Subsurface and Alternate-Middle Micro Irrigation for the Southeastern Coastal Plain

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ABSTRACT

Micro irrigation offers advantages in water and energy conservation, but cost of annual replacement of many components makes it unprofitable for most agronomic crops. Alternative tubing placements could improve profitability. An experiment was conducted for a three-year period (1985-87) to evaluate three micro-irrigation lateral placements and two irrigation application modes for corn in a coarse-textured southeastern Coastal Plain soil. Tubing placements were surface in-row (SIR), subsurface in-row (SSIR), and surface alternate middle (SAM). Irrigation application modes were continuous and pulsed. There were no differences in corn grain yield except during moderate-to-severe drought. Yields were significantly lower for the SAM treatments in 1986 and for the SAM-pulsed application mode treatment in 1987. Small differences in irrigation water were required among the three tubing-placement treatments. The SSIR treatment required the least amount of irrigation water each year. There was no evidence of emitter plugging on any treatment. The systems, still in use, will be evaluated for longevity; profitability can then be estimated. Based on these results, all of these placements of micro-irrigation tubing can produce acceptable corn yields in the southeastern Coastal Plain.

INTRODUCTION

Micro irrigation offers several advantages, including low water delivery rate, low water pressure, and precise placement of water. Unfortunately, the high cost of annual replacement of many system components has limited its application to high-value crops such as vegetables and some tree crops. Micro-irrigation technology may be made more profitable for agronomic crops by increasing lateral spacing or installing tubes beneath the reach of tillage tools. 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 much lower for laterals placed every third row (3-m spacing) (French et al., 1985). Installing micro-irrigation tubing 0.2-0.3 m below the soil surface to allow shallow tillage and cultivation has been used for fruits and vegetables (Bucks et al., 1981), potato (Sammis, 1980), cotton (Tollefson, 1985; Plaut et al., 1985) and tomato (Phene et al., 1983). This design should allow continued use of the system for several years without tubing replacement. Subsurface tubing placement was considered in much of the early micro-irrigation research in the United States, and its feasibility has been increased by the development of inexpensive plastics (Davis, 1967). Goldberg et al. (1976) summarized the major problems with subsurface micro irrigation as system clogging and difficulty in inspecting, repairing, and maintaining buried equipment.

In the humid southeastern Coastal Plain, seasonal rainfall amount are often sufficient to satisfy evapotranspiration requirements, but the combination of short drought periods (5-20 days) and low water storage capacity of the coarse-textured soils often results in periods of yield-reducing plant water stress. Shallow crop rooting caused by compacted soil layers at depths of 0.2-0.4 m aggravates the problem. Traditional irrigation can alleviate some of these problems and increase crop yield most years. However, the higher cost of energy and equipment combined with low farm commodity prices reduces its profitability.

Normal tillage practices for Coastal Plain soils with compacted layers include annual in-row subsoiling during planting to disrupt the compacted layer and allow deeper root growth (Busscher et al., 1986). This may be impractical for subsurface micro irrigation. However, the resistance of these soil layers to penetration by roots is much lower when the soil water content is between saturation and the upper limit of plant-available water (Campbell et al., 1974). If micro-irrigation laterals were buried in or slightly above the compacted layer and the irrigation system were operated in a high-frequency mode, the compacted soil layer should remain moist, offer less resistance to root penetration, and thus reduce the need for subsoiling.

In 1985, an experiment was initiated to evaluate six micro-irrigation systems for row crops in coarse-textured soils of the southeastern Coastal Plain. Objectives of the study were (1) to determine the feasibility of surface and subsurface micro irrigation for corn on a Norfolk loamy sand, (2) to determine yield response to micro-irrigation lateral placements and modes of irrigation application, and (3) to determine irrigation water requirements for

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combinations of placement and application modes.

