost (\$ ha^{-1} mm^{-1})[a]	0.20	0.21	0.30	0.31
Haul corn (\$ Mg^{-1})[a]	7.87	10.24	9.45	11.02
Subsoiler low-till (\$ ha^{-1})[a]	23.75	23.94	28.49	28.32
Corn price (\$ Mg $^{-1}$[b]	130.31	162.98	266.91	286.99

[a] Yearly Mississippi State University Budget Report.
[b] Greenville Farmers Grain Terminal average quote, Mississippi Daily Grain Report (USDA-AMS, n.d.) for week of harvest (30 September 2009, 27 August 2010, 25 August 2011, and 27August 2012).

2010

Lower than normal winter rainfall and June-July rainfall, and relatively high maximum and minimum air temperatures during June (tasseling, silking, and pollination) in 2010, resulted in NI yields of 6.84 Mg ha^{-1}. All initiations produced yields greater than NI corn due to increased kernel weight and kernel ear^{-1} (table 5). When averaged across initiations, DT increased corn yield by an average of 1.00 Mg ha^{-1} and net returns by an average of \$131 ha^{-1}, by increasing kernel ear^{-1} harvested and likely due to increase water infiltration into the soil profile as compared to NDT plots during the lower than normal winter and June-July rainfall (table 1). The 26 May (47 DAP), V11 and 1 June (53 DAP), V15 irrigation initiation treatments had the greatest average yields of 12.0 Mg ha^{-1} and average net returns of \$1642 ha^{-1}, and total irrigation water applied was very similar. The SIWUEs, ranging from 1.35 to 1.52 kg m^{-3}, were similar for all initiation treatments.

2011

In 2011, an extremely dry winter and a hot and dry June-July period (table 1) resulted in the lowest NI yields observed across the four years of this study (1.82 Mg ha^{-1}) shown in table 6. When averaged across initiations, yields and net returns for all treatments were increased 1.00 Mg ha^{-1} and \$240 ha^{-1} on average with DT, respectively. All irrigated treatments had greater yields compared to the NI corn. The greatest

Table 4. Furrow irrigated initiation (Init) date, growth stage, irrigation water applied, irrigation costs, corn yields, yield components, net returns, and seasonal irrigation water use efficiency (SIWUE) by initiation and tillage treatment on a Dundee/Forestdale SiCL soil, Tribbett, Mississippi, 2009.

Irrigation Initiation Date (DAP)	Init 1 9 June(71)	Init 2 15 June(77)	Init 3 19 June(81)	Init 4 24 June(86	Init 5 27 June(89)	Non-irrigated	Average[a,c,e,g]
Stage of Growth	V11	V15	V16	VT	R2	R6	
Irrigation Water Applied (mm)	305	236	229	152	132	0	
Irrigation and Tillage Costs ($ ha^{-1})							
No Deep Tillage	249	235	230	195	175	47	
Deep Tillage	279	264	259	225	215	79	
Yield (Mg ha^{-1})							
No Deep Tillage	10.9	10.7	10.5	8.0	5.8	5.9	6.9 b
Deep Tillage	11.8	11.6	11.3	8.8	8.0	6.8	9.7 a
Average[b]	11.4 a	11.2 a	10.9 a	8.3 b	6.9 c	6.4 c	
Kernels ear^{-1}							
No Deep Tillage	401	398	371	208	341	220	323 b
Deep Tillage	395	416	412	265	321	314	354 a
Average[d]	398 a	407 a	392 a	236 c	331 b	267 c	
Kernel wt (g 100^{-1})							
No Deep Tillage	42.5	42.4	42.0	42.9	40.7	41.0	41.9 a
Deep Tillage	42.9	42.4	42.4	42.0	40.8	40.7	41.9 a
Average[f]	42.7 a	42.4 a	42.2 a	42.4 a	40.8 b	40.9 b	
Net Return ($ ha^{-1})							
No Deep Tillage	1173	1166	1136	842	583	721	936 b
Deep Tillage	1260	1247	1210	919	823	818	1047 a
Average[h]	1215 a	1208 a	1173 a	882 b	704 c	771 c	
Average SIWUE (kg m^{-3})	1.63	2.02	1.98	1.28	0.38		

