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MICROIRRIGATION SYSTEMS FOR DEFICIT IRRIGATION IN HUMID AREAS

SYSTEMES DE MICROIRRIGATION POUR L'IRRIGATION DEFICITAIRE DANS LES REGIONS HUMIDES

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ABSTRACT

Rainfall is often sufficient to satisfy evapotranspiration in humid areas but the combination of short droughts and low water storage often results in yield-reducing water stress. Irrigation could alleviate this problem, but its profitability and acceptance has been extremely variable. Obstacles include higher labor requirements, infrequent need during some years, and the need for more skilled management. Microirrigation offers an attractive system for humid areas because of its low operational cost, precise water and chemical application, and low labor requirement. Feasibility of this system was demonstrated using two 3-year experiments, one with maize (*Zea mays*) and one with cotton (*Gossypium hirsutum* L.), which were conducted on coarse-textured Coastal Plain soils in the southeastern USA. Both experiments included two tube placements on the soil surface: one adjacent to every row and the other in alternate furrows. Growing season rainfall amounts ranged from 161 mm to 544 mm during the 6-year period (1985-1990) and seasonal irrigation amounts varied with rainfall amounts.

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Maize grain yield for the alternate-furrow tube placement was not significantly lower than the every-row tube placement except in 1986 when a severe drought occurred. There was no significant difference in cotton lint yield between tube placements during any of the three years. With the similar yields at about 30% reduced cost, the alternate-furrow microirrigation system appears to offer a viable alternative irrigation system for agronomic crops in many humid areas. Economics of this system would improve further if the tubes were buried below the tillage zone where they would not need to be removed annually.

RESUME ET CONCLUSIONS

La pluie est souvent suffisante à satisfaire l'évapotranspiration dans les régions humides mais la combinaison de courtes sécheresses et d'emmagasinage insuffisant de l'eau mène souvent à la contrainte de l'eau qui réduit les récoltes. Ce problème peut être soulagé par l'irrigation, mais sa rentabilité et son acceptation ont été extrêmement variables. Les obstacles comprennent les exigences plus grandes de travail, le manque de besoin pendant certaines années, et un besoin pour une direction plus qualifiée. La microirrigation (l'irrigation goutte à goutte) offre une solution intéressante pour les régions humides à cause du bas coût d'exploitation, d'application précise de l'eau et des produits chimiques, et d'une exigence de travail moins grande. Les projets pour des systèmes qui réduisent la quantité de tube exigée ou qui permettent l'usage des pièces d'un système pour des saisons multiples peuvent réduire le coût du système et rendent cette méthode plus rentable. Le potentiel pour succès de ce système a été démontré en utilisant les résultats de deux expériences de 3 ans, l'un avec le maïs (*Zea mays*) et l'autre avec le coton (*Gossypium hirsutum* L.). Ces expériences ont été conduites sur les terres sablonneuses de la Plaine de la Côte au sud-est des USA. Les deux expériences ont compris deux placements de tube d'irrigation sur la surface : l'un adjacent à chaque ligne de la plante cultivée (ER) et l'autre dans les sillons alternatifs (AF). Les quantités de la pluie pendant la période de végétation ont varié de 161 mm à 544 mm pendant la période de 1985 à 1990, et les quantités d'irrigation ont varié avec les quantités de la chute. Pendant les six ans de ces deux expériences, une réduction importante dans la récolte pour le placement AF n'a eu lieu qu'une année (la sécheresse la plus sévère sur le registre). De plus, la réduction de la récolte pour cette année était seulement à peu près de 10%, ce qui peut être un risque acceptable quand on considère la grandeur de la perte de la récolte et la probabilité d'un tel événement. Le coût initial d'un système d'irrigation utilisant le placement AF est à peu près de 30% plus bas qu'un système utilisant des tubes adjacents à chaque ligne. Ces résultats indiquent que les projets des systèmes d'irrigation moins que maximaux peuvent produire des récoltes acceptables dans les régions où la chute pendant la période de végétation est généralement suffisante, mais que sa distribution produit des périodes de sécheresse importantes pendant de nombreuses années. A cause de la différence dans les besoins en eau pour le maïs et le coton, le risque serait plus grand pour le maïs que pour le coton, particulièrement quand on considère les périodes de croissance critiques et la capacité de la plante cultivée pour se rétablir de la contrainte de sécheresse pendant ces périodes.

