INTRODUCTION

Subsurface drip irrigation has been used extensively for cotton production in arid and semi-arid areas, e.g., Arizona and western Texas (Tollefson, 1985a,b; Henngeler, 1995). Because of longer system life and wider lateral spacings, these systems may be profitable for cotton and other agronomic crops in humid areas if good marginal return with irrigation is obtained. Interest in subsurface drip irrigation for humid areas such as the southeastern USA has increased during the last 5-10 years, especially for cotton on the coarse-textured, low-water-holding-capacity soils of the southeastern Coastal Plain. Irrigation can substantially increase cotton yields some years, depending primarily upon seasonal rainfall amount and distribution.

Subsurface drip irrigation offers several advantages, including water applications more closely matched to crop use, frequent fertilization via injection into the irrigation system, potential for less leaching of nutrients and less ground water contamination, installation below the tillage zone, and longer system life and amortization of system cost over 10-15 years. The use of wider lateral spacing (2 m) without yield reduction (Camp et al. 1993, 1997, 1999) significantly reduces system cost and makes the technology more affordable.

Conservation tillage has been used extensively for soybean in the region, but its use for cotton has been limited. Conservation tillage could complement subsurface drip irrigation because deep tillage is restricted when laterals are installed at depths of 0.30 m or less. However, subsurface drip irrigation did not increase cotton lint yield in a strict no-tillage system during a two-year experiment (Camp et al., 1999). In that study, shallow (< 15 cm) compacted layers restricted rooting and reduced the effectiveness of drip irrigation, which was 30 cm deep. Consequently, research was initiated in 1998 with the objective of evaluating three conservation tillage methods and subsurface drip irrigation for a two-year cotton-soybean rotation. Only the results for cotton will be reported in this paper.

MATERIALS AND METHODS

The study was conducted on a 1.2-ha site of Eunola loamy sand (Aquic Hapludults) near Florence, S.C. Cotton and soybean were grown in a two-year rotation. There were three conservation tillage methods and three irrigation regimes. Tillage methods included a stubble mulch plow (Roll-A-Cone Mfg. Co., Tulia, Texas*), a Beasley in-row chisel (Naderman, 1993), and no tillage. Irrigation regimes included drip irrigation laterals spaced either 1 m or 2 m apart, and rainfed. Treatments included all combinations of the two lateral spacings and the three

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* Mention of a trade name, proprietary produce, or specific equipment does not constitute a guarantee or warranty by the USDA and does not imply approval of a product to the exclusion of others that may be suitable.

tillage variables, plus rainfall only (rainfed), both with and without subsoiling in each row, which provided at total of eight treatments.

The stubble mulch plow consisted of five overlapping sweeps each 1.1 m wide, that disturbed the soil across the entire plot area to a depth of 15 cm but the residue remained on the surface. In the Beasley in-row chisel, a shank operating to a 20-cm depth disturbed a narrow soil band directly under the row and immediately ahead of the planter. The soil surface was firmed behind the shanks by pneumatic wheels. In one of the rainfed treatments, the row area was subsoiled to a 30-cm depth immediately prior to planting.

The subsurface drip irrigation system had been used for seven years when this study was initiated. Drip irrigation laterals had been installed 0.30 m below the soil surface at spacings of either 1 m or 2 m, which placed them either directly under each cotton row (1 m) or under alternate furrows (midpoint between rows) (2 m). Each plot was 15 m long (irrigation lateral length) and 8 m wide, which provided eight cotton rows spaced 1 m apart. The experimental design was a randomized complete block with four replications.

The irrigation system included individual polyvinyl chloride (PVC) pipe manifolds (supply and discharge) for each subplot. Each discharge manifold had removable end caps for flushing. Irrigation laterals (GEOFLOW ROOTGUARD®) had in-line, labyrinth emitters spaced 0.6 m apart, each delivering 1.9 L/h at 140 kPa pressure. Pressure was regulated at about 140 kPa using in-line pressure regulators in the supply manifold for individual plots. Water was supplied from a well and filtered via a 100-mesh cartridge filter; see Camp et al. (1997) for additional details regarding the irrigation system.

