## Subsurface Drip Irrigation for Cotton in the Southeast

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### Abstract

Drip irrigation offers several advantages over sprinkler irrigation in humid areas, including ease of system start-up each season, ease of automation, lower water pressure, lower water flow rate, and improved management of water and nutrients. Subsurface drip irrigation (SDI) cost can be reduced and made more profitable for cotton through the use of wider lateral spacing and placement of laterals below the tillage zone, which allows multiple-year use. Results from three experiments (eight site-years) that evaluated SDI for cotton show no lint yield difference between the 1-m and 2-m spacing. Although shallow soil compaction occurred after changing from a traditional disking to a no-tillage culture (after fourth year), moderately deep conservation tillage intended to remove the compaction during the last two years did not improve cotton lint yields. Consequently, it appears that subsurface drip irrigation systems can largely overcome the adverse effects of shallow compaction for cotton in the southeastern Coastal Plain. However, reduction of compaction and soil strength may reduce the amount of irrigation required.

### Introduction

Cotton production area has increased dramatically in the southeastern U. S. during the past decade. Several years with below-normal rainfall during the growing season have caused increased interest in irrigation of cotton. While most irrigation systems use sprinklers, drip irrigation offers several advantages, including low water supply pressure, relatively low application rates, ease of automation, and flexible system size and shape. Flexibility in system layout is especially important in the southeastern Coastal Plain, where fields are relatively small in size and have irregularly shaped boundaries. Subsurface drip irrigation (SDI) offers the additional advantage of multiple-year life, which reduces annual cost. SDI has been used extensively for cotton production in arid and semi-arid areas (Tollefson, 1985a,b; Henggeler, 1995) and has been demonstrated as a possible alternative to sprinkler irrigation for cotton in the southeastern U. S. (Camp et al., 1997, 1999).

The major disadvantage of SDI is high system cost, especially if most components are replaced each year. Profitability with lower-valued agronomic crops, such as cotton, requires that system cost be reduced. Reducing the amount of drip tubing (wider spacing) and using drip lines for multiple years (installed below tillage depth) decrease system cost. On a coarse textured soil in Arizona, cotton yields were similar for laterals placed every row (1 m) and every other row (2 m) but were much lower for laterals placed every third row (3 m) (French et al., 1985). Camp et al. (1998) reported only 10-20% yield reduction during extreme drought in some years for corn, cotton, and soybean (13 site-years) with

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[1] Contribution of the U. S. Department of Agriculture, Agricultural Research Service, Coastal Plains Soil, Water, and Plant Research Center, Florence, SC, in cooperation with the South Carolina Agricultural Experiment Station, Clemson, SC. Mention of a trade name, proprietary product, 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

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wider lateral spacing (1.5-2 m). However, a question remains regarding the long-term efficacy of SDI in soils where periodic deep tillage is needed to disrupt compacted soil.

Soils of the southeastern Coastal Plain have a coarse-textured Ap horizon, and many have a compacted E horizon that restricts root growth and development to a shallow soil layer. Annual deep tillage is generally recommended for these soils to increase rooting depth, which also increases plant available water, especially when irrigation is not used. Conservation tillage has been used extensively for various agronomic crops for some time and for cotton more recently. This practice complements SDI because surface tillage that could damage SDI laterals, especially if installed at shallow depths, is not used. However, deep tillage, such as subsoiling, which is often used with conservation tillage, could also damage SDI laterals. Consequently, an ideal SDI system for these soils would not require deep tillage.

A potential irrigation system for cotton on the coarse-textured soils of the southeastern Coastal Plain is SDI with laterals spaced 2 m apart, installed about 0.30 m deep (top of E horizon), and operated for multiple (10-20) years. Because the greatest compaction and greatest strength often occurs in the E horizon, installing the lateral near this horizon might keep it wet enough to reduce the strength to a level that would allow root penetration. To investigate the feasibility of this potential irrigation system, results are reviewed from three SDI experiments, all with cotton in combination with other crops (peanut, wheat, soybean).

