MICROIRRIGATION MANAGEMENT FOR DOUBLE-CROPPED VEGETABLES IN A HUMID AREA

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ABSTRACT. *Installation of microirrigation tubing below the tillage zone and/or at wide spacings could make microirrigation more profitable for supplemental irrigation of vegetable crops in humid areas such as the southeastern U.S. coastal plain. Two surface (surface 1 and surface 2, either one or two tubes/bed) and one subsurface (Subsurface 2, two tubes below each bed) microirrigation treatments and two application frequencies, high (three times per day) and low (one time per day), were evaluated for cowpea, green bean, squash, and muskmelon production in the spring seasons and for broccoli in the fall seasons. The same irrigation equipment was used in both years and for three years prior to the experiment. There were few yield differences among irrigation treatments, both for tubing placement and irrigation frequency. There was no yield reduction for the surface 1 treatment, although it received only half the irrigation volume as the other treatments. Therefore, for the irrigation systems evaluated, the surface 1 system would be more profitable for vegetable production in the southeastern coastal plain. All yields were as high or higher than industry yields, except for broccoli, which was slightly lower. These results demonstrate the feasibility of multicropping vegetables with the same irrigation system. The satisfactory performance of the microirrigation tubing after five years of use indicates a high probability that the longevity of this system may be sufficient to make it profitable for use with lower-valued crops and other vegetable crops.* ***Keywords.*** *Microirrigation, Subsurface irrigation, Trickle irrigation, Broccoli, Green bean, Squash, Cowpea, Muskmelon, Tensionmeters, Tubing placement.*

Microirrigation offers several advantages over conventional irrigation systems, including more precise water placement, a lower water pressure requirement, and lower water delivery rate. In most cases, tubing and other system components are replaced annually or seasonally, limiting microirrigation application to high-value crops. Practices or designs that would either reduce the number of replaceable components or prolong their use beyond a single season would make this technology more profitable for lower-valued crops. Any such design changes must be made with minimal reduction in crop yield to be accepted by growers. On a coarse-textured soil in Arizona, cotton yields were comparable for tubes placed every row (1-m spacing) and every other row (2-m spacing) but were much lower for tubes placed every third row (3-m spacing) (French et al., 1985). Microirrigation tubing installed 0.2 to 0.3 m below the soil surface to allow shallow tillage and cultivation has been used successfully for several fruits and vegetables (Sammis, 1980; Bucks et al., 1981; Phene et al., 1987), cotton (Tollefson, 1985; Plaut et al., 1985) and corn (Camp et al., 1989). If preventive maintenance methods could be developed to prevent or reduce emitter plugging caused by root penetration and poor water quality, this design would allow continued use of the system for several years without tubing replacement.

Seasonal rainfall amounts in the southeastern coastal plain are often adequate to satisfy crop water requirements, but short drought periods (5 to 20 days) occur in most years. The coarse-textured soils have a low water storage capacity, and water storage available for plant extraction is further reduced by compacted soil layers that can restrict crop rooting to a relatively shallow depth in many soils. This combination of poor rainfall distribution and low soil water storage results in yield-reducing plant water stress in most years. Consequently, during drought periods, irrigation is needed to produce crops of consistent high quality and yield. Other types of irrigation can alleviate some of these problems and increase crop yield in most years, but energy and equipment costs and low commodity prices reduce profitability.

In-row subsoiling at planting is often used to disrupt compacted layers and allow deeper root growth in coastal plain soils (Busscher et al., 1986). Improved root growth also occurs in these soils when the water content is between saturation and the upper limit of plant-available water (Campbell et al., 1974). Consequently, placement of a microirrigation system near the top of a compacted layer could maintain the compacted soil in a low-resistance state,

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thereby promoting improved root growth and reducing the need for subsoiling.

To evaluate such hypotheses, microirrigation systems were installed in 1984 and used to evaluate six microirrigation treatments for corn production during the period 1985 to 1987 (Camp et al., 1989). Busscher et al. (1991) reported corn root growth for these systems during this period. These same systems were used in this experiment to evaluate six microirrigation treatments for five vegetable crops during the spring and fall growing seasons of 1988 and 1989. Objectives of this study were to:

- Evaluate the effect of tubing placement and irrigation frequency on yield of five vegetable crops.
- Determine the feasibility of double-cropping vegetable crops using the same irrigation equipment.
- Evaluate the long-term performance of subsurface microirrigation tubing.

