SUBSURFACE AND ALTERNATE-MIDDLE MICRO IRRIGATION IN HUMID REGIONS[1]

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Micro-irrigation technology may be made profitable for agronomic crops by increasing lateral spacing or installing tubes below normal plow depths. In Arizona, placing laterals in every or every other row (1 or 2 m) resulted in comparable cotton yields but placing them in every third row (3 m) reduced yield (French, 1985). Installing tubes 0.2-0.3 m deep to allow shallow tillage, cultivation, and use of the system for several years before replacement has been used for fruits and vegetables (Bucks et al., 1981), potato (Sammis, 1980), cotton (Tollefson, 1985), and tomato (Phene et al., 1983).

In the humid Southeastern Coastal Plain of the U.S.A., seasonal rainfall is often sufficient to satisfy evapotranspiration requirements, but the combination of short drought periods (5-20 days) and low soil water storage capacity often result 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. Thus, irrigation can increase crop yield in most years. Micro irrigation has been used effectively to irrigate high-value crops, but annual replacement cost has prevented its use on agronomic crops.

Normal tillage practices for many Coastal Plain soils include annual in-row subsoiling to disrupt compacted layers and allow deeper root growth. This might not be possible with subsurface micro irrigation, depending upon tubing placements, but root penetration resistance is much lower at high soil water contents (Campbell et al., 1974). Laterals buried slightly above the compacted layer may keep the layer moist enough to allow root penetration and possibly preclude the need for annual subsoiling.

An experiment was initiated in 1985 to evaluate various micro-irrigation systems and water application modes for maize on a coarse-textured Coastal Plain soil. Objectives were (1) to determine the feasibility of surface and subsurface micro irrigation for maize, (2) to determine yield response to various lateral placements and water application modes, and (3) to determine if irrigation water requirements varied for various placement application modes.

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MATERIALS AND METHODS

Maize (cv. Asgrow/O's Gold 5509) was grown on a 0.20-ha site of Norfolk loamy sand near Florence, South Carolina, USA, for three years (1985-87). Each of the 24 experimental plots had eight 0.24-m twin-row pairs spaced 0.76 m apart and 12 m long (Fig. 1). Six treatments, consisting of all combinations of three tubing placements and two irrigation application modes, were completely randomized in each of four blocks. Irrigation tubing placements were (1) subsurface, 0.3 m below twin rows (SSIR), (2) surface, between twin rows (SIR), and (3) surface, between alternate twin-row pairs (SAM) (Fig. 1). Irrigation was applied in either continuous or pulsed modes. In the continuous mode, irrigation was applied without interruption until the desired amount was applied. In the pulsed mode, the desired irrigation was applied in pulses such that on and off times were equal and the duration of each was either 20 or 40 minutes depending upon the number of laterals.

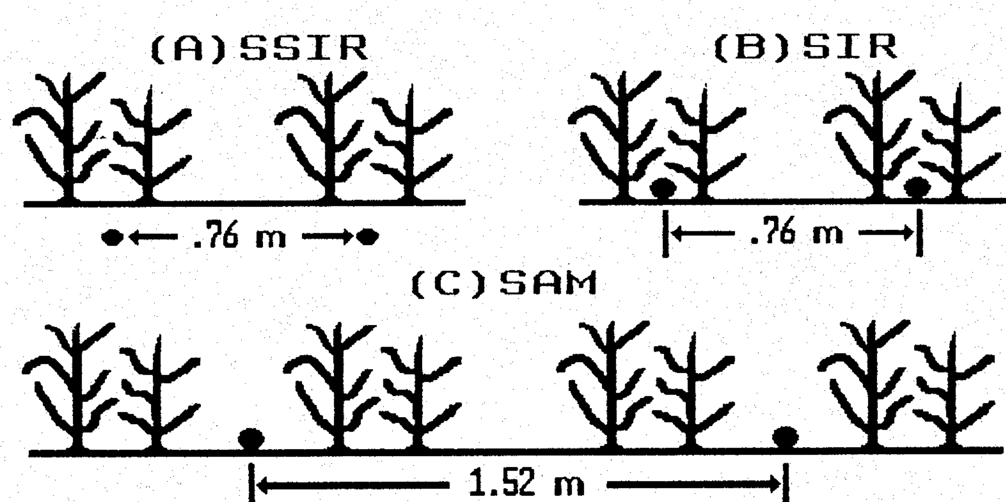

Fig. 1. Schematic diagram of micro-irrigation tubing placements and row configurations. SSIR = Subsurface, in-row; SIR = Surface, in-row; and SAM = Surface, alternate middle.