The site had been subsoiled in two directions prior to installation of irrigation laterals in 1991 and was disked annually to a depth of about 0.20 m until 1995 to prepare the seed bed. No surface tillage was performed during the period 1996-1997. In both years of this experiment, P, K, lime, sulphur, boron and Mn were applied in granular form prior to planting based on soil test results. Each year 112 kg/ha N fertilizer (UAN 30) was applied in four increments via injection into the irrigation system. The same amount of N fertilizer was applied to the rainfed treatments as ammonium nitrate. Weeds were controlled with a combination of herbicides and hand weeding. An in-furrow insecticide was applied at planting, and foliar insecticides were applied throughout the season as warranted. Cotton was planted on 13 May 1998 (Delta Pine and Land Acala 90) and on 10 May 1999 (Delta Pine and Land NuCotn 33B) to achieve a final plant density of 6 plants/m. Cotton yield was determined by harvesting the four center rows of each plot with a spindle picker on 29 September 1998 and 22 October 1999. Sub-samples of seed cotton were collected from each plot at harvest, and cotton lint yield was calculated from lint percentages determined after ginning the samples on a laboratory saw gin.

Soil water potential (SWP) measurements were made using gauge-type tensiometers installed in the row area in two replicates of all treatments at depths of 20 cm and 60 cm. Tensiometers were serviced as required and measurements were recorded three times each week. Meteorological parameters were measured at a weather station located adjacent to the experimental area. Seasonal rainfall for each crop was computed for the period between planting and two weeks prior to first harvest.

Irrigation was initiated when SWP values at the 0.2-m depth in any two plots reached -30 kPa. The irrigation application depths ranged from 9 mm to 18 mm during the season depending upon plant requirements. Equal irrigation depths were applied to the two lateral spacings (1 m and 2 m) at each application; consequently, the 2-m system was operated twice as long as the 1-m system. Root growth in all tillage treatments was observed in 1998 by excavating soil pits adjacent to the row and carefully extracting tap roots. Soil strength measurements in all tillage treatments were made using a cone penetrometer (data not reported).

Data were analyzed using analysis of variance (ANOVA). Treatment sums of squares were partitioned with single degree of freedom contrasts (SAS, 1990). With these contrasts, we compared (1) 1-m and 2-m lateral spacings, averaged over tillage method; (2) rainfed (RAIN) and irrigated, averaged over lateral spacing and tillage method; (3) 1-m lateral spacing and rainfed, both averaged over tillage method; (4) 2-m lateral spacing and rainfed, both averaged over tillage method; (5) all possible pairs of tillage method for irrigated treatments, averaged over lateral spacing; and (6) subsoiled and no tillage for rainfed treatment.

RESULTS AND DISCUSSION

Seasonal irrigation depths were similar for the two years (248 mm in 1998 and 237 mm in 1999) although seasonal rainfall was greater in 1999 (399 mm vs. 306 mm). During the previous six years in two experiments at this site, seasonal rainfall ranged from 331 mm to 684 mm and irrigation ranged from 24 mm to 136 mm. For this eight-year period, the two years of this experiment rank among the driest and required the greatest amount of irrigation.

Within the 1998 growing season, little rainfall occurred for an extended period between about day of the year (DOY) 160 and DOY206 (Fig. 1). Consequently, most irrigation was applied during this period. Most rainfall occurred in five events, ranging from 25 mm to 64 mm each. Soil matric potential (SMP) values at the 22-mm depth remained wetter than -40 kPa for the entire growing season. During the 1999 growing season, rainfall was better distributed throughout the growing season than in 1998 but irrigation was required earlier in the season (Fig. 2). Again, SWP values at the 22-cm depth remained wetter than -40 kPa until the end of the season. In both years, there were no differences in SWP among lateral spacings and tillage method. The similarity in SWP values among tillage treatments indicates that rooting patterns were similar for the three tillage treatments and that irrigation water was able to move through the compacted soil layer that separated the primary rooting depth (22 mm) and the drip irrigation lateral (30-cm depth).