Materials and Methods

Broccoli (*Brassica oleracea*), green bean (*Phaseolus vulgaris*), squash (*Cucurbita pepo*), muskmelon (*Cucumis melo*), and cowpea (*Vigna unguiculata*) were grown on raised beds spaced 1.5 m apart on a 0.20-ha site of Norfolk loamy sand (Typic Kandiudults), near Florence, South Carolina, for a two-year period (1988 through 1989). 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 48 experimental plots had two beds 12 m long, with each bed having either one or two plant rows spaced about 0.50 m apart, depending upon the crop. Irrigation could be controlled independently for each of the 48 plots, but was managed by treatment during this experiment. Every plot was split into two crop subplots, each 6 m long, but the subplots could not be irrigated independently. Consequently, crops with similar water requirements were planted on the same bed, e.g., green bean-cowpea and squash-muskmelon (fig. 1). Green bean, cowpea, squash, and muskmelon were planted in the spring of each year, one crop on each irrigation treatment subplot. Broccoli was transplanted in the fall of each year (table 1). The broccoli plots were 12 m long in 1988 and 6 m long in 1989 because of a limited supply of plants (fig. 1). Crops were rotated within an irrigation treatment so that no crop was grown on the same site both years. Plot areas harvested for each crop and year are shown in table 1.

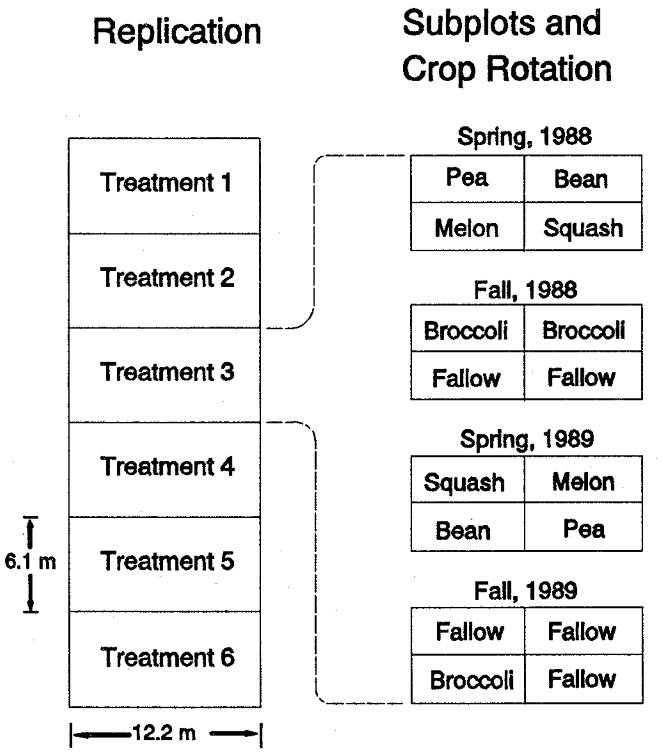

Figure 1–Schematic diagram of plots in one replication and crop rotations between two adjacent subplots for four spring (green bean, cowpea, squash, and muskmelon) crops and a fall broccoli crop.

Six irrigation treatments were completely randomized in each of four blocks when the systems were installed in 1984. Treatments and crops were randomized each year subject to the restrictions of existing subsurface irrigation plots. Treatments consisted of all combinations of three

Table 1. Vegetable varieties, planting and harvesting dates, and fertilizer applications for a microirrigation experiment on a southeastern coastal plain soil during 1988-1989

Year / Crop	Crop Variety	Planting Date	Last Harvest Date	Harvested Area (m^2)	Fertilizer (kg/ha) Preplant N	P	K	Sidedress* N	K	S
1988										
Cowpea	Magnolia Blackeye	26 April	28 July (4)†	9.3	34	29	56	22	—	—
Green Bean	Blue Lake 274	28 April	1 July (3)	9.3	34	29	56	22	—	—
Muskmelon	Mainstream	20 May	29 July (7)	18.6	34	29	56	78 (2)	—	5
Squash	Pavo	20 May	15 August (15)	18.6	34	29	56	78 (2)	—	5
Broccoli	Green Comet	14 September	30 November (6)	37.2	42	36	70	104 (3)	—	8
1989										
Cowpea	Mississippi Silver	31 May	15 August (2)	9.3	34	29	56	34	34	—
Green Bean	Blue Lake 274	31 May	7 August (3)	9.3	34	29	56	34	34	—
Muskmelon	Magnum 45	4 May	2 August (14)	18.6	34	29	56	34	34	—
Squash	Pavo	28 April	14 July (23)	18.6	34	29	56	34	34	—
Broccoli	Early Dawn	12 September	16 November (6)	13.9	84	36	70	109 (2)	100 (2)	—

