SURFACE AND SUBSURFACE TRICKLE IRRIGATION FOR CORN

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Seasonal rainfall amounts in the humid Southeastern Coastal Plain are often sufficient to satisfy evapotranspiration requirements, but the combination of short drought periods (5-10 days) and low water storage capacity of the coarse-texture soils result in periods of yield-reducing plant water stress most years. Shallow crop rooting in many soils, caused by compacted soil layers at depths of 20-40 cm, further aggravates the problem. Crop yields can be increased most years if irrigation is used to supplement rainfall. However, the higher cost of energy and equipment and lower farm commodity prices have greatly reduced the profitability of this option, when traditional irrigation methods are used. Trickle irrigation has been utilized effectively in the region to irrigate high-value vegetable crops and some tree crops, but the annual cost for replacement of field components of these systems has prevented use of this technology on agronomic crops.

In an effort to reduce the annual cost of trickle irrigation equipment and to make this technology profitable for use on agronomic crops, spacings of laterals have been increased to as high as 2m and commercial equipment has been developed to retrieve surface-installed trickle irrigation laterals. On a coarse-textured soil in Arizona, cotton yields were comparable for laterals placed every row (1-m spacing) and every other row (2-m spacing) but were drastically lower for laterals placed every third row (3-m spacing) (French et al., 1985). Phene and Beale (1979) used a single trickle irrigation lateral (5 cm deep) placed between twin rows that were spaced 35 cm apart on beds spaced 1.65-m apart to produce sweet corn in South Carolina on a coarse-textured soil. The system was operated in a high-frequency mode to provide water and nutrients on a daily basis.

Another approach to increased profitability for trickle irrigation of row crops is the installation of trickle irrigation tubing about 20-30 cm below the soil surface, a depth that will allow normal shallow tillage and cultivation operations and, hopefully, will allow continued use of the system for several years before replacement is necessary. This approach was considered in much of the early research in trickle irrigation in the U.S. and was aided by the development of inexpensive plastics (Davis, 1967). Goldberg et al. (1976) summarized the major problems with subsurface trickle irrigation as

(1) Difficulty in inspection of buried material and in assessing the condition of equipment,
(2) Clogging may cause system to malfunction and create havoc in cultivated fields, and
(3) Subsurface equipment is not easily repaired and maintained, and, consequently, farmers have avoided its use.

Recently, placement of trickle irrigation laterals at soil depths of 20-40 cm has become more popular. Bucks et al. (1981) successfully produced several multiple crops (fruit and vegetable) on a fine-textured soil in Arizona using a subsurface trickle irrigation system without experiencing deteriorated performance or emitter plugging.

Sammis (1980) found higher water-use efficiencies for potato with both surface and subsurface trickle irrigation than with sprinkler and furrow irrigation, concluding that subsurface trickle irrigation offered the best method for supplying uniform soil moisture in the root zone throughout the growing season. Subsurface trickle irrigation has also been successfully used with cotton (Plaut et al., 1985; Tollefson, 1985). Phene (1983) reported the successful application of subsurface trickle irrigation to processing tomato production and suggested management practices for improving irrigation system longevity.

Normal tillage practices for Coastal Plain soils in which compacted layers are present include in-row subsoiling during planting to disrupt the compacted layer and allow deeper root growth. If subsurface trickle irrigation were used, it would be difficult, if not impossible, to subsoil near the row. However, the resistance of these soil layers to penetration by roots is much lower, when the soil water content is high, between saturation and the upper limit of plant-available water (Campbell et al., 1974). If trickle irrigation laterals were buried very near or above the compacted layer and the irrigation system were operated in a high-frequency mode, the compacted soil layer should remain moist and offer low resistance to root penetration. This practice might preclude the need for subsoiling each year at planting.

An experiment was initiated in 1984 to evaluate various trickle irrigation systems and modes of operation for row crops in coarse-textured soils of the Coastal Plain. Objectives of the study were (1) to determine yield responses to various trickle irrigation lateral placement and modes of irrigation application, (2) to determine irrigation water requirements for the various placement-operational mode combinations, (3) to determine soil wetting and drying patterns for the various placement-operational mode combinations, and (4) to determine the effectiveness of high-frequency irrigation in promoting root growth through compacted soil layers.