With irrigation, cotton yields for the three tillage methods and the two lateral spacings were not different in either year (Table 1). In 1998, yields in the irrigated treatments were 40 percent greater than in the rainfed treatments. Lint yields in 1999 were less than expected for all treatments, but yields in irrigated treatments were 82% greater than in rainfed treatments. The lower lint yields in 1999 were probably caused by cool temperatures early in the growing season. Calculated accumulated heat units and number of days with the minimum temperature less than 16° C were similar to those for the year in a previous experiment when cool temperatures caused very low lint yields. Also, subsoiling did not increase lint yield in the rainfed treatments either year. Inadequate rainfall caused sufficient water deficits to limit cotton yield in the rainfed treatments, even with subsoiling.

Previously, on the same site under conventional tillage, cotton lint yields ranged from 1145 to 1815 kg/ha for three years and 535-770 kg/ha for the fourth year. In the fourth year, yields decreased primarily because of cool temperatures for 20-30 days following emergence (Camp et al., 1997). In a subsequent experiment after converting to a no-tillage system, there was no difference in lint yield between irrigated and rainfed treatments or among irrigation treatments in either of two years (1996-1997) (Camp et al., 1999). Based on observations of root growth and soil strength measurements, they concluded that shallow compacted soil zones (< 5 cm) restricted availability of irrigation water, which was provided at the 30-cm depth.

Observations during this experiment indicated that rooting depth was slightly greater with the Beasley in-row chisel and the stubble mulch plow than with the no-tillage system. However, soil strength measurements (data not reported) indicated that soil strength values at depths of 20-25 cm for these two tillage methods were great enough to limit crop rooting. Root-limiting soil strength values existed at the 15-cm depth or less in the no-tillage treatment. This soil compaction was probably caused by soil re-consolidation, the absence of deep tillage for nine years, conventional tillage (disking) for the first four years, and equipment traffic (combines, cotton pickers, etc.). Apparently, enough water moved from the drip lateral through the compacted zone into the active rooting zone to maintain the SWP values measured, even in the no-tillage treatment where the compacted zone was thicker.

The questions remaining are whether soil water in the root zone was adequate for optimum growth and lint yield and whether less irrigation volume would have been required if roots had been able to explore the zone wetted directly by drip irrigation. More irrigation was applied during these two years than for any of the previous six years in similar experiments with cotton. Observations suggest that the high soil strength, although less than in the previous experiment, probably prevented optimal benefit from the subsurface drip irrigation system. With annual disking, high soil strength near the soil surface normally does not occur. It appears that strategies to further reduce soil strength at relatively shallow soil depths are needed for conservation tillage culture in these soils if the full benefits of subsurface drip irrigation are to be realized.

SUMMARY AND CONCLUSIONS

Three conservation tillage methods were evaluated on a site with drip irrigation laterals spaced at either 1 m or 2 m and at a depth of 0.30 m. Both phases of a cotton-soybean rotation were grown in each of two years. The site had not been deep tilled since 1991 when the irrigation system was installed. There were no differences in cotton yield for two irrigation lateral spacings (1 m and 2 m) or for the three conservation tillage methods. Lint yield was greater for irrigated treatments than for the rainfed treatment in both years. Without irrigation, subsoiling did not increase lint yield either year. Observations indicate that two of the conservation tillage methods increased rooting depth, but compacted soil zones still limited root growth and reduced the effect of irrigation on these crops. Based on these results, it appears that strategies to further reduce soil strength in the surface 30 cm of these soils are required for conservation tillage systems to realize the benefits of subsurface drip irrigation.

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Table 1. Cotton lint yields for two subsurface drip irrigation lateral spacings, rainfall only, and four conservation tillage methods in a cotton-soybean rotation experiment on a southeastern Coastal Plain soil during 1998-1999.

Year	Tillage	Irrigated		Rainfed
		ER*	AF	
		---------------------kg/ha---------------------		
1998	No tillage	1170 a**	1210 a	880 b
	Beasley in-row chisel	1295 a	1285 a	---
	Stubble mulch plow	1220 a	1115 a	---
	Subsoiled	---	---	830 b
1999	No tillage	800 a	670 a	375 b
	Beasley in-row chisel	635 a	700 a	---
	Stubble mulch plow	640 a	760 a	---
	Subsoiled	---	---	395 b

* ER = under every row (1-m spacing) and AF = under alternate furrow (mid-row area) (2-m spacing).