* All sidedress applications were injected through the irrigation system except the first application for broccoli each year, which was applied to the soil surface as granular ammonium nitrate in 1988 and as 15-0-14 fertilizer in 1989. For sidedress fertilizer applications S = sulphur.

† Numbers in parentheses reflect either numberof harvests or number of sidedress fertilizer applications, if greater than one.

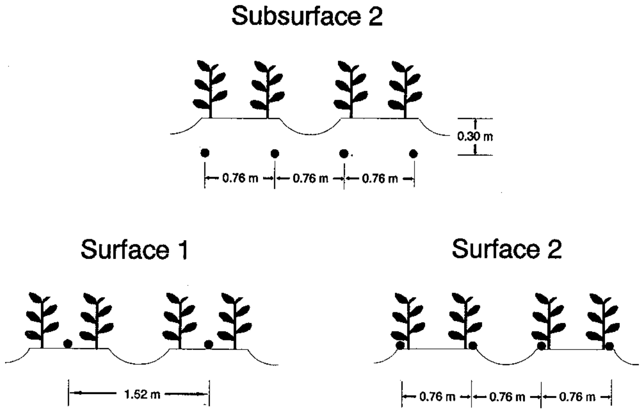

Figure 2–Schematic diagram of microirrigation system treatments. Solid circles indicate microirrigation tubing locations.

microirrigation tubing locations and two application modes. Irrigation tubing locations were (1) two tubes buried 0.3 m under each bed (subsurface 2), (2) two tubes on the surface of each bed (surface 2), and (3) one tube on the surface of each bed (surface 1) (fig. 2). Irrigation was applied through each system at either high or low frequencies. In the low-frequency treatments, irrigation was applied without interruption until the desired daily amount of water had been applied. In the high-frequency treatment, irrigation was applied in three equal pulses each day, with one-third of the volume applied every 4 h.

The subsurface tubing had been installed in the fall of 1984 at a depth of 0.3 m using a modified subsoiler shank and had remained in the soil continuously. At this depth, the tubing was at the interface between the Ap and B soil horizons and was below the frost line. Surface tubing was installed each season after transplanting and/or planting and was removed after harvest. The same tubing was used continuously for five years (two in this experiment and three in a previous experiment) in all treatments. Irrigation tubing (Lake Drip-In) has in-line, labyrinth emitters spaced 0.6 m apart, each delivering 1.9 L/h at 125 kPa pressure. Each lateral was equipped with a removable end cap that was used for flushing the lines. All laterals within a plot were connected to a separate manifold where flow was controlled by a solenoid valve and pressure was regulated at about 105 kPa by individual, in-line pressure regulators.

Prior to installation of the subsurface irrigation system in 1984, the site was subsoiled in two directions (45° to the row direction and perpendicular to each other) and was disked until the surface was smooth. Thereafter, the only tillage used was disking and smoothing to remove weeds and to incorporate chemicals, rotary tilling to prepare for bed shaping, and shaping and compressing of the beds. Pesticides were applied in accordance with South Carolina Cooperative Extension Service recommendations. In 1988, beds used for squash and muskmelon were injected with a methyl bromide-chloropicrin (67-33) mixture (280 kg/ha) at a depth of about 0.15 m using two shanks spaced about 0.5 m apart. The beds were immediately covered with white plastic mulch. In 1989, the entire experimental area was treated with the methyl bromide-chloropicrin mixture and covered with plastic for three days. Beds were formed after removing the plastic sheet and the squash and muskmelon beds were again covered with white plastic mulch. Following harvest of the spring crops and removal of all plant material, beds were prepared for transplanting broccoli in the fall, but plastic mulch was not used for broccoli.