[a] Tillage treatment yield means followed by a common letter range are not different ($p<0.05$; LSD = 0.46 Mg ha^{-1}).
[b] Irrigation initiation treatment yield means followed by a common letter range are not different ($p<0.05$; LSD = 0.80 Mg ha^{-1}).
[c] Tillage treatment kernel ear^{-1} means followed by a common letter range are not different ($p<0.05$; LSD = 30 kernels. ear^{-1}).
[d] Irrigation initiation treatment kernel ear^{-1} means followed by a common letter range are not different ($p<0.05$; LSD = 52 kernels ear^{-1}).
[e] Tillage treatment kernel weight means followed by a common letter range are not different ($p<0.05$; LSD = 0.50 g 100^{-1}; ns).
[f] Irrigation initiation treatment kernel weight means followed by a common letter range are not different ($p<0.05$; LSD = 0.87 g 100^{-1}).
[g] Tillage treatment means followed by a common letter range are not different ($p<0.05$; LSD = $57 ha^{-1}).
[h] Irrigation initiation treatment means followed by a common letter range are not different ($p<0.05$; LSD = $96 ha^{-1}).

yielding irrigation treatments, averaging 11.7 Mg ha^{-1}, were initiated at 28 May (66 DAP) and 1 June (70 DAP), at the V13 and V16 growth stages, had increased kernel weight and kernel ear^{-1} as compared to the NI treatments. Greater average net returns ($2681 ha^{-1}) were found when irrigations were initiated on 28 May (66 DAP), V13; 1 June (70 DAP), V16; and 6 June (75 DAP), VT growth stages. The 1 June initiation had 23 mm less irrigation water applied compared to the 28 May initiation and occurred at the onset of a 20-day period during which maximum air temperature averaged 35.6°C and occurred prior to and during silking and pollination (table 1). Yields were reduced with the 6 June (75 DAP), VT initiation as compared to the 28 May (70 DAP), V13 initiation, but SIWUE was similar. Irrigated yields, net returns, and SIWUE dropped off sharply with the 12 June (81 DAP), R2 and 16 June (85 DAP), R3 initiation treatments likely due to the hot temperatures which occurred through the entire tasseling, silking, and pollination period and to the delay in initiation of irrigation.

2012

Favorable moisture and temperature conditions in 2012 (table 1) led to the greatest average NI yields (9.16 Mg ha^{-1}) in the four year study as shown in table 7. When averaged across initiations, yields and net returns were similar for the DT and NDT treatments. All initiations had greater yields and net returns compared to the NI corn due to increased kernel weight, except for the irrigated treatment initiated on 3 June (62 DAP), V15, in which the net returns were similar with the NI corn. The irrigation on 3 June was not terminated on time, affecting the second irrigation of the 22 May (50 DAP) initiation treatment and 3 June initiation treatment, thus more total irrigation water was applied than desired. A 48 mm rain event occurring one day after the 3 June irrigation compounded the excess-water situation and decreased yield for the 3 June initiation (10.5 Mg ha^{-1}). This 48 mm rain on 4 June and an 81 mm rain on 12 June likely provided adequate moisture during silking and pollination, such that irrigation treatments did not increase kernel ear^{-1}. The 4 June rain event resulted in the actual date of initiation for the 20 June (79 DAP), R3 initiation treatment being 4 June. Delaying irrigation initiation to 20 June resulted in the capture of those 4 June and 12 June rain events, which resulted in a reduction of water applied by two irrigations (154 mm) and the highest SIWUE of 0.121 kg m^{-3}.

Soil Water Potential and Environmental Conditions

Changes in SWP readings suggested root activity at all three sensor depths (23, 46, and 69 cm) each year at the time of initiation. Since there was no interaction between the main effects of tillage and irrigation initiation (table 2), the SWP readings were averaged over all sensor sites, tillage treatments, and sensor installation depths. Yields and average SWP at the time of each irrigation initiation are shown for each year in figure 3. A window, denoted the Window of Opportunity (WOP), is drawn and highlighted around the two to five initiations where yields and net returns were maximized. The SWP readings were highly variable and site-specific due to differences in soil texture, root density, and rooting depth.

Table 5. Furrow irrigated initiation (Init) date, growth stage, irrigation water applied, irrigation costs, corn yields, yield components, net returns, and seasonal irrigation water use efficiency (SIWUE) by initiation and tillage treatment on a Dundee/Forestdale SiCL soil, Tribbett, Mississippi, 2010.