For SSIR, tubing was placed above the interface between the Ap and B horizons using a modified subsoiler shank. This tubing remained in the soil continuously after installation in the fall of 1984. Tubing for SIR and SAM was installed each season after maize emergence and removed prior to harvest. The tubing (Lake Drip-In[3]) had in-line, labyrinth-type emitters (2 L/hr) spaced 0.61 m apart. Water pressure in each plot manifold was regulated at 100 kPa.

The experimental site was subsoiled in two directions, each 45° to the row direction at a depth of 0.40 m before smoothing with a disk harrow and installing the system. Thereafter, only a disk harrow and field cultivator were used to remove weeds and incorporate chemicals. Pesticides and preplant fertilizers were applied in accordance with South Carolina Cooperative Extension Service recommendations and soil test results. Sidedress N was injected into the system three (1985) or four (1986 and 1987) times beginning 4-6 weeks after planting. The chlorinated water supply was filtered with a 100-mesh cartridge filter. At the beginning of and periodically during each season, the entire system was flushed. At the end of each growing season, a higher-concentration chlorine solution was injected to reduce biological activity and to retard entry of roots into the emitters.

Tensiometers were installed at four depths, at two locations relative to the emitter, and at three distances from the irrigation tubing. Tensiometer readings were recorded three times each week during the growing season. Rainfall was measured on site with a tipping-bucket rain gauge. Analyses for N, P, K, Ca, Mg, S, Zn, and Cu were determined from ear-leaf samples each year, and whole plant samples in 1986 and 1987 to assess adequacy of nutrient management.

Irrigation (6 mm) was applied daily to all treatments. When soil water potential at the 0.3-m depth reached -25 kPa in a tubing-placement treatment (either mode), an additional 6 mm was applied to both modes for that treatment. Scheduled irrigations were discontinued if rainfall sufficient to supply estimated ET occurred. A programmable irrigation controller monitored and controlled all irrigation applications. Water volume applied to each plot was also measured with indicating flow meters. The center 46.5-m^2 area of each plot was hand-harvested to determine grain yield, plant population, barren and lodged stalks, and grain per ear. Grain yields were corrected to 15.5% moisture. All data were analyzed statistically using analysis of variance and mean separation procedures.

RESULTS AND DISCUSSION

Total growing season rainfall and irrigation for all treatments and years are listed in Table 1. Rainfall was 288 mm, 174 mm, and 213 mm in 1985, 1986, and 1987, respectively. Early-season drought was severe in 1986 thus requiring the greatest irrigation amounts, but in 1987 amounts were also moderately high.

Table 1. Seasonal rainfall and irrigation amounts for three micro-irrigation systems in a Coastal Plain soil.

Micro-Irrigation Treatment	Seasonal Rainfall or Irrigation*		
	1985	1986	1987
	----------mm----------		
SSIR**	279 (36)***	362 (53)	337 (51)
SIR	318 (38)	413 (55)	337 (51)
SAM	318 (38)	375 (55)	362 (55)
Rainfall	288 (36)	174 (28)	213 (27)

* 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.
***Number of rainfall or irrigation events during the season in parentheses.

Because equal irrigation amounts were applied to both continuous and pulsed modes for each treatment, effects of tubing placement on irrigation water requirements can be compared using seasonal irrigation totals, but differences caused by application mode can only be observed by comparing soil wetting patterns. The SSIR (subsurface, in-row) treatment required the smallest amount of irrigation. The greatest amount was required by SIR (surface, in-row) and SAM (surface, alternate middle) in 1985, by SIR in

1986, and by SAM in 1987. However, the SAM treatment required only 13 mm more irrigation than SSIR in 1986. Maximum differences in irrigation amounts were 39 mm, 51 mm, and 25 mm, respectively, for 1985, 1986, and 1987.

Tensiometer data indicate that soil water potential was generally maintained within the desired range. Preliminary analyses indicate consistent differences in wetting patterns only between SAM and the other two placements. While differences in wetting patterns would normally be expected between the surface and subsurface placements, variations in soil texture, density, and hydraulic conductivity were great enough to compensate for tubing placement differences in some cases. Differences in wetting patterns between the continuous and pulsed application modes were inconsistent.