Fertilizer P and K requirements were determined by soil test each year. Preplant fertilizer and liquid herbicide were broadcast and incorporated. Additional fertilizer nutrients were added through the irrigation system or as granules on the surface at various intervals, depending upon the particular crop, and did not vary with irrigation amount. Fertilizer applications, planting and harvesting dates, and varieties for all crops are shown in table 1 for both years.

The chlorinated irrigation water supply was filtered using a 100-mesh cartridge filter. The system was flushed at the beginning of and periodically during each growing season 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 root entry into the emitters. In 1989, immediately prior to the spring growing season, the system was also sequentially treated with sulfuric acid and a more concentrated chlorine solution. Sulfuric acid (10%) and sodium hypochlorite (5.25%) solutions were injected into the irrigation system long enough to provide a solution of pH 2 and a chlorine concentration of 10 ppm throughout the system. Irrigation and injection were terminated and the solution was allowed to remain in the system for about 12 h before removing end caps and flushing with water.

Tensiometers were installed either midway between double rows (green bean and cowpea) or within single rows (squash, broccoli, and muskmelon) in each subplot (one set for each crop) in two replications. Tensiometer depths were 0.15 m and 0.30 m for broccoli, and 0.30 m and 0.60 m for all other crops. Tensiometer readings were recorded three times each week and the tensiometers were serviced at least once each week. Rainfall was measured on site with a tipping-bucket rain gauge. A programmable irrigation controller monitored and controlled all irrigation applications. Water volume applied to each pair of replications was also measured with indicating flow meters. Irrigation was applied when the tensiometers at the 0.3-m depth (0.15-m depth for broccoli) in the two-tube treatments reached −30 kPa. In the spring, an irrigation application equivalent to 6 mm rainfall was normally applied to all two-tube treatments; one-half of this amount was applied to one-tube treatments. In the fall, the normal irrigation application to two-tube treatments for broccoli was 3 mm. Equal water volumes were applied to high- and low-frequency treatments. Uniform applications of sprinkler irrigation were used to enhance germination and stand establishment, particularly for the spring crop in 1989.

Squash and muskmelon yields were determined for each grade by location personnel according to industry grading standards (United Fresh Fruit and Vegetable Assoc., 1971). Sieve analyses and shell-out percentages were determined from yield subsamples for green bean and cowpea, respectively. Broccoli yields were determined for market-standard stalk length and grade. All yields were analyzed using analysis of variance and least-squares difference procedures (SAS, 1989). Each crop was analyzed as an independent experiment. Differences among treatment

Table 2. Seasonal rainfall and irrigation amounts for five vegetable crops on a southeastern coastal plain soil during 1988-1989

Year/ Source	Crop (depth, mm)				
	Cowpea	G. Bean	Muskmelon	Squash	Broccoli
1988					
Rainfall					
irrigation	304 (26)*	150 (16)	278 (24)	262 (19)	179 (17)
2 tube	267 (43)	124 (20)	267 (43)	241 (39)	50 (15)
1 tube	133 (43)	62 (20)	133 (43)	121 (39)	25 (15)
Pan Evap.†	540	380	420	510	260
1989					
Rainfall					
irrigation	390 (34)	332 (30)	381 (34)	220 (26)	100 (15)
2 tube	149 (24)	136 (22)	224 (36)	217 (34)	133 (20)
1 tube	82 (24)	76 (22)	122 (36)	119 (34)	69 (20)
Pan Evap.	380	360	500	430	190

* Numbers in parentheses refer to the number of rainfall or irrigation events during the season.
† NWS Class A pan evaporation for the respective growing seasons of each crop.

means at the $P \leq 0.05$ level are reported only if the F-test in ANOVA procedure (SAS, 1989) indicated significant treatment differences.

Results and Discussion

Seasonal rainfall and irrigation amounts were tabulated for all treatments, crops, and years using the daily rainfall and irrigation amounts between planting and final harvest dates for each crop (table 2); consequently, each value is specific to that crop and year. Similarly, growing season pan evaporation amounts are provided for each crop and year for comparison with irrigation amounts and to provide an indication of evapotranspiration demand for these crops each year. Growing season rainfall was lower in 1988 than in 1989 for all crops except squash and broccoli. This inconsistency among crops within the same year was caused by variance in growing season duration and timing among crops. There was significant variation in rainfall amount among cropping seasons within each year. Similarly, irrigation amounts varied considerably among crops and between years. Seasonal irrigation amounts were higher for most crops in 1988 when most rainfall amounts were lower. Irrigation amounts for the one-tube treatments were about one-half those for the two-tube treatments because all systems were operated for equal time periods. Minor exceptions occurred in 1989 when uniform sprinkler irrigation was used on all treatments to enhance germination and to establish transplants.