Irrigation Initiation Date (DAP)	Init 1 26 May(47)	Init 2 1 June(53)	Init 3 4 June(56)	Init 4 8 June(60)	Init 5 14 June(66)	Non-Irrigated	Average[a,c,e,g]
Stage of Growth	V11	V15	V17	R1	R2	R6	
Irrigation Water Applied (mm)	357	353	315	323	254	0	
Irrigation and Tillage Costs ($ ha^{-1})							
No Deep Tillage	304	299	287	284	267	64	
Deep Tillage	334	334	321	321	299	99	
Yield (Mg ha^{-1})							
No Deep Tillage	11.9	11.4	10.9	10.5	10.3	6.3	10.2 b
Deep Tillage	12.4	12.4	12.0	11.9	11.2	7.4	11.2 a
Average[b]	12.2 a	11.9 ab	11.5 bc	11.2 cd	10.7 d	6.8 e	
Kernels ear^{-1}							
No Deep Tillage	438	451	413	450	422	356	422 b
Deep Tillage	479	446	481	447	427	385	444 a
Average[d]	458 a	448 a	447 a	449 a	424 a	370 b	
Kernel wt (g 100^{-1})							
No Deep Tillage	39.2	38.1	37.7	37.9	37.8	30.3	36.8 a
Deep Tillage	39.5	38.8	38.6	38.4	38.2	29.4	37.2 a
Average[f]	39.3 a	38.4 ab	38.2 ab	38.2 ab	38.0 b	29.9 c	
Net Return ($ ha^{-1})							
No Deep Tillage	1633	1554	1490	1438	1416	954	1413 b
Deep Tillage	1695	1680	1641	1614	1520	1112	1544 a
Average[h]	1665 a	1619 ab	1567 bc	1525 cd	1468 d	1033 e	
Average SIWUE (kg m^{-3})	1.50	1.43	1.48	1.35	1.52		

[a] Tillage treatment means followed by a common letter range are not different ($p<0.05$; LSD = 0.80 Mg ha^{-1}).
[b] Irrigation initiation treatment means followed by a common letter range are not different ($p<0.05$; LSD = 0.51 Mg ha^{-1}).
[c] Tillage treatment kernel ear^{-1} means followed by a common letter range are not different ($p<0.05$; LSD = 21 kernels. ear^{-1}).
[d] Irrigation initiation treatment kernel ear^{-1} means followed by a common letter range are not different ($p<0.05$; LSD = 36 kernels ear^{-1}).
[e] Tillage treatment kernel weight means followed by a common letter range are not different ($p<0.05$; LSD = 0.68 g 100^{-1}; NS).
[f] Irrigation initiation treatment kernel weight means followed by a common letter range are not different ($p<0.05$; LSD = 1.2 g 100^{-1}).
[g] Tillage treatment means followed by a common letter range are not different ($p<0.05$; LSD = $44 ha^{-1}).
[h] Irrigation initiation treatment means followed by a common letter range are not different ($p<0.05$; LSD = $79 ha^{-1}).

Table 6. Furrow irrigated initiation (Init) date, growth stage, irrigation water applied, irrigation costs, corn yields, yield components, net returns, and seasonal irrigation water use efficiency (SIWUE) by initiation and tillage treatment on a Dundee/Forestdale SiCL soil, Tribbett, Mississippi, 2011.

Irrigation Initiation Date (DAP)	Init 1 28 May(66)	Init 2 1 June(70)	Init 3 6 June(75)	Init 4 12 June(81)	Init 5 16 June(85)	Non-Irrigated	Average[a,c,e,g]
Stage of Growth	V13	V16	R1	R2	R3	R6	
Irrigation Water Applied (mm)	455	432	376	384	305	0	
Irrigation and Tillage Costs ($ ha^{-1})							
No Deep Tillage	351	339	316	287	242	17	
Deep Tillage	385	381	356	326	287	44	
Yield (Mg ha^{-1})							
No Deep Tillage	11.4	10.9	10.1	6.8	4.1	1.9	7.5 b
Deep Tillage	12.1	12.4	11.5	7.8	5.9	1.8	8.5 a
Average[b]	11.7 a	11.6 ab	10.8 b	7.3 c	5.0 d	1.8 e	
Kernels ear^{-1}							
No Deep Tillage	440	428	469	331	338	222	371 a
Deep Tillage	450	466	465	279	331	189	363 a
Average[d]	445 a	447 a	467 a	305 b	335 b	206 c	
Kernel wt (g 100^{-1})							
No Deep Tillage	36.5	35.6	34.2	34.5	31.2	23.8	32.6 a
Deep Tillage	36.5	36.1	36.9	35.1	32.0	22.8	33.2 a
Average[f]	36.5 a	35.8 ab	35.5 ab	34.8 b	31.6 c	23.3 d	
Net Return ($ ha^{-1})							
No Deep Tillage	2681	2560	2385	1530	857	487	1749 b
Deep Tillage	2842	2913	2703	1769	1287	418	1989 a
Average[h]	2760 a	2735 a	2545 a	1648 b	1072 c	452 d	
Average SIWUE (kg m^{-3})	2.17	2.26	2.39	1.44	1.05		