## Materials and Methods

During the period 1991–1999, three experiments were conducted to evaluate the SDI system. All three experiments included cotton in combination with other crops (only cotton results are reported here) and each had different surface tillage methods (Traditional, Conservation, and Deep Tillage). The studies were conducted on a 1.2-ha site of Eunola loamy sand near Florence, South Carolina, in the southeastern Coastal Plain. Prior to installation of the SDI system in 1991, the site was subsoiled in two directions, each diagonal to the row (and SDI lateral) direction. Irrigation laterals (GEOFLOW ROOTGUARD®) had in-line, labyrinth emitters spaced 0.6 m apart, each delivering 1.9 L/h at 140-kPa pressure. Laterals were installed at a depth of 0.30 m and at two spacings, under each row (1.0 m apart) or under alternate furrows (2.0 m apart). To achieve equal irrigation amounts (equivalent rainfall depth) on the two lateral-spacing treatments (1 m and 2 m), the 2-m system operated twice as long as the 1-m system. Water was supplied from a well and was filtered via a 100-mesh cartridge filter. Pressure was regulated at each plot manifold using pressure-regulating valves. Solenoid valves switched by a computer-based controller managed irrigation applications. The experimental design was a randomized complete block with four replications. The same SDI system was used for all three experiments; consequently, lateral spacing and depth remained the same for all years.

### Experiment 1: Traditional Tillage

During 1991-94, cotton was grown in an experiment that evaluated the two SDI lateral spacings and three sidedress-nitrogen (urea) treatments applied via the irrigation system. The N treatments were (1) a single N application of 112 kg/ha (STD), as recommended by the Clemson University Cooperative Extension Service, (2) 112 kg/ha applied in five equal weekly increments (INC), and (3) periodic applications (11-23 kg/ha N) based on a cotton growth model, GOSSYM/COMAX (GOS). A total of eight treatments included all combinations of the two lateral spacings and the three sidedress-N methods, plus rainfall only (rainfed) with the STD and GOS sidedress-N methods. Additionally, all treatments were included in the cotton phase of two crop rotations, continuous cotton and peanut-cotton rotation. In one half of the plots, peanut was grown in 1991 and 1993. The seedbed was prepared annually by disking to a depth of about 0.20 m. Irrigation applications were managed using both the GOSSYM/COMAX model and tensiometers. Irrigation was applied when both the GOSSYM/COMAX water-stress index indicated water stress and the soil water potential (SWP) was less than -35 kPa at the 0.30-m depth. Irrigation applications were normally 6 mm/d, but greater amounts were applied as needed based on observations and model simulation results. The GOSSYM/COMAX model was operated three times each week to determine the need for irrigation and nitrogen applications. Additional details regarding this experiment and the irrigation system were reported by Camp et al. (1997).

### Experiment 2. Conservation Tillage

During 1996-97, cotton was grown in an experiment that included all combinations of two lateral spacings, two crop rotation phases, and three irrigation amounts, plus rainfall only. This experiment was on the same site and used the same SDI system as the Traditional Experiment, but there was no tillage after 1994 (except for subsoiling in a rainfed treatment). The three irrigation amounts were 6, 9, and 12 mm/application. Both phases of a winter wheat-soybean-cotton rotation in a no-tillage culture were included in each of two years. Soybean followed winter wheat in one phase, and cotton followed winter fallow in the other phase. Irrigation applications were initiated when the SWP at the 0.30-m depth in the 6-mm treatment was -35 kPa. In the 6-mm treatment, each irrigation event was continuous. In the 9-mm and 12-mm treatments, each irrigation event was split into two equal applications, separated by an equal time without irrigation; e.g., 2 hr on, 2 hr off, 2 hr on. Additional details regarding this experiment were reported by Camp et al. (1999).

### Experiment 3. Deep Tillage

During 1998-99, 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 the two lateral spacings and rainfed. A total of eight treatments included all combinations of the two lateral spacings and the three tillage methods, plus rainfall only (rainfed), both with and without subsoiling in each row. 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. The Beasley in-row chisel had shanks operating to a 20-cm depth that 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. Irrigation was initiated when SWP values at the 0.2-m depth in any two plots reached -30 kPa. Irrigation amounts for a single irrigation event ranged from 9 mm to 18 mm during the season depending upon plant requirements. Equal irrigation amounts were applied to the two lateral spacings (1 m and 2 m) at each application. Root growth in all tillage treatments was observed in 1998 by excavating soil pits adjacent to the row and carefully extracting taproots. Soil strength measurements in all tillage treatments were made using a cone penetrometer (data not reported). Additional details regarding this experiment were reported by Camp et al. (2000).