MATERIALS AND METHODS

Corn was grown on a 0.20-ha site of Norfolk loamy sand near Florence, South Carolina, for a three-year period (1985-87). Plant-available water in the surface horizon is about 10% by volume, but over half of this is depleted at a matric potential of -80 kPa (Campbell et al., 1988). The E soil horizon was not clearly defined and appeared to be mixed with the Ap horizon to a depth of 0.3 m, probably because of antecedent deep tillage. Each of the 24 experimental plots had eight 12-m long twin-row pairs spaced 0.24 m apart and each pair spaced 0.76 m apart. Six treatments, consisting of all combinations of three tubing locations and two irrigation application modes, were completely randomized in each of four blocks. Tubing locations were (1) buried 0.3 m directly under the twin-row pair (subsurface in-row or SSIR), (2) placed on the surface between the twin-row pair (surface in-row or SIR), and (3) placed on the surface between alternate twin-row pairs (surface alternate middle or SAM) (Fig. 1). Irrigation was applied through each system in both continuous and pulsed modes. In the continuous mode, irrigation was applied without interruption for the entire amount. In the pulsed mode, irrigation was applied in a series of 2-mm pulses with equal on and off times. The duration of each pulse was 40 min for SAM and 20 min for the other treatments.

Tubing for the SSIR treatment had been installed in fall 1984 at the 0.3-m depth using a modified subsoiler shank, and it remained in the soil thereafter. At this depth, the tubing was located at the interface between the Ap and B horizons and below the frost line. The surface tubing was installed each season after a plant stand was established and was removed prior to harvest. Each irrigation lateral was equipped with a removable end cap that allowed system flushing. The micro-irrigation tubing (Lake Drip-In[3]) had in-line, labyrinth-type emitters spaced 0.61 m apart, each delivering 2.0 L/hr. The SSIR and SIR treatments required eight laterals per plot, while the SAM treatment required four laterals. All laterals within a plot were connected to a single manifold, in which flow was controlled by a solenoid valve, and manifold pressure was regulated at approximately 100 kPa.

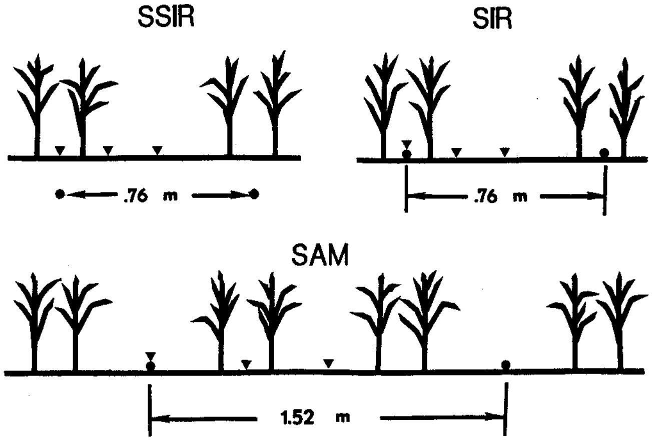

Fig. 1—Schematic of micro-irrigation tubing placements (solid circle), row configurations, and tensiometer locations (solid triangle) across rows for three treatments. SSIR = Subsurface, in-row; SIR = Surface, in-row; and SAM = Surface, alternate-middle.

Prior to installing the system, the experimental site had been subsoiled to a 0.4-m depth in two directions, each 45° to the row, and then smoothed with a disk harrow. Thereafter, only a disk harrow and field cultivator were used to remove weeds and incorporate chemicals. Pesticides were applied in accordance with South Carolina Cooperative Extension Service recommendations. Preplant fertilizer and liquid herbicide were broadcast and incorporated. At planting, a granular insecticide was applied in the furrow with the seed. Plant nutrients added as either preplant granular fertilizer or sidedress solution through the irrigation system are shown in Table 1. In 1985, the source of sidedress nitrogen was urea ammonium nitrate (UAN) (30% N solution). In 1986 and 1987, the source of nitrogen and sulfur was urea ammonium sulfate (UAS) (25% N solution), and the source of boron was Sol-u-bor (20% B). First sidedress N applications were made four to six weeks after planting with additional applications following at two-week intervals.

The irrigation water supply was a chlorinated municipal supply during 1985 and the first portions of the 1986 and 1987 seasons. At other times, water was supplied from a well. Well water was filtered through a sand filter, and all water was passed through a 200-mesh cartridge filter. At the beginning of and periodically during each growing season, the system was flushed by removing tubing end caps. At the end of each growing season, a higher concentration chlorine solution (10-50 ppm available chlorine) was injected into the system, allowed to stand for a period of 1 h, and flushed with water. This treatment was applied to reduce biological activity and to retard root entry into emitters during the dormant season.