[a] Tillage treatment means followed by a common letter range are not different ($p<0.05$; LSD = 0.50 Mg ha^{-1}).
[b] Irrigation initiation treatment means followed by a common letter range are not different ($p<0.05$; LSD = 0.86 Mg ha^{-1}).
[c] Tillage treatment kernel ear^{-1} means followed by a common letter range are not different ($p<0.05$; LSD = 34 kernels. ear^{-1}; ns).
[d] Irrigation initiation treatment kernel ear^{-1} means followed by a common letter range are not different ($p<0.05$; LSD = 58 kernels ear^{-1}).
[e] Tillage treatment kernel weight means followed by a common letter range are not different ($p<0.05$; LSD = 0.83 g 100^{-1}; ns).
[f] Irrigation initiation treatment kernel weight means followed by a common letter range are not different ($p<0.05$; LSD = 1.4 g 100^{-1}).
[g] Tillage treatment means followed by a common letter range are not different ($p<0.05$; LSD = $129 ha^{-1}).
[h] Irrigation initiation treatment means followed by a common letter range are not different ($p<0.05$; LSD = $222 ha^{-1}).

Table 7. Furrow irrigated initiation (Init) date, growth stage, irrigation water applied, irrigation costs, corn yields, yield components, net returns, and seasonal irrigation water use efficiency (SIWUE) by initiation and tillage treatment on a Dundee/Forestdale SiCL soil, Tribbett, Mississippi, 2012.

Irrigation Initiation Date (DAP)	Init 1 17 May(45)	Init 2 22 May(50)	Init 3 27 May(55)	Init 4 3 June(62)	Init 5 20 June(79)	Non-Irrigated	Average[a,c,e,g]
Stage of Growth	V8	V10	V11	V15	R3	R6	
Irrigation Water Applied (mm)	345	437	269	361	191	0	
Irrigation and Tillage Costs ($ ha^{-1})							
No Deep Tillage	403	430	376	400	353	96	
Deep Tillage	435	460	408	423	383	133	
Yield (Mg ha^{-1})							
No Deep Tillage	11.5	11.5	11.1	10.8	11.4	8.8	10.8 a
Deep Tillage	11.9	11.5	11.5	10.3	11.5	9.5	11.0 a
Average[b]	11.7 a	11.5 a	11.3 ab	10.5 b	11.5 a	9.2 c	
Kernels ear^{-1}							
No Deep Tillage	477	492	495	464	330	470	455 a
Deep Tillage	477	480	398	493	517	419	464 a
Average[d]	477 a	486 a	446 a	479 a	424 a	445 a	
Kernel wt (g 100^{-1})							
No Deep Tillage	36.8	36.2	36.2	36.1	36.3	33.1	35.8 a
Deep Tillage	36.0	36.2	35.9	36.1	36.9	32.8	35.6 a
Average[f]	36.4 a	36.2 a	36.1 a	36.1 a	36.6 a	32.9 b	
Net Return ($ ha^{-1})							
No Deep Tillage	2916	2871	2807	2703	2933	2427	2775 a
Deep Tillage	2980	2839	2889	2528	2913	2602	2792 a
Average[h]	2948 a	2856 a	2849 a	2614 b	2923 a	2513 b	
Average SIWUE (kg m^{-3})	0.736	0.536	0.796	0.371	0.123		