MATERIALS AND METHODS

The experiment was conducted on a 0.20-ha site of ?name loamy sand in Florence, South Carolina, for a two-year period (1985-86). The E soil horizon was not clearly defined and appeared to be mixed with the Ap horizon to a depth of 30-cm, probably because of antecedent deep tillage. Each of the 24 experimental plots were 8 rows wide and 12 m long ($74m^2$). Six treatments were completely randomized in each of four blocks. Treatments consisted of all combinations of three trickle tubing locations and two irrigation application modes. Irrigation tubing locations were (1) buried directly under the twin-rows, (2) on the surface between the twin rows, and (3) on the surface in alternate row middles. Irrigation was applied through each system in both continuous and pulsed modes. In the continuous mode, irrigation was applied without interruption until the desired amount was applied, while in the pulsed mode, irrigation was applied in a series of pulses where the on and off times were equal and the duration of each varied from 20 to 40 minutes.

Subsurface trickle tubing was installed prior to planting and remained in the soil continuously, while the surface tubing was installed each season after a stand was established and removed prior to harvest. Subsurface trickle tubing was buried at a depth of 30 cm using a modified subsoil shank. At this depth, the trickle tubing was at the interface between the Ap and B horizons and below the frost line. Each irrigation lateral was equipped with a removable end cap at the soil surface that was utilized for line flushing. The trickle irrigation tubing (Lake Drip-In*) had in-line, labyrinth-type emitters which were spaced 61-cm apart and delivered 1.9 L/hr. Treatments in which laterals were placed on or under each twin-row required eight laterals per plot, while the alternate-middle treatment required four laterals. All laterals within a plot were connected to a single manifold where flow was controlled by a solenoid valve and pressure was regulated at approximately 100 kPa by individual pressure regulators for each manifold.

Prior to installation of the subsurface irrigation system, the site was subsoiled in two different directions (parallel and perpendicular to row direction) and was disked until the surface was smooth. After installation of the subsurface trickle tubing, the only tillage possible was disking and smoothing to remove weeds and to incorporate chemicals. Pesticides were applied in accordance with South Carolina Cooperative Extension Service recommendations. Preplant fertilizer and liquid herbicide were applied broadcast and incorporated. At planting, a granular insecticide was applied in the furrow with the seed. Total plant nutrients added as either preplant granular or sidedress N solution fertilizer included 99 kg/ha N, 24 kg/ha P, and 140 kg/ha K in 1985 and 112 kg/ha N, 24 kg/ha P, 47 kg/ha K, 6 kg/ha B, and 8 kg/ha S in 1986. Sidedress nitrogen was applied through the irrigation system using an injector pump. Nitrogen was applied three times after corn emergence using urea ammonium nitrate (UAN) (30% N solution) in 1985 and four times in 1986 using urea ammonium sulfate (UAS) (25% N solution). First N sidedress applications were made 4-6 weeks after planting with additional applications following at two-week intervals.

The chlorinated irrigation water supply was filtered using a 100-mesh? cartridge filter. At the beginning of each growing season and periodically during the season, all end caps were removed and the system was flushed to remove any sediment or residue that might cause emitter plugging. At the end of each growing season, a higher-concentration chlorine solution was injected into the system to reduce biological activity and to retard entry of roots into the emitters during the dormant season.

Corn (Zea mays L. cv. O's Gold 5509) was planted 27 March 1985 and 31 March 1986 in a twin-row configuration with the twin rows spaced 76 cm apart. The target plant population was 74,100 plants/ha each year, but plots were not hand-thinned in 1985 as they were in 1986. This resulted in mean plant populations at harvest of 87,500 and 76,100 plants/ha for 1985 and 1986, respectively.

Tensiometers were installed at depths of 30, 60, 90, and 120 cm, at two locations relative to the emitter (at the emitter and midway between emitters), and at three distances from the irrigation lateral (at the lateral, 19 cm away and 38 cm away). A tensiometer was installed at the 45-cm depth at one location only (at the emitter and lateral). This provided a total of twenty-five tensiometers in each of six plots, one plot for each treatment. Tensiometer readings were recorded three times each week, and tensiometers were serviced one or two times each week during the growing season. Rainfall was measured on site with a tipping-bucket rain gauge connected to an automated weather station. Tissue analyses for N, P, K, Ca, Mg, S, Zn, and Cu were determined from ear-leaf samples taken both years and whole plant samples taken in 1986.