Soil matric potential measurements during the spring growing season for squash and green bean in the subsurface 2 and surface 2 systems during 1988 are shown in figure 3. Soil matric potential values were generally greater than −30 kPa for squash on both irrigation systems. Similar values were also measured for muskmelons (data not presented). Soil matric potential values for green bean were also generally greater than −30 kPa for most of the 1988 season, except for the surface 2 system, where values were as low as −55 kPa during the first half of the season. Matric potential values for cowpea (data not presented) were similar to those for green bean. The soil profile for squash was slightly drier in 1989 than in 1988, possibly because of the slightly lower seasonal rainfall (fig. 4). Matric potential values were generally greater than

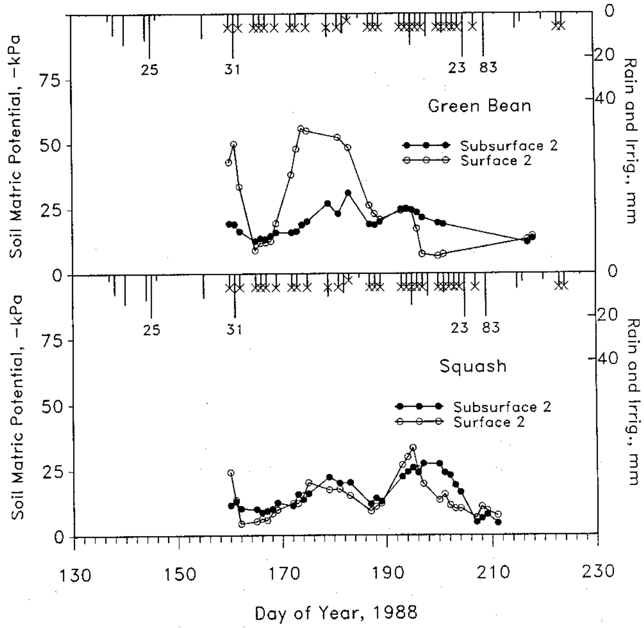

Figure 3–Soil matric potential at the 30-cm depth during the growing season in 1988 for squash and green bean on subsurface 2 and surface 2 microirrigation treatments. Daily rainfall and irrigation amounts are indicated at the top of each graph with solid lines (stars indicate irrigation and numbers indicate values for out-of-range rainfall events).

−40 kPa for both irrigation systems. The soil profile for green bean was slightly wetter (> −20 kPa) in 1989 than in 1988, because of the much higher rainfall during the growing season. Matric potential values for muskmelon and cowpea were similar to those measured for squash and

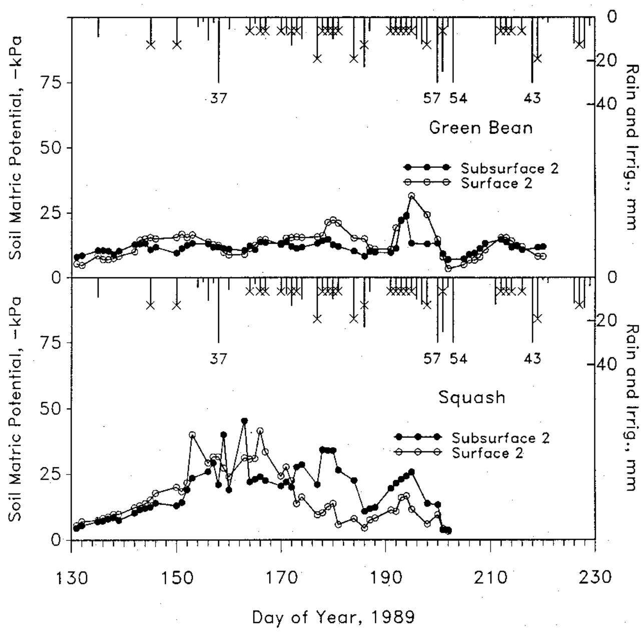

Figure 4–Soil matric potential at the 30-cm depth during the growing season in 1989 for squash and green bean on subsurface 2 and surface 2 microirrigation treatments. Daily rainfall and irrigation amounts are indicated at the top of each graph with solid lines (stars indicate irrigation and numbers indicate values for out-of-range rainfall events).