[a] Tillage treatment means followed by a common letter range are not different ($p<0.05$; LSD = ns).
[b] Irrigation initiation treatment means followed by a common letter range are not different ($p<0.05$; LSD = 0.77 Mg ha^{-1}).
[c] Tillage treatment kernel ear^{-1} means followed by a common letter range are not different ($p<0.05$; LSD = 67 kernels. ear^{-1}: ns).
[d] Irrigation initiation treatment kernel ear^{-1} means followed by a common letter range are not different ($p<0.05$; LSD = 116 kernels ear^{-1}; ns).
[e] Tillage treatment kernel weight means followed by a common letter range are not different ($p<0.05$; LSD = 0.82 g 100^{-1}: ns).
[f] Irrigation initiation treatment kernel weight means followed by a common letter range are not different ($p<0.05$; LSD = 1.4 g 100^{-1}).
[g] Tillage treatment means followed by a common letter range are not different ($p<0.05$; LSD = $124 ha^{-1}).
[h] Irrigation initiation treatment means followed by a common letter range are not different ($p<0.05$; LSD = $213 ha^{-1}).

The 4 June date (63 DAP) could be considered the actual date of initiation for the 20 June (79 DAP) initiation treatment in 2012 due to rainfall occurring on 4 June. The yield and economic results then show irrigations should be initiated at or before -100, -62, -46, and -80 kPa trigger values in 2009-2012, respectively (fig. 3). Initiating irrigations 1 June (70 DAP) at the greater value of -46 kPa in 2011 likely abated the negative effects of an extended heat stress (maximum air temperature greater than or equal to 35°C) occurring 1 June to 16 June during tasseling and pollination (table 1). Likewise, initiating irrigations 19 June (81 DAP) at the lower value of -100 kPa in 2009 likely abated the negative effects of an extended heat stress occurring 20 June to 30 June (fig. 2a). Prior research has shown that corn growth and photosynthesis processes stop at 35°C (Singh et al., 1976), which supports the greater yield reductions observed among irrigation initiations in 2009 and 2011 when experiencing extended heat periods during tasseling and pollination. Smaller yield reductions were observed among irrigation initiations in 2010 and 2012 when initiating irrigations at the wetter values of -62 and -80 kPa when there was no obvious extended heat period occurring at tasseling (table 1). These values are all wetter than the -159 kPa calculated from the soil water retention curve for this soil texture at SWC of 50%.

This year-to-year variation of trigger values is a concern when trying to recommend a single value for timing of irrigation initiation that will maximize yield and minimize irrigation water applied every year. Granular matrix sensors are reported to have a slow response to rapid drying of the soil or partial rewetting of the soil (McCann et al., 1992), and need to be adjusted due to soil temperature (Shock et al., 1998). Both of these issues and hysteresis could cause variations in the readings, but variations could also be attributed to yearly differences in stored water or effective rooting zone in these low infiltration rate soils. Not having direct measurements of available water in the soil for each year, rainfall was totaled for November to May in each year since it would be related to the amount of water infiltrating the soil for each growing season ahead of initiating irrigations. A linear relationship exists between the SWP readings on the drier side of the WOP in which irrigations should be started at or before to maximize yield and the sum of November to May rainfall (fig. 4). The lower the total rainfall during this November to May period, suggesting less stored water in the profile, the wetter the SWP reading at which irrigations should be initiated. This relationship indicates that there may be yearly differences in water stored in this soil and/or differences in the effective rooting zone for this soil. Further research will be necessary to examine this relationship.

Variation in average SWP readings among sites and years highlights the difficulty in recommending a single trigger value for timing of irrigation initiation that will maximize yield and minimize irrigation water applied every year. If using SWP alone, scheduling irrigations initiations at the greater SWP value of -50 kPa that should ensure maximum yield but at the expense of applying excess irrigation in some years. Scheduling irrigation initiations at the lower -100 kPa would minimize irrigation water applied but risks reducing