Irrigation was applied daily at a rate of 6 mm to all treatments to replace the estimated losses by evapotranspiration (ET), but when soil water potential at the 30-cm depth reached -25 kPa in any tubing-location treatment (continuous or pulsed), an additional 6 mm of irrigation was applied to that treatment (continuous and pulsed). Irrigation application times for the alternate-middle treatments were double those for other treatments because there were only half as many laterals per plot and the same volume of water was applied to each plot at each irrigation. Scheduled irrigations were discontinued if rainfall sufficient to supply the required ET occurred. Irrigation was controlled with an irrigation controller which controlled the irrigation sequence for all 24 plots, timed and controlled the pulsed treatments, monitored flow rates, and monitored and recorded the amount applied to each treatment. The amount of water applied to each block was measured with positive displacement flowmeters which were monitored manually.

The center 46.5-m^2 area of each plot (6-m segment of the middle six rows) was harvested by hand 30 July-2 August 1985 and 11-14 August 1986. Other yield parameters determined at harvest included percent barren and lodged stalks and grain per ear. Grain yields were corrected to 15.5% moisture. All yield parameters, tissue analyses, and plant populations were analyzed statistically using analysis of variance and least squares differences.

RESULTS AND DISCUSSION

Total growing season rainfall and irrigation amounts for all treatments and for both years are included in Table 1. Rainfall and irrigation distribution during the growing season in 1985 and 1986 are shown for all treatments in Figures 1 and 2, respectively. Rainfall was much higher in 1985 than in 1986, when one of the worst droughts of this century occurred during the corn growing season. Rainfall was only 160 mm in 1986, while it was 274 mm in 1985. The drought was particularly severe during the early part of the growing season. Because of the drought in 1986, irrigation amounts were much higher than in 1985. The subsurface, in-row tubing location required the smallest amount of irrigation both years, while the two surface locations (1985) or the surface, in-row location (1986) required the largest amount of irrigation. The surface, alternate middle location required only 12 mm more irrigation than the subsurface, in-row location in 1986. The maximum differences in irrigation amounts were 38 mm and 50 mm, respectively, for 1985 and 1986.

Plant population data for all treatments in 1985 and 1986 are included in Table 2. Mean plant populations were 87,400 and 76,200 plants/ha in 1985 and 1986, respectively. Plant populations at harvest were much higher in 1985 (14.7%) because of over-seeding and better seed germination than expected. Hand thinning in 1986 provided plant populations much closer to the target of 74,100 plants/ha. There were no significant differences in plant population among the trickle irrigation treatments in either 1985 or 1986.

Corn grain yields for all treatments and both years are included in Table 3. There were no significant differences in yields among the six treatments in 1985, but all yields were high. Undoubtedly, harvested yields were reduced this year by severe lodging (92%) caused by high winds associated with a hurricane on 24 July 1985. This occurred just prior to physiological maturity, preventing the crop from proceeding to normal maturity and potential yield. Unfortunately, the experiment had to be harvested early, at a much higher grain moisture than normal, in order to preserve grain quality and prevent germination caused by lodging and wet soil conditions. Moderately severe lodging (49%) occurred in 1986 because of high winds associated with a local thunderstorm on 21 July 1986, but damage was not as severe as in 1985. Corn was able to proceed to normal maturity and was harvested by hand at normal grain moisture conditions. There were no significant differences in lodging among the treatments in either year. Mean grain yields were lower in 1986 than in 1985, probably because of the severe drought and high temperatures. Grain yields in 1986 were significantly lower for the alternate middle placement than for the other two trickle tubing placements. There was no significant difference in yield between the irrigation application mode treatments.