Corn was planted 27 March 1985, 31 March 1986, and 14 April 1987. Target plant population was 74,100 plants/ha. Because plant populations were higher than expected in 1985 (data reported later in this report), plants were hand thinned in 1986 and 1987 to provide plant populations closer to the target.

Tensiometers were installed at depths of 0.3, 0.6, 0.9 and 1.2 m, at two locations along the lateral relative to the emitter (at the emitter and midway between emitters), and at three distances from the irrigation lateral (at the lateral; 0.19 m and 0.38 m away for SIR and SSIR; 0.38 m and 0.76 m away for SAM) (Fig. 1). A

TABLE 1. Nutrients Added as Preplant Granular and as Sidedress Solution Injected Through a Micro-Irrigation System for Corn

Year	Fertilizer nutrients					
	Preplant granular*			Solution injected		
	N	P	K	N	B	S
	kg/ha					
1985	28	24	140	235(3)†	0	0
1986	56	24	46	224(4)	1	31
1987	34	29	84	224(4)	1	31

* Preplant granular fertilizer applied broadcast except in 1987 when it was applied as a band between twin rows

† Numbers within parentheses indicate the number of sidedress applications.

tensiometer was installed at the 0.45-m depth at one location only (at the emitter and lateral). This provided a total of 25 tensiometers in each of six plots, one plot for each treatment. Tensiometer readings were recorded three times each week, and tensiometers were serviced at least once each week during the growing season. Rainfall was measured on site with a tipping-bucket rain gauge. To assess adequacy of nutrient management, analyses for N, P, K, Ca, Mg, S, Zn, Cu, Mn and B were determined from ear-leaf samples each year and from whole plant samples taken in 1986 and 1987.

A programmable irrigation controller monitored and controlled all irrigation applications. Water volume applied to each block was also measured with indicating flow meters. Irrigation was scheduled using a combination of tensiometer measurements at the 0.3-m depth and the occurrence of rainfall. Equal water volumes were applied for both pulsed and continuous modes for each treatment. The irrigation system for the SAM treatment was operated twice as long for each application because there were only half as many emitters in each plot. Irrigation was suspended any day that soil water potential was greater than -10 kPa or if rainfall greater than 8 mm occurred. Irrigation (6 mm) was applied daily when soil water potential was between -10 and -25 kPa. When soil water potential was less than -25 kPa, 12 mm of irrigation was applied.

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, 11-14 August 1986, and 18-21 August 1987. 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 rainfall and irrigation amounts between planting and crop maturity for all treatments and all years are included in Table 2. Rainfall and irrigation distributions during the growing season in all years are shown for all treatments in Fig. 2-4, respectively. Rainfall was much higher in 1985 (274 mm) than in 1986 (161 mm), when one of this century's worst droughts occurred during the season. The drought, particularly severe early in the growing season, caused seasonal irrigation amounts to be much higher in 1986. Rainfall in 1987 (202 mm) was intermediate between the other two years as were the irrigation amounts.

TABLE 2. Seasonal Rainfall and Irrigation Amounts for Three Micro-Irrigation Systems in a Southeastern Coastal Plain Soil

Micro-Irrigation Treatment	Seasonal Rainfall or Irrigation*		
	1985	1986	1987
	mm		
SSIR†	293 (38)‡	375 (54)	348 (52)
SIR	331 (40)	425 (56)	348 (52)
SAM	331 (40)	387 (56)	373 (56)
Rainfall	274 (35)	161 (27)	202 (26)

* Equal irrigation amounts were applied to the continuous and pulsed modes for each tubing-placement treatment.

† SSIR = Subsurface, in-row; SIR = Surface, in-row; and SAM = Surface, alternate middle. All irrigation amounts include initial sprinkler applications each year.

‡ Number of rainfall or irrigation events during the season.