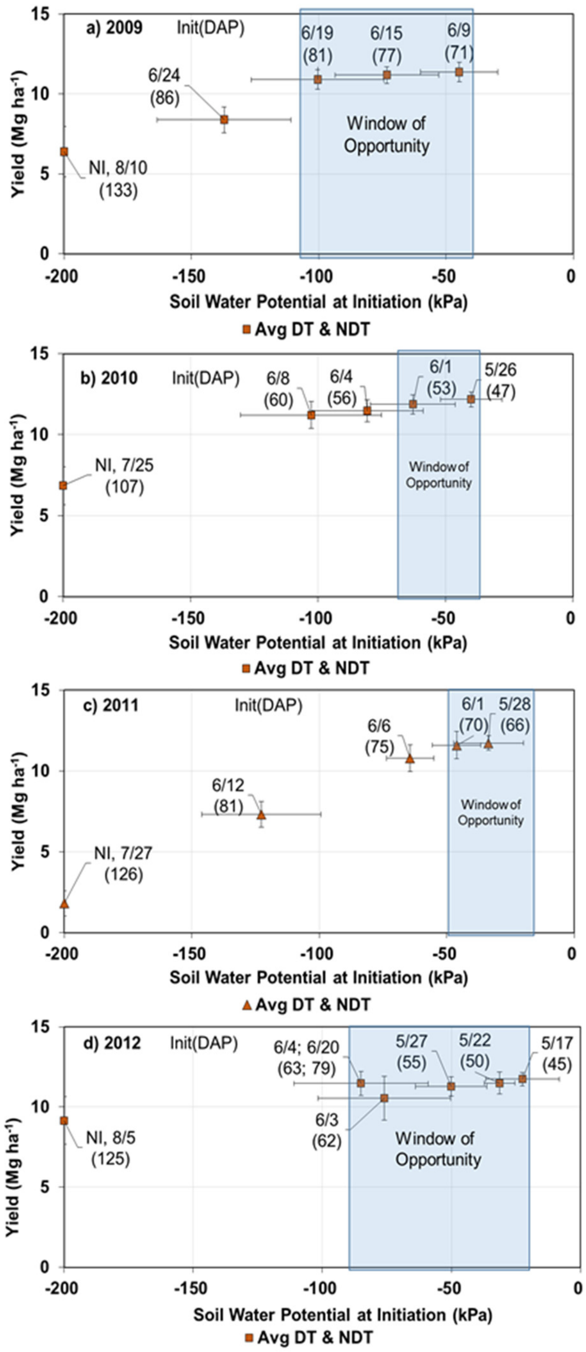

Figure 3. Average corn yield and soil water potential at irrigation initiation (average of sensor readings from 23, 46, and 69 cm depths) for an irrigation initiation study, furrow irrigated, Pioneer 31P42, Dundee/Forestdale SiCL, Tribbett, Mississippi, 2009-2012 averaged over deep till (DT) and non-subsoil (NDT) conditions. Window of opportunity indicates times of initiation where no significant differences among yield and economic net returns were observed.

yield in some years. The difference of -50 to -100 kPa would equate to nine to ten days difference in triggering initiation under dry conditions when using a range of average SWP rates of 5 to 6 kPa d^{-1} occurring in this study.

Soil Water Deficit

The SWD estimates at time of initiation from the FAO-56 weather-based water-balance (Allen et al., 1998) were the same for all treatments whether DT or NDT. These estimates

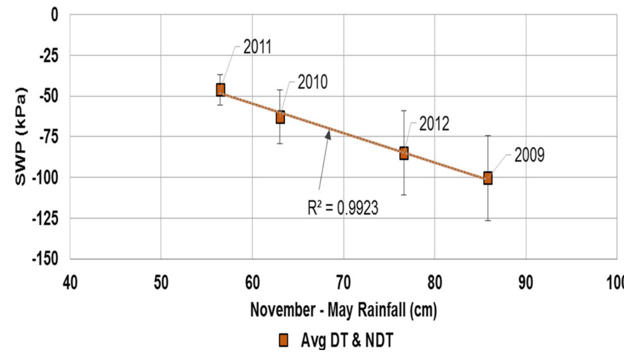

Figure 4. The relationship of Watermark soil water potential (SWP) readings (average of sensor measurements 23, 46, and 69 cm depths) on the drier side of the window of opportunity for each year in which irrigations should be started at or before to maximize yield compared to the sum of November-May rainfall. An irrigation initiation study, furrow irrigated, Pioneer 31P42, Dundee/Forestdale SiCL, Tribbett, Mississippi, 2009-2012 averaged over deep till (DT) and non-subsoil (NDT) conditions.

are plotted for each year in figure 5. Again, the 4 June date (63 DAP) was used as the actual date of initiation for the 20 June (71 DAP) initiation treatment in 2012. Results indicate that irrigations should have been initiated at or before a 140, 104, 158, and 147 mm SWD trigger value is reached in 2009, 2010, 2011, and 2012, respectively. These values are considerably lower than the 61 mm estimated from the soil-water retention curve, equal to 50% of the available water for a 76.2 cm depth. Since the water-balance model relies on estimates of all of its components, errors in the estimates would lead to errors in the final SWD values. Over-estimating ET_c, due to high values of ET_o or K_c, as well as lengths of the maximum water use period and/or magnitude, and over-estimating ET_c when the soil was not well-watered, could lead to overly large estimates of SWD. Under-estimating I_e and P_e would also result in larger SWD values.