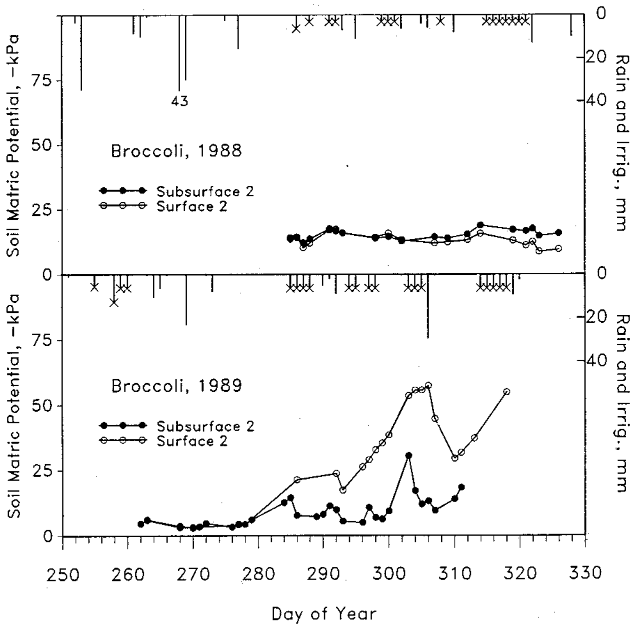

Figure 5–Soil matric potential at the 30-cm depth during the growing seasons in 1988 and 1989 for broccoli on subsurface 2 and surface 2 microirrigation treatments. Daily rainfall and irrigation amounts are indicated at the top of each graph with solid lines (stars indicate irrigation and numbers indicate values for out-of-range rainfall events).

Table 3. Yields for five vegetable crops, three microirrigation treatments and two irrigation application frequencies during 1988-1989

Crop/ Irrigation Treatment	1988 High*	1988 Low	1989 High	1989 Low
	Yield, Mg / ha			
Cowpea				
Subsurface 2	4.4 a†	5.7 a	6.8 ab	6.9 ab
Surface 2	4.0 a	4.6 a	6.4 b	5.4 c
Surface 1	4.7 a	4.8 a	7.5 a	6.2 bc
Green Bean				
Subsurface 2	6.5 a	7.1 a	4.5 b	6.7 ab
Surface 2	8.9 a	8.4 a	8.5 a	7.7 a
Surface 1	8.9 a	6.9 a	4.4 b	4.3 b
Muskmelon				
Subsurface 2	47.3 a	48.5 a	49.2 a	56.0 a
Surface 2	46.2 a	46.0 a	49.8 a	50.4 a
Surface 1	48.4 a	48.1 a	47.7 a	60.9 a
Squash				
Subsurface 2	33.1 a	32.8 a	51.3 a	57.9 a
Surface 2	36.1 a	35.3 a	52.1 a	52.2 a
Surface 1	39.5 a	37.1 a	50.1 a	50.8 a
Broccoli				
Subsurface 2	7.1 a	7.0 a	7.0 a	8.3 a
Surface 2	8.0 a	7.6 a	8.1 a	8.4 a
Surface 1	8.1 a	6.7 a	8.5 a	9.0 a

* Irrigation application frequency.
† Numbers followed by the same letter within a crop and year are not significantly different using analysis of variance and least significant differences at $P \leq 0.05$.

green bean, respectively, in 1989 (data not presented). During the fall growing season, the soil profile was wetter (> −20 kPa) in 1988 than in 1989 (> −60 kPa), particularly for the surface 2 system late in the growing season (fig. 5). Again, much of this difference could have been caused by the much higher rainfall in 1988. Overall, with the minor exceptions noted, irrigation provided an adequate soil environment for good plant growth and yield for all systems. Busscher et al. (1993) reported green bean root growth for these systems both years.