The effect of tubing placement on irrigation water requirement can be compared using seasonal irrigation totals. However, because equal irrigation amounts were applied to both continuous and pulsed modes for each treatment, the effect of application mode can only be determined from detailed comparison of soil wetting and drying, which will not be included in this paper. The most apparent differences were among tubing locations. The SSIR treatment required the least amount of irrigation each year. One or both of the two surface locations required the greatest amount of irrigation, but neither was consistently higher. In 1985, the SIR and SAM treatments required 38 mm more irrigation than the SSIR treatment. In 1986, the SIR treatment required 38 mm more irrigation than the SAM treatment, but in 1987, the SAM treatment required 25 mm more than the SIR and SSIR treatments. For the three years, the maximum differences in irrigation amounts were 38, 50

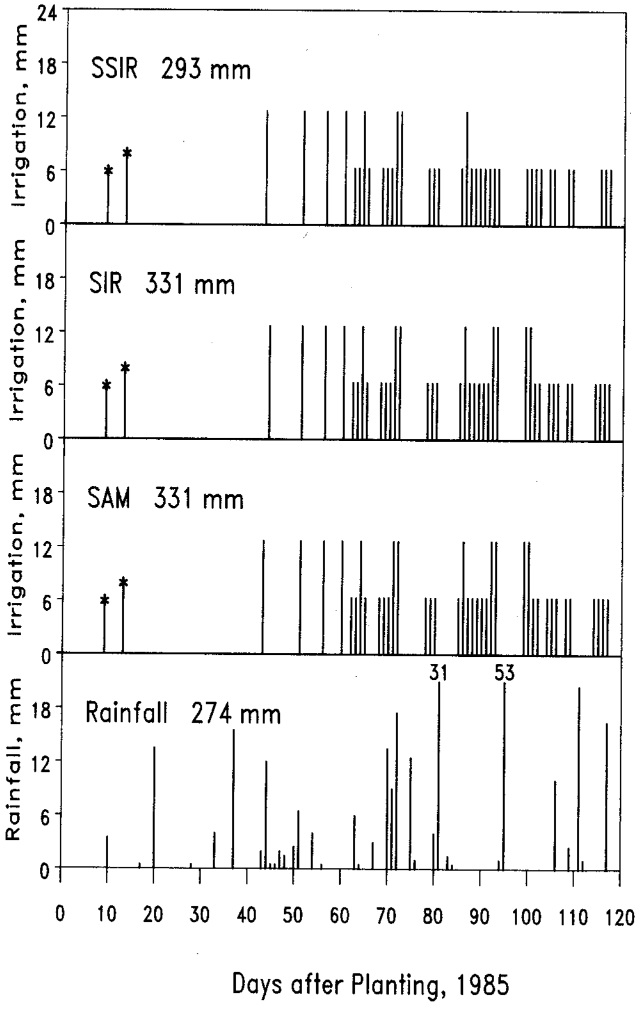

Fig. 2—Rainfall and irrigation distributions for three irrigation-tubing placements in 1985. Seasonal rainfall or irrigation totals are annotated on the appropriate graph. Sprinkler irrigation amounts are indicated with asterisks. Numbers annotated above plotted lines indicate off-scale data values. SSIR = Subsurface, in-row; SIR = Surface, in-row placement; and SAM = Surface, alternate-middle placement.

and 25 mm, respectively.

Tensiometer data indicate that soil water potential was generally maintained within the desired range. The SIR treatment was the driest treatment in the first two years, and the SAM treatment was slightly drier in the last year (Fig. 5). Analyses of these data showed consistent differences in wetting patterns only between SAM and the other two placements. Differences in wetting patterns between SIR and SSIR tubing placements were expected but were not observed. Variations in soil texture, density and hydraulic conductivity were probably great enough to partially compensate for differences in tubing placement. A more detailed analysis of differences in wetting patterns caused by the continuous and pulsed application modes was reported by Camp et al. (1987).

To be feasible, laterals in these micro-irrigation systems must be strong enough to survive repeated installation and removal for surface placements and resist plugging, root intrusions and collapse for the subsurface placement. Although occasional slight damage to tubing was caused by tillage equipment and soil samplers, no serious problems were observed. A few instances of insect or rodent damage to surface tubing were observed. Small amounts of sediment or other discoloration were observed during periodic flushing of the SSIR treatment. There was no evidence of emitter plugging; however, all tubing will be more thoroughly evaluated in the future for emitter uniformity, plugging and root intrusion using destructive techniques. No degradation in water delivery rate was observed for any tubing placement.