SWD trigger values can be different for each method of calculation for $ET_{c,}$ (ET_o and its associated K_c values), and effective runoff and rainfall, and values need to be determined for each. For the method of calculating SWD described in this text, the trigger values varied from 104 to 158 mm, a difference in the maximum allowable SWD of 53 mm. This difference of 53 mm would equate to eight to ten days difference in triggering initiation when using an average ET_c of 6.1 and 7.6 mm d^{-1}, respectively, during this time period. This is a wide range to select a single trigger value.

Growth Stage

Results indicate that irrigations should be initiated at or before the V16 (81 DAP), V15 (53 DAP), V16 (70 DAP), and V15 (63 DAP) growth stage, which represent trigger values of five, five, three, and five days before reaching VT in 2009, 2010, 2011, and 2012, respectively (tables 4-7). Relative yields (treatment yield divided by the maximum yielding treatment for a given year in percent) for each initiation treatment for each year, and highlighting those treatments that maximized yield but were not statistically different each year, are shown in figure 6. The chart shows that the drier side of each WOP for each year is similar at V15 to V16

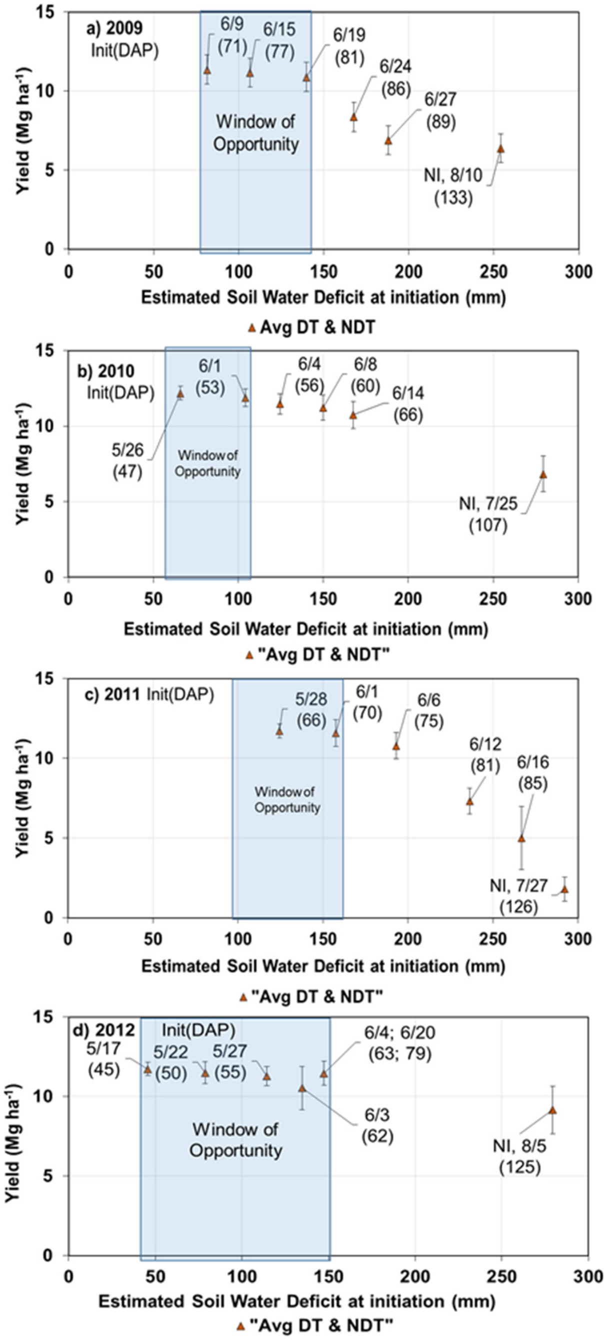

Figure 5. Average deep till (DT) and non-subsoil (NDT) corn yields and estimated soil water deficit at time of irrigation initiation (Init) for 2009-2012. Window of opportunity indicates times of initiation during which no significant differences found among yield and/or economic net returns were observed.

which was 3 to 5 days before VT. These results reinforce the sensitivity of corn to drought stress during the tasseling and pollination period and the need to ensure that water is not limiting as the corn enters into this critical time period (Hiler and Howell, 1983; Stegman 1983; Rhoads and Bennett, 1990; Heatherly and Ray, 2007).