** Means within a year followed by the same letter are not significantly different at $P \leq 0.05$.

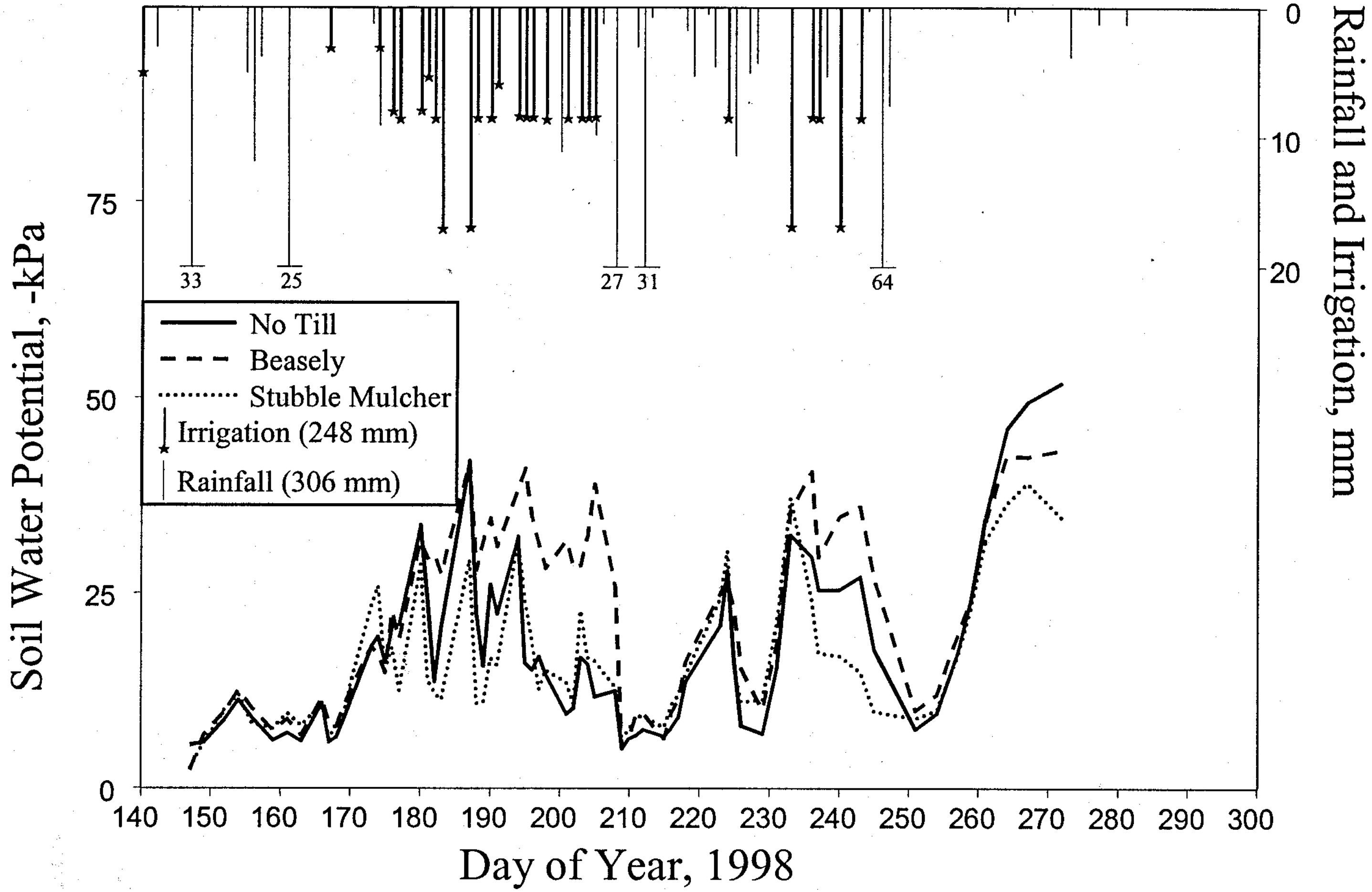

Figure 1. Daily rainfall and irrigation depths, and soil water potential (SWP) values at 22-cm depth in three conservation tillage treatments under subsurface drip irrigation at Florence, SC, during 1998. Each SWP value is mean of two drip lateral spacings (1 m and 2 m) and two replications. Annotated numerals indicate off-scale values.