## Results and Discussion

### Experiment 1. Traditional Tillage

Seasonal rainfall was greater in 1992 and 1994 than in 1991 and 1993 (Table 1). Seasonal rainfall distribution was more uniform in 1991 and 1994 than the other years. Consequently, irrigation volumes were lowest in these years, 24 mm in 1994 and 57 mm in 1991 (Table 1). Much of the rainfall in 1992 occurred late in the growing season after irrigation had been applied; hence irrigation volume was somewhat high relative to seasonal rainfall. Irrigation volume was greatest in 1993 when seasonal rainfall was least, but much of this rainfall occurred late in the growing season. Rainfall was so great during the last half of the growing season in 1992 and 1994 that soils were near saturation at times.

Mean lint yields for the three sidedress-N methods are reported in Table 1 because they were not different for any of the four years. Cotton lint yields were not different for the two lateral spacings in any of the four years. Irrigation increased yield by 16% in 1992 and 65% in 1993 but had no effect in the other two years. In each of the four years, the GOS N-fertilizer treatment received 45 kg/ha less fertilizer N than the two treatments that followed state recommendations, but lint yields were not different. Overall, lint yields were greatest in 1991, lowest in 1992, and about double the 1992 yields in other years. Low yields in 1992 appear to have been caused by unseasonably low spring temperatures. Regression analysis indicated that lint yield was reduced by 80 kg/ha for each day during the first 20 days after planting on which the minimum daily temperature was less than 15.6°C. In 1992, 18 of the first 20 days after planting met this criterion

### Experiment 2. Conservation Tillage

Seasonal rainfall was slightly greater in 1996 (542 mm) than in 1997 (470 mm) and was more uniformly distributed throughout the growing season. Although seasonal rainfall was about 87% of that in 1996, the seasonal irrigation requirement was 266% of 1996 requirement, reflecting little relationship between seasonal rainfall and irrigation (Table 1).

Cotton lint yields were not different for the three irrigation amounts (6, 9, and 12 mm) in either year, so only mean cotton lint yields are reported in Table 1. Also, cotton lint yields for the two lateral spacings were not different either year nor for the irrigated and rainfed treatments either year. All yields were lower in 1997 than in 1996, possibly because of cool temperatures during the early spring of 1997, as in 1992. Observations during both years indicated limited rooting depth. Very different cotton root growth occurred between the irrigated and rainfed treatments. In the irrigated treatment, taproots were only about 10 cm long and had limited horizontal root development. In the rainfed treatment, which had been subsoiled annually, taproots were at least 20 cm long with extensive horizontal development. In both years, soil strength measurements, as reflected by penetrometer cone index values, indicated that the root-limiting value of 2 MPa was located 3 to 5 cm from the soil surface in the irrigated treatments and at least 20 cm deep in the rainfed treatment that had been subsoiled annually (Camp et al., 1999). These measurements and the limited root growth suggest that high soil strength prevented optimal benefit from the SDI system. Soil compaction at this shallow soil depth was probably caused by equipment traffic (combine, cotton picker, etc.).

**Experiment 3. Deep Tillage**

Seasonal irrigation amounts 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). For the eight-year period of the three experiments, these two years were among the driest and required the greatest amount of irrigation (Table 1). During 1998, little rainfall occurred for an extended period between day of the year (DOY) 160 and DOY 206. Consequently, most irrigation was applied during this period. Most rainfall occurred in five events, ranging from 25 mm to 64 mm each. During 1999, rainfall was better distributed throughout the growing season than in 1998, but irrigation was required earlier in the season.

In both years, there were no differences in SWP among lateral spacing and tillage method. Data indicated that rooting patterns were similar for the three tillage treatments and that irrigation water was able to move through a compacted soil layer that separated the primary rooting depth (22 mm) and the drip irrigation lateral (30-cm depth). With irrigation, cotton lint 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% greater than in the rainfed treatments. In 1999, lint yields in irrigated treatments were 82% greater than those in rainfed treatments, but all yields were lower than expected. Cool temperatures early in the growing season probably caused the lower lint yields in 1999, as occurred in 1992 and 1997. Cotton lint yields, calculated accumulated heat units, and the total days with the minimum temperature less than 16°C were all similar to those in 1992. 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.