Using growth stage (initiate at V15-V16, 3-5 d before VT) alone to schedule initiation of irrigations is a better option rather than using SWP or SWD alone, but could be improved by adding SWP or SWD minimums and forecasted

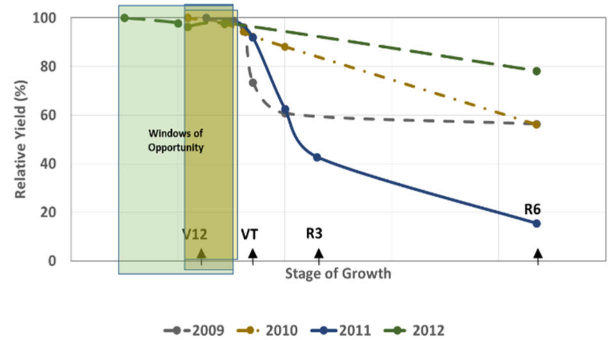

Figure 6. Relative corn yield and stage of growth at irrigation initiation averaged over deep tilled (DT) and non-subsoiled (NDT) conditions. Window of opportunity indicates the times of initiation at which no significant differences among yield and economic net returns were observed. An irrigation initiation study, furrow irrigated, Pioneer 31P42, Dundee/Forestdale SiCL, Tribbett, Mississippi, 2009-2012.

rainfall, resulting in a recommendation based on more complete information. Such a recommendation would be to initiate irrigations in corn on this soil at the V15-V16 growth stage (3-5 d before VT) or later, when SWP readings are -50 kPa or drier or when SWD estimates are 100 mm or higher and rainfall is not imminent. This would be a better recommendation since capturing and utilizing more rainfall during the growing season is key to minimizing irrigation water applied, but we have also seen that rainfall following an initial irrigation can reduce yield [the 3 June (62 DAP) initiation in 2012]. This recommendation may not be as robust on shallower soils, or in a year with very low winter rainfall coupled with lower than normal rainfall in April and May, or in a year with an extended heat period occurring during vegetative growth. This recommendation using growth stage and SWP or SWD is a starting point if irrigating just one field or set but is an ending point if irrigating multiple fields or sets with the same well. Producers will need to furrow irrigate all their corn fields irrigated by the same well before the last field or set to be irrigated reaches this recommendation or ending point. The initiation of the first field or set to be irrigated would then have to be initiated earlier, depending on how long it takes to irrigate all fields in question and taking into consideration soil differences.

Conclusions

Deep tillage increased irrigated corn yields in this corn/cotton rotation by disrupting naturally forming hard pans and/or tillage pans in three of the four years when winter rainfall (November-March) and/or June-July rainfall were below normal or when excessive rainfall occurred ahead of V6. Irrigation increased corn yields all four years of the study. We describe a window of opportunity for each year where initiating irrigations will produce maximum yields and net returns that are similar and the drier side of these window of opportunities consistently occurs at the V15-V16 growth stage (3-5 d before VT). Yield reductions were greater when irrigation initiations were delayed during extended periods of high heat (average maximum air temperatures ≥ 35°C) during tasseling and pollination. Irrigation that provided adequate moisture from tasseling to physiological maturity maximized yields and net returns all four years of the study. For the initiation protocol used in this study, there was no interaction between the main effects of tillage and irrigation initiation, so there was no justification for different irrigation scheduling recommendations with (DT) or without deep tillage (NDT). Using growth stage alone is a better option than using soil water potential or soil water deficit alone in scheduling irrigation initiation, but in combination results in a recommendation with more complete information. Thus, furrow irrigations in corn on this deep silty clay loam soil in the Mississippi Delta should be initiated at the V15-V16 growth stage (3-5 d before VT) or later, when SWP readings are -50 kPa or drier or when SWD estimates are 100 mm or higher and rainfall is not imminent.

Irrigation initiations may have to be started earlier than the above recommendation when taking into account multiple fields irrigated by the same well and the time it takes to irrigate all fields or sets, and taking into consideration soil differences within these fields and sets. Further irrigation initiation research needs to be conducted with different varieties on multiple soil types to further refine these recommendations.

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