Yield results for all five crops and both years are included in table 3. Cowpea yields were slightly higher in 1989 (5.4 to 7.5 Mg/ha) than in 1988 (4.0 to 5.7 Mg/ha). There were no significance differences among cowpea yields for irrigation treatments in 1988. In 1989, cowpea yield was significantly higher for the surface 1 treatment than for the surface 2 treatment at high irrigation frequency, and was higher for the subsurface 2 treatment than for the surface 2 treatment at low irrigation frequency. There were no differences in green bean yields in 1988 (6.5 to 8.9 Mg/ha) among irrigation treatments. In 1989, green bean yield for the surface 2 treatment (8.5 Mg/ha) was significantly higher than for other treatments (4.4 to 4.5 Mg/ha) with high irrigation frequency, but was higher than only the surface 1 treatment at low frequency. There appears to be no consistent yield difference between the high and low irrigation frequencies for cowpea and green bean.

There were no significant differences in muskmelon yield either year. There was a nonsignificant trend toward higher yield for the low-frequency application in 1989, particularly for the subsurface 2 and surface 1 irrigation treatments. Although there were twice as many harvests in 1989, yields were only slightly higher. Similarly, there were no significant differences in squash yields (grades 1 and 2 combined) for the various irrigation treatments either year, and all yields were very high (32.8 to 57.9 Mg/ha). Yields in 1989 were almost double those in 1988, primarily because of an extended harvest period (50% more harvests) which is attributed to a lower incidence of disease. There were no significant yield differences between high and low irrigation frequencies for muskmelon and squash.

Broccoli yields were similar in both years and there were no yield differences among treatments either year. The major problem encountered with producing broccoli in the fall was plant establishment during hot, dry weather normally experienced during August in the southeastern coastal plain. Availability of quality transplants was also a problem, even when we attempted to produce transplants in the greenhouse. Sprinkler irrigation was used, particularly in 1989, to establish transplants. Microirrigation, especially with tubing as used in this experiment, may not wet an area large enough to support small root systems during critical periods, such as immediately following transplanting.

All yields during this study compare favorably with those produced by industry. Cowpea, green bean, muskmelon, and squash yields were all greater than average industry yields (4 Mg/ha, 4 Mg/ha, 15 Mg/ha, and 28 Mg/ha, respectively) for both years. Muskmelon yields for both years and squash yields for 1989 were much greater than industry yields. Broccoli yields (6.7 to 9.0 Mg/ha) were slightly less than those expected by industry (9 Mg/ha) for both years (Lorenz and Maynard, 1980).

Generally, there was little difference in crop yield among the various irrigation treatments, even though the surface 1 treatment received about one half as much irrigation water as the two-tube treatments. Part of the reason for this response is placement of the irrigation source in the middle of the bed where it is nearer the single rows (squash, muskmelons, and broccoli) and midway between the double rows (cowpea and green bean), which usually resulted in less runoff. Water was observed running from under the plastic mulch into furrows in several instances, even with the subsurface 2 treatment. This was probably caused by local variations in soil surface slope and infiltration, and by preferential flow of irrigation water through the soil profile. In the subsurface 2 treatment, water often moved to the soil surface or to the edge of the bed very soon after irrigation commenced. The final result may have been more efficient use of irrigation water and fertilizer in the single-tube treatment, primarily because of better placement. Field observations of better plant growth on the one-tube treatment, particularly for squash and muskmelon, during various growth periods support this hypothesis. Consequently, the one-tube treatment should conserve water and provide the most profitable system for vegetable production for soils and climate of this region.

SUMMARY AND CONCLUSIONS

Acceptable to very high yields were obtained for all crops and for all irrigation treatments, demonstrating the feasibility of this type of production system for the southeastern coastal Pplain. There were few significant differences in crop yields among the irrigation treatments, but the one-tube treatment applied about half as much irrigation water as the two-tube treatments. The one-tube treatment could conserve water and reduce initial capital expense because of the reduced application volume and the lesser amount of tubing required; consequently, it should be more profitable and appears to be the system of choice for this application. The primary reason for more efficient performance of the one-tube system is probably the better placement of the tubing and irrigation water with respect to the plant. There were no consistent differences between the high- and low-frequency irrigation application rates. The subsurface microirrigation system performed well although it had been used for a total of five years at the end of this experiment. Limited evaluation of the system indicates minimal problems with emitter plugging. Extensive evaluation of emitter plugging will be conducted later, but will probably require destructive methods, which will be delayed until subsequent experiments are terminated. Multiple cropping of vegetables, such as broccoli following one of the spring crops, was successfully demonstrated, using the same irrigation system for both crops and for both years of this experiment. Since these irrigation systems had been used in a previous experiment for three years, a total useful life of at least five years has been demonstrated.

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