To be feasible for multiple season use, surface-placed tubing must be durable enough to survive repeated installation, and subsurface-placed tubing must resist plugging, root intrusion, and collapse. Tillage equipment and soil samplers caused slight cuts in the tubing which required repair, but no serious problems were observed during this study. Some insect and/or rodent damage to tubing was also observed with surface placement. Small amounts of sediment or precipitate were observed during periodic flushing of subsurface tubing. In the future, this tubing will be evaluated more thoroughly for emitter plugging and root intrusion. No degradation of delivery rate was observed for any tubing placement during this study.

Maize grain yields for all treatments and years are presented in Table 2. In 1985, all yields were high, and there was no significant difference in yield among the six treatments. Hurricane Bob caused severe lodging (92%) on 24 July at crop maturity which required all plots to be harvested by hand. This damage may have reduced yield, but the effect was probably equal across all treatments because there was no significant difference in lodging among treatments. In 1986, grain yields were significantly lower for the SAM treatment. There was no significant difference in yield between the pulsed and continuous modes. Moderately

Table 2. Maize grain yields for three micro-irrigation treatments and two application modes in a Coastal Plain soil.

Micro-Irrigation Treatment	Maize grain yield					
	1985		1986		1987	
	Cont.*	Pulsed	Cont.	Pulsed	Cont.	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 $LSD_{.05}$.

severe lodging (49%) occurred because of high winds associated with a thunderstorm on 21 July but was not as severe as in 1985. Again, lodging was uniform across all treatments. Lower grain yields in 1986 may have been caused by severe early-season drought and high temperatures although irrigation was managed carefully.

Lower maize grain yield for the SAM treatment in 1986 can be partly explained by observations, plant biomass measurements, and tissue analyses made during the early part of the growing season. About 35 days after emergence, maize in the row farthest from the lateral was shorter and lighter green in color. The combination of a small root system, greater distance from the irrigation tubing, and dry soil conditions probably caused these symptoms. Plant biomass measurements confirmed a 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 that were measured. Consequently, 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 most likely reduced grain yield for SAM.

In 1987, there was no significant difference in grain yield when averaged across placement for the pulsed and continuous modes. The interaction, however, was significant because grain yields among the tubing placement treatments were not different in the continuous mode, but for the pulsed mode, yield for SAM was significantly lower than for SIR. The lower yield for SAM in the pulsed mode cannot be fully explained. In view of the documented yield reduction caused by soil water deficit during early growing season in 1986, it is possible that a similar effect occurred in 1987 during a shorter drought period.

Results of ear leaf analyses indicated that all nutrient concentrations were within the sufficiency ranges. Furthermore, analyses using the Diagnosis and Recommendation Integrated System (DRIS) (Elwali et al., 1985) showed that all nutrient ratios were within normal ranges. Consequently, it appeared that plant nutrition was not a limiting factor.

The estimated savings in capital expense for SAM when compared to the SIR placement is 10-20%, which amounts to about \$350/ha for a system costing \$2450/ha. Because equal volumes of irrigation water are required for both systems, operational costs should be about equal. Although the delivery rate per hectare would be lower, the system would probably be designed to cover a larger area with the same water volume. If the tubing were retrieved and reused, operational costs for SAM would be less because only half as much tubing would be handled. If the tubing were replaced each year, the relative savings for SAM would be substantially greater because only half as much tubing would be purchased each year. In humid areas, the probability of reduced yield for SAM may be an acceptable risk in view of reduced capital expense and the probability of receiving rainfall that would ameliorate yield reduction. The SSIR placement probably offers the best alternative provided the tubing will perform satisfactorily for a sufficient number of years, primarily because of reduced operational costs to retrieve the tubing each year. A final economic analysis cannot be completed until the useful life of irrigation tubing has been determined for each placement.

SUMMARY AND CONCLUSIONS

Small differences in irrigation water were required among the three irrigation tubing placements. There were no differences in maize grain yield except during moderate-to-severe drought. Yields for SAM were significantly lower in 1986 and 1987. In 1986 this was caused by extreme drought in the early part of the growing season, when the maize 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. There was no evidence of emitter plugging.

Based on these results, it appears that subsurface and alternate-middle placements of micro-irrigation tubing are viable alternatives for agronomic crops in the Southeastern Coastal Plain; however, profitability cannot be estimated until longevity is determined for each tubing placement. These systems will be utilized in future experiments to determine longevity for these soils, climate, and operating conditions.

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