Grâce aux pressions d'application moins sévères et grâce aussi à un besoin d'énergie moins grand, la réduction du coût avec ces systèmes et le coût plus bas éventuel de leur application, rendent la microirrigation avec AF un choix acceptable pour les cultures dans beaucoup de régions humides. L'installation des tubes de microirrigation dans les terres au-dessous de la zone de travail du sol, réduit le coût d'installation et d'enlèvement des tubes chaque année mais augmente le potentiel pour l'émetteur, le colmatage par les racines de la plante et par les agents biologiques. Cependant, d'autres données (non rapportées ici) suggèrent que les tubes souterraines marcheront satisfaisamment pour des périodes de 8-10 ans. Donc, on économise en matériaux et en frais d'application. Finalement, l'occasion pour l'application fréquente et précise d'éléments nutritifs à une frequence basse quand on utilise la microirrigation, devrait mener à l'usage plus efficace de fertilisant et à une réduction de lessivage à l'eau souterraine.

INTRODUCTION

In humid areas, such as the Coastal Plain in the southeastern USA, seasonal rainfall is often sufficient to satisfy evapotranspiration (ET) requirements. However, the combination of short drought periods (5-20 days) and low water storage capacity (about 5-10 days storage) of the coarse-textured soils often results in periods of yield-reducing plant water stress. Shallow crop rooting, often caused by compacted soil layers, further aggravates the problem. Periods of 5-20 days without rainfall occur during most growing seasons. The consequences of these drought periods are dependent upon the timing, crop, soil, and antecedent soil water conditions. Irrigation can alleviate these problems, but profitability of the practice is extremely variable. Because irrigation is not required on a regular basis, managers often do not have sufficient labor available to manage irrigation along with other farm operations. Consequently, prerequisites for irrigation systems in humid areas include low labor requirements (preferably automatic control), easy annual start-up/convenience, multiple-year life, and capacity to sustain crops during extreme drought periods. To improve profitability, crop management practices must be improved, the irrigation system must have low annualized and low operational costs, and the farm manager must have a clear management strategy, i.e., risk reduction, optimal yield, or marginal yield.

Although sprinkler irrigation is most often used for agronomic crops, microirrigation offers several advantageous capabilities, including low application rates, precise water placement, and low pressure requirements. The major disadvantage of microirrigation when used in the conventional manner is high cost, which is partially caused by annual replacement of many system components. System designs that reduce the amount of tubing and/or allow use of components for multiple seasons would reduce the system cost. On a coarse-textured soil in Arizona, cotton yields were similar 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). Microirrigation tubing has been installed 0.2 - 0.3 m deep to allow shallow tillage and cultivation for cotton (Tollefson, 1985), potato (Sammis, 1980), and fruits and vegetables (Bucks et al., 1981; Phene et al., 1987; Camp et al., 1989a).

A suggested microirrigation system for humid areas includes wider tube spacing (about 2 m), capacity to sustain a crop during short- to mid-term drought periods with possible yield reduction during severe drought, multiple-year life, and subsurface installation (below tillage zone) to reduce labor and material costs. To demonstrate the feasibility of this irrigation system design, results from two separate experiments are reported, one for maize (1985-87) and one for cotton (1988-90), which used various microirrigation tubing locations on the soil surface.

MATERIALS AND METHODS

The experiments were conducted on two sites, both Norfolk loamy sand (Typic Paleudults) near Florence, South Carolina (34°14'N, 79°49'W, 40 m elevation) for two separate three-year periods. Plant-available water for this soil is about 10% by volume, but over half is depleted at a soil water potential of -80 kPa (Campbell et al., 1988). The soils at both sites have a compacted E horizon at a depth of about 0.3 m, but this horizon is less clearly defined at the maize site, probably because of past deep tillage.