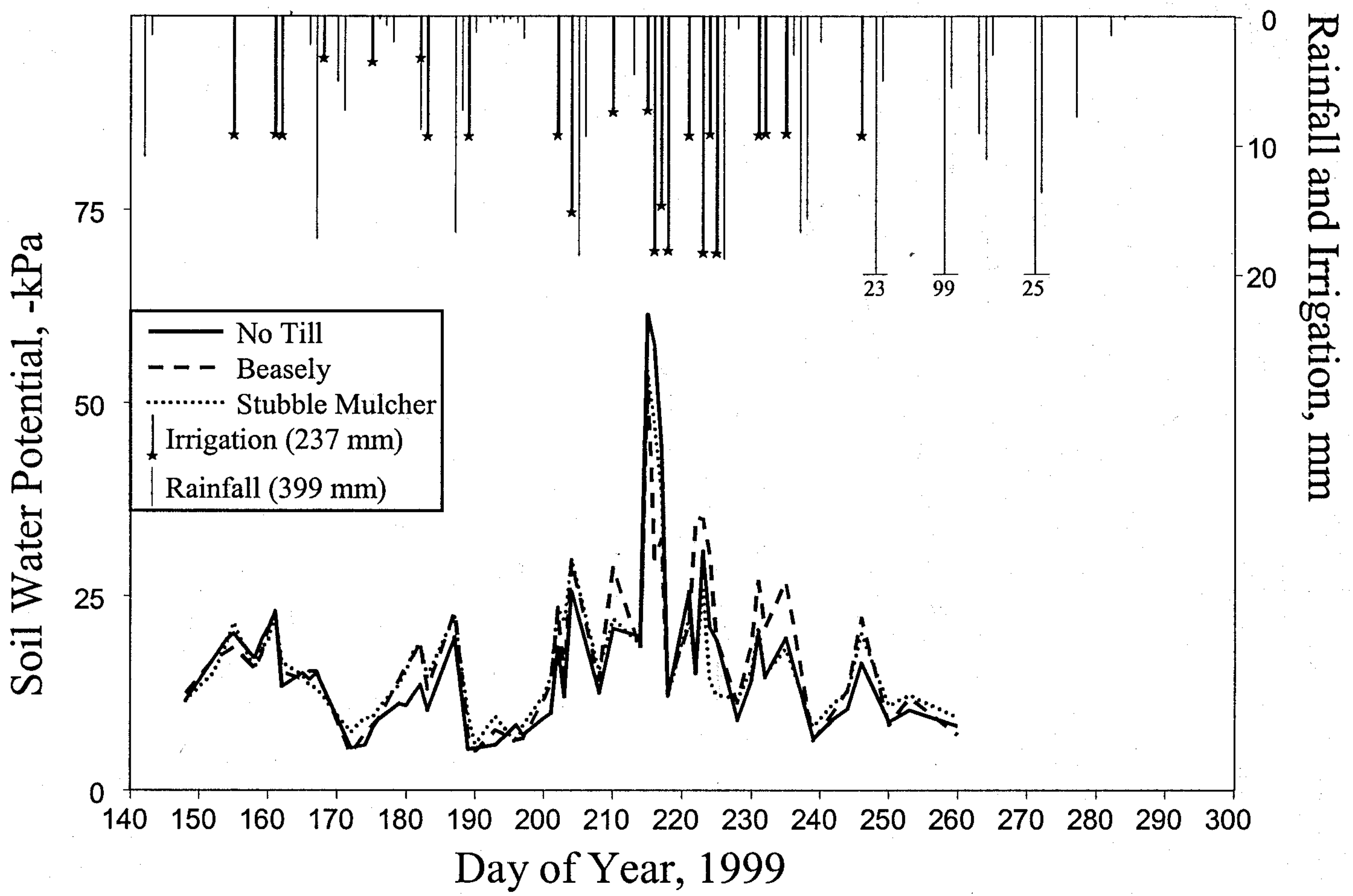

Figure 2. Daily rainfall and irrigation depths, and soil water potential (SWP) values at 22-cm depth in three conservation tillage treatments under subsurface drip irrigation at Florence, SC, during 1999. Each SWP value is mean of two drip lateral spacings (1 m and 2 m) and two replications. Annotated numerals indicate off-scale values.