Mean plant population at harvest in 1985 was 87,400 plants/ha, 18% higher than the target population because of higher-than-expected seed germination. Because of hand thinning in 1986 and 1987, plant populations, 76,200 and 76,500 plants/ha, respectively, were much closer to the target. There were no significant differences in plant populations among the various placement and application mode treatments within each year.

Corn grain yields for all treatments and all years are included in Table 3. In 1985, all yields were high, and there were no significant differences in yields among the six treatments. The effect of Hurricane Bob, which caused severe lodging (92%) on 24 July 1985, was not evaluated. Because of its timing (about physiological maturity) yield reduction was probably minimal since the plots were hand harvested. There were no significant differences in lodging among treatments. The experiment was harvested early, at about 40% grain moisture, in order to preserve grain quality and prevent germination caused by lodging and wet soil conditions.

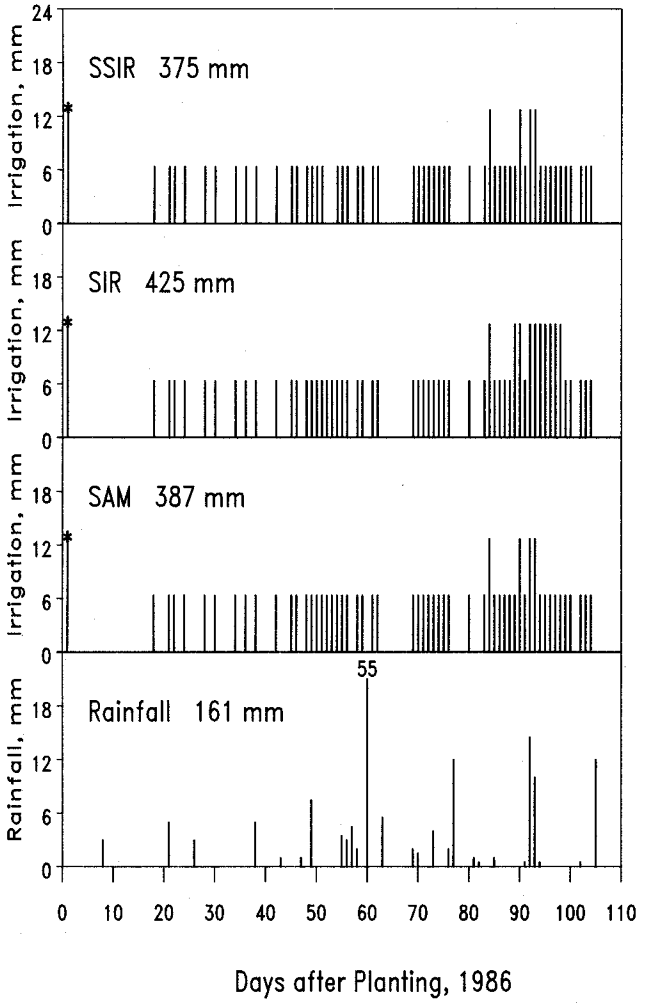

Fig. 3—Rainfall and irrigation distributions for three irrigation-tubing placements in 1986. Explanatory notes and definitions as shown for Fig. 2.