The lower corn grain yield for the alternate middle treatment in 1986 can be explained, at least in part, by observations, plant biomass, and tissue analyses made during the early part of the growing season. About 35 days after emergence, we observed that corn in the outside rows (fartherest from the trickle irrigation lateral in the twin-row drill) was much shorter and was light green to yellowishgreen in color. We hypothesized that this was the result of dry soil conditions and small root systems caused by the extreme drought during the early part of the season (Fig. 2) and the greater distance of the plants from the irrigation system emitters. Plant biomass data confirmed the difference in plant size (6.4 vs. 5.5 g/plant), but whole plant tissue analyses indicated no difference in concentration for the eight plant nutrients analyzed. Therefore, we concluded that the difference in plant size and color was caused by low water availability in the plant root zone and low water uptake by the plants. This period of stress was probably sufficient to cause the reduced grain yield measure this year for the alternate middle tubing placement.

Results of tissue analyses for 1985 and 1986 indicated that all nutrient concentrations were in the sufficiency range. Furthermore, analyses of ear-leaf tissue using the Diagnosis and Recommendation Integrated System (DRIS) (Elwali et al., 1985) indicated that all nutrient ratios were within normal ranges. Consequently, we concluded that from the plant nutrition standpoint, there were no differences among treatments and that no corn grain yield differences among treatments were caused by differences in plant nutrition.

Tensiometer data from ? locations for the 1985 and 1986 seasons are shown in Figure 3. These data confirm that soil water potential was maintained between -? and -? k/Pa for the in-row treatments and between -? and -? k/Pa for the alternate middle treatments. (Note: will expand this section once we refine the plots - don't expect data to show large differences among treatments, even for middles in alt-middle treatment, which is difficult to explain.)

SUMMARY AND CONCLUSIONS

Two years of results from an experiment in which three trickle irrigation lateral placements and two irrigation application modes were evaluated for corn in a coarse-textured Coastal Plain soil indicate small differences in the irrigation water required among the tubing placement treatments, no difference between application modes, and differences in corn grain yield only during severe drought. Severe lodging occurred both years due to high winds associated with storms, which probably reduced mean grain yield in 1985, but there were no significant differences among treatments either year. Yields for the alternate middle trickle tubing placement was significantly lower in 1986 than other treatments because of extreme drought in the early part of the growing season, when the corn root system was not large enough to reach the irrigated soil area. There was no evidence of irrigation system plugging on the subsurface, in-row treatments for this two-year period. Based on these results, it appears that subsurface trickle irrigation is a viable alternative for agronomic crops in the Southeastern Coastal Plain; however, the profitability potential of this irrigation system cannot be estimated until the system longevity is determined.

This experiment will be continued for another year, after which the subsurface trickle tubing will be evaluated for plugging. If found to be capable of continued use, it will be utilized in a future experiment to determine its useful life for these soils, climate, and operating conditions.

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Table 1. Season rainfall and irrigation amounts for three trickle irrigation systems in a Coastal Plain soil.

Trickle Irrigation Treatment	Seasonal Rainfall or Irrigation*			
	1985		1986	
	Number**	Amount	Number	Amount
	---------- mm ----------			
Subsurface, in-row	38	293	54	375
Surface, in-row	40	331	56	425
Surface, alternate-middle	40	331	56	387
Rainfall	35	274	27	160

*Irrigation amounts for each treatment were equal for continuous and pulsed application modes.
**Number of rainfall or irrigation events during the season.

Table 2. Plant populations for three trickle irrigation treatments in 1985 and 1986 in a Coastal Plain soil.

Trickle Irrigation Treatment	Plant Population			
	1985		1986	
	Continuous	Pulsed	Continuous	Pulsed
	---------------plants/ha---------------			
Subsurface, in-row	87900 a*	87000 a	75600 a	76500 a
Surface, in-row	88300 a	87000 a	74300 a	75300 a
Surface, alternate-middle	86500 a	87800 a	77400 a	77900 a

*Means within a column followed by the same letter are not significantly different using $LSD_{.05}$.

Table 3. Corn grain yields for three trickle irrigation treatments in 1985 and 1986 in a Coastal Plain soil.

Trickle Irrigation Treatment	Corn grain yield			
	1985		1986	
	Continuous	Pulsed	Continuous	Pulsed
	----------Mg/ha----------			
Subsurface, in-row	12.6 a*	12.6 a	10.6 a	11.0 a
Surface, in-row	12.9 a	12.2 a	11.4 a	11.7 a
Surface, alternate-middle	13.1 a	12.8 a	9.8 b	9.6 b

*Means within a column followed by the same letter are not significantly different using $LSD_{.05}$.

LIST OF FIGURES