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, penetrometer cone index measurements in these two tillage methods (data not reported) indicated that soil strength values at depths of 20-25 cm 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 seven years, conventional tillage (disking) for the first four years, and equipment traffic (combine, cotton picker, etc.). Apparently, enough water moved from the drip lateral through the compacted zone into the active rooting zone to maintain adequate SWP values, even in the no-tillage treatment where the compacted zone was thicker. In these two driest years of this eight-year period, it appears that the SDI system provided sufficient soil water to overcome soil compaction effects in this no-tillage system.

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. Results indicate that the effect of high soil strength, although less than in the previous experiment, was largely overcome by SDI. However, observations indicate that compaction probably reduced the efficiency of the SDI system. Consequently, it appears that strategies to further reduce soil strength at relatively shallow soil depths for conservation tillage culture in these soils might improve the water use efficiency of SDI.

## Summary and Conclusions

An ideal irrigation system for the humid Southeast would require minimal labor (preferably automatic control), start easily each year, and have the capacity to sustain crops during extended periods without rainfall. Subsurface drip irrigation (SDI) systems with a multiple year life (>10 year) and a wider lateral spacing (2 m) provide a lower cost (annual basis) drip irrigation system that could make this technology profitable for cotton in this region. Eight site-years of data from three experiments on a single SDI system indicate that this technology is feasible. These data show no additional cotton lint yield for a narrower lateral spacing (1 m), although previous results with other crops indicate a potential yield reduction of about 10% during extreme drought. Soil compaction occurred at shallow soil depths (3 to 5 cm) after changing from traditional tillage (annual disking) to no tillage. However, in a later experiment, cotton lint yields for two shallow (15-20 cm) conservation tillage methods were no different than the no-tillage treatment when subsurface drip irrigation was used. From these data, it appears that SDI can overcome most adverse effects of soil compaction with no-tillage culture. However, water use efficiency may be improved by reducing compaction and soil strength, especially at shallow soil depths.

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Table 1. Cotton lint yields with subsurface drip irrigation for three experiments conducted during the period 1991-1999 on a southeastern Coastal Plain soil near Florence, SC.

| Experiment | Year | Tillage Treatment* | Rainfall | Irrigation | Cotton Lint Yield # Irrigated 1-m spacing | Cotton Lint Yield # Irrigated 2-m spacing | Cotton Lint Yield # Rainfed |
|---|---|---|---|---|---|---|---|
| | | | ---------- mm ---------- | | ---------- kg/ha ---------- | | |
| 1 | 1991 | CONV | 418 | 57 | 1740 a + | 1690 a | 1740 a |
| 1 | 1992 | CONV | 589 | 90 | 690 a | 650 a | 590 b |
| 1 | 1993 | CONV | 331 | 133 | 1220 a | 1200 a | 750 b |
| 1 | 1994 | CONV | 684 | 24 | 1480 a | 1460 a | 1440 a |
| 2 | 1996 | None | 542 | 42 | 1255 a | 1385 a | 1345 a |
| 2 | 1997 | None | 470 | 112 | 1120 a | 1140 a | 1110 a |
| 3 | 1998 | None | 306 | 248 | 1170 a | 1210 a | 880 b |
| 3 | 1998 | SSS | 306 | 248 | 1295 a | 1285 a | -- |
| 3 | 1998 | SM | 306 | 248 | 1220 a | 1115 a | -- |
| 3 | 1998 | DSS | 306 | -- | -- | -- | 830 b |
| 3 | 1999 | None | 399 | 237 | 670 a | 800 a | 375 b |
| 3 | 1999 | SSS | 399 | 237 | 635 a | 700 a | -- |
| 3 | 1999 | SM | 399 | 237 | 640 a | 760 a | -- |
| 3 | 1999 | DSS | 399 | -- | -- | -- | 395 b |

* Tillage treatment codes are defined as follows: CONV = conventional surface tillage each year (disked); None = no surface tillage; SSS = shallow (20 cm) in-row subsoiled; SM = stubble mulch plow (10-15 cm deep); and DSS = deep (35-40 cm) in-row subsoiled.

# Yield values are means of four replications for each experiment plus treatments that were not statistically different for that experiment in some years. Experiment 1 values include three N-sidedress methods and two crop rotations, and Experiment 2 values include three irrigation depths (6, 9, or 12 mm at each application).

+ Means followed by the same letter within the same year at not different at $P \leq 0.05$.