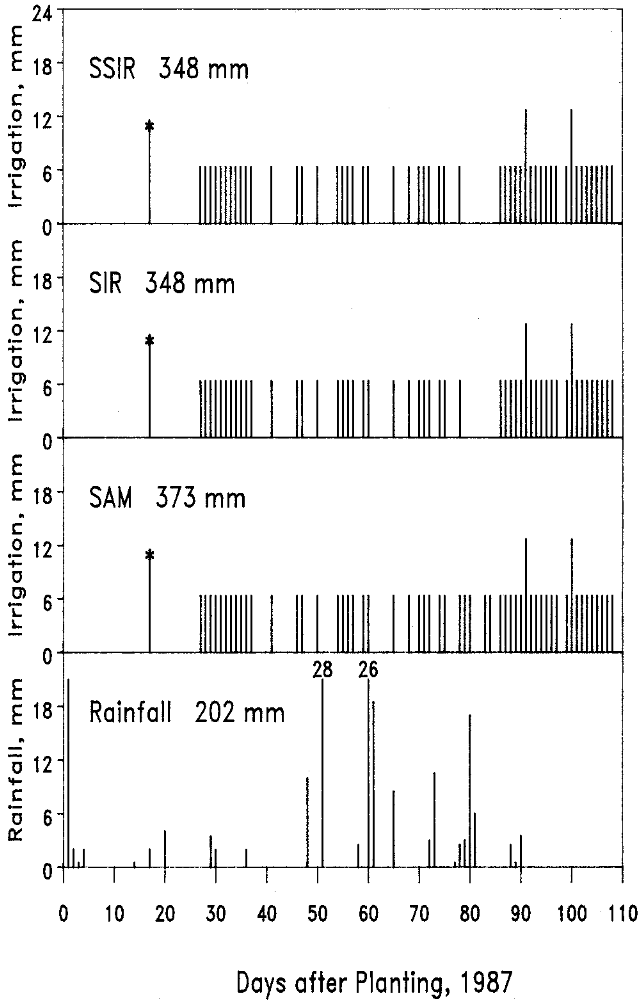

Fig. 4—Rainfall and irrigation distributions for three irrigation-tubing placements in 1987. Explanatory notes and definitions as shown for Fig. 2.

In 1986, grain yields were significantly lower for the SAM treatment than for the other two tubing placements. There was no significant difference in yield between the irrigation application mode treatments. Moderately severe lodging (49%) occurred because of high winds associated with a local thunderstorm on 21 July, but damage was not as severe as in 1985. Again, lodging was the same for all treatments. Corn was harvested by hand after maturity at normal (15-20%) grain moisture content. The lower grain yields for all treatments in 1986 were possibly caused by high temperatures associated with the severe drought, even with irrigation.

The lower corn grain yield for the SAM treatment in 1986 can be partly explained by observations, plant biomass and tissue analyses made during the early part of the growing season. About 35 days after emergence, corn in the row farthest from the irrigation lateral in the twin-row drill was observed to be shorter and a lighter green color. This plant condition may be attributed to small root systems being farther from irrigation emitters and to extremely dry soil conditions that caused low water availability in the root zone. Plant biomass and whole plant tissue analyses for seven plant nutrients most critical for corn in this region are shown in Table 4. Plant biomass data confirmed the difference in plant size, but nutrient concentrations were in the sufficiency range for the 10 plant nutrients measured. This suggests that small plant size and pale color were caused by low water availability in the plant root zone and that low water uptake limited plant growth. This period of stress probably caused the reduced grain yield measured for the SAM treatment.

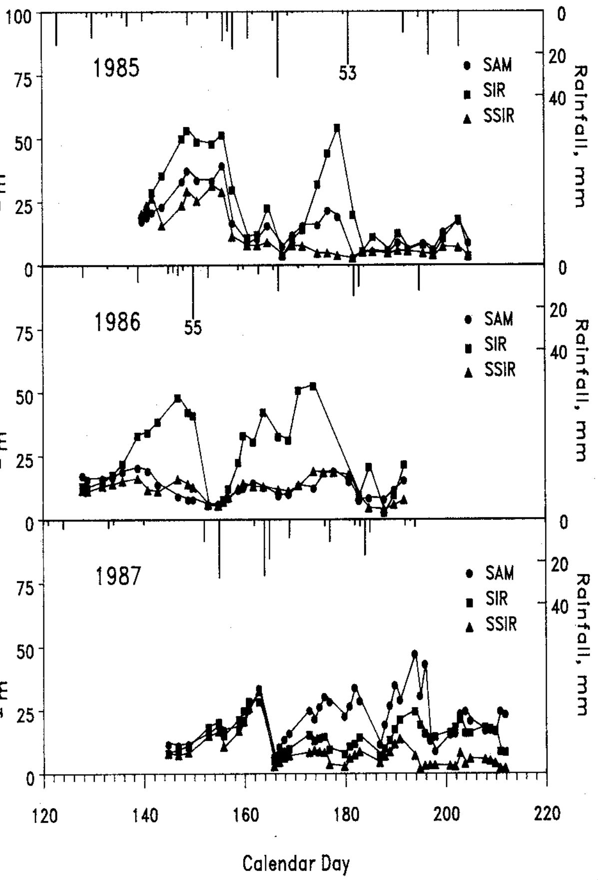

Fig. 5—Mean soil matric potential (ψ_m) at the 0.30-m depth for locations farthest from irrigation tubing, for all tubing placements and all years. Each point is the mean of four data values. SSIR = subsurface, in-row; SIR = surface, inrow; and SAM = surface, alternate-middle.

TABLE 3. Corn Grain Yields for Three Micro-Irrigation Treatments and Two Application Modes in a Southeastern Coastal Plain Soil

Micro Irrigation Treatment	Corn Grain Yield 1985 Cont.*	1985 Pulsed	1986 Cont.	1986 Pulsed	1987 Cont.	1987 Pulsed
	Mg/ha					
SSIR†	12.6a‡	12.6a	10.6a	11.0a	11.1a	11.3ab
SIR	12.9a	12.1a	11.4a	11.7a	12.4a	12.4a
SAM	13.1a	12.8a	9.8b	9.6b	11.4a	10.0b

* Cont. = Continuous mode.
† Same as defined in Table 1.
‡ Means within a column followed by the same letter are not significantly different using $LSD_{.05}$.

In 1987, there was no significant difference in grain yield when averaged across placement for the pulsed and continuous modes. However, the interaction was significant because grain yield for the SAM treatment was significantly lower than for the SIR treatment in the pulsed mode, but treatment differences were not significant in the continuous mode. The lower yield for SAM treatment in the pulsed mode cannot be fully explained. In view of the documented yield reduction caused by soil water deficit in 1986, it is possible that a similar effect occurred in 1987.

Results of tissue analyses indicated that all nutrient concentrations were within 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, it appears that plant nutrition was not a limiting factor.

SUMMARY AND CONCLUSIONS

Three micro-irrigation lateral placements and two irrigation application modes were evaluated for corn in a coarse-textured Coastal Plain soil. There were no dif-

TABLE 4. Plant Biomass and Tissue Analyses for Corn Plants from Two Row Locations Relative to a Micro-Irrigation Lateral in 1986.

Treatment	Row Location*	Plant Biomass	Plant Nutrient N	P	K	Ca	S	Zn	B
		g/plant	%					ppm	
SSIR†	1	6.2	3.32	0.34	4.29	0.39	0.24	51	5
	2	5.4	3.21	0.34	4.29	0.35	0.22	46	4
SIR	1	6.3	3.17	0.34	4.66	0.37	0.22	55	4
	2	6.4	3.46	0.35	4.58	0.34	0.25	53	4
SAM	1	6.6	3.57	0.33	4.37	0.40	0.28	62	5
	2	4.8	3.38	0.40	4.66	0.38	0.26	52	5
Sufficiency	Low		2.80	0.25	1.75	0.25	0.15	15	4
Range	High		3.20	0.45	2.25	0.50	0.50	60	25

* Horizontal distance between the lateral and row location is 0.14 m for both locations in the SIR and SSIR treatments; 0.24 m for location 1 and 0.52 m for location 2 in the SAM treatment.
† Same as defined in Table 2.

ferences in corn grain yield except during moderate-to-severe drought. Yields were significantly lower for the SAM treatments in 1986 and for the SAM-pulsed application mode treatment in 1987. In 1986, this was apparently caused by extreme drought during the early part of the growing season when the corn root system was not large enough to reach the irrigated area. Lodging occurred in all treatments in 1985 and 1986 because of high winds associated with storms, but this had little or no effect on grain yields.

Small differences in irrigation water were required among the three tubing-placement treatments. The SSIR treatment required the least amount of irrigation water (0-50 mm advantage out of about 350 mm annual requirement) each year. Wetting patterns indicated no difficulty for the SSIR treatment in delivery of water upwards from the emitter to higher portions of the root system. No serious problems were encountered in tubing installation, annual removal of surface tubing, tillage above subsurface tubing, uniform delivery of irrigation water or emitter plugging.

Economic feasibility of micro irrigation for agronomic crops will depend upon tubing longevity. However, based on these results, any of these micro-irrigation treatments can produce acceptable corn yields in the southeastern Coastal Plain with the possible exception of the alternate-middle treatment which yielded less corn grain during severe drought. However, this treatment may be acceptable for some conditions in view of the reduced tubing requirement.

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