In the maize experiment, there were two tube locations, (1) on the surface between every pair of rows (ER) and (2) on the surface between alternate pairs of rows (alternate furrow or AF) (Figure 1). A parallel treatment to the ER treatment included tubing installed about 0.30 m below each row, but results for this treatment are not reported here. The microirrigation tubing (Lake Drip-In[2]) had in-line, labyrinth-type emitters spaced 0.6 m apart, each delivering 2.0 L/h. The microirrigation tubing was recovered each year before harvesting maize and used the following year. Irrigation was suspended any day that soil water potential (SWP) was greater than -10 kPa at a depth of 0.30 m or if rainfall greater than 8 mm occurred. Irrigation (6 mm) was applied daily when SWP was between -10 and -25 kPa. When SWP was less than -25 kPa, 12 mm of irrigation was applied. Pesticides and fertilizer were applied in accordance with extension service and soil test recommendations. Preplant fertilizer was broadcast and

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incorporated. Sidedress nitrogen solution was applied through the irrigation system, beginning about 4-6 weeks after planting and continuing at 2-week intervals. The water supply was either a well or a chlorinated municipal system, depending upon availability and demand. Maize was planted during late March or early April each year and was harvested during August. Additional details regarding this experiment were reported by Camp et al. (1989b).

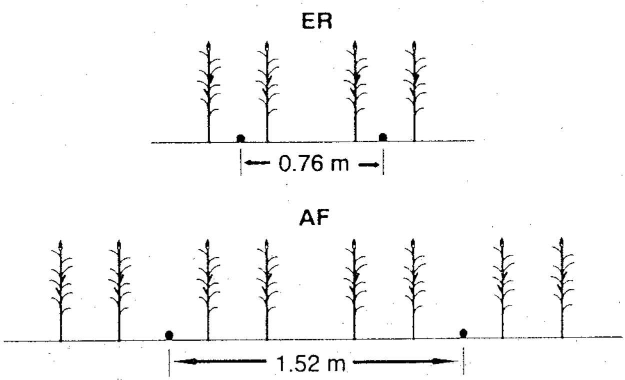

Figure 1. Schematic diagrams of two microirrigation tube placements in maize (Schémas d'installation des tuyaux de micro irrigation pour le maïs)

In the cotton experiment, there were two microirrigation tube placements and one treatment that received only rainfall (RAIN). Microirrigation tubing was placed on the soil surface, either immediately adjacent to every row (ER) or in alternate furrows (AF) (Figure 2). The microirrigation tubing (Netafim Inline Dripperline) had in-line, labyrinth emitters spaced 0.6 m apart, each delivering 1.9 L/h. The tubing was recovered each year before harvesting cotton and used

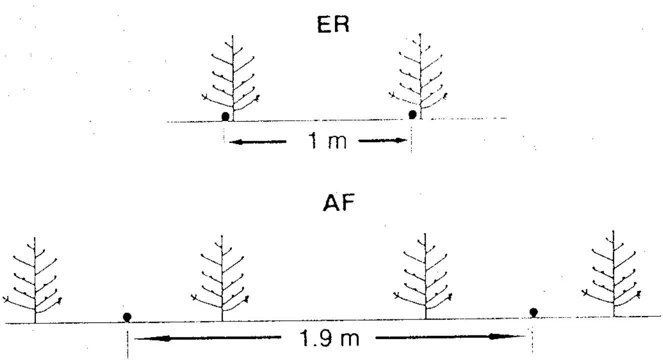

Figure 2. Schematic diagrams of two microirrigation tube placements in cotton (Schémas d'installation des tuyaux de micro irrigation pour le coton)

the following year. Water was supplied from a well, stored in a pressurized tank, and filtered using a 100-mesh cartridge filter. Irrigation timing and amount was determined by GOSSYM/COMAX, a cotton growth model (Baker et al., 1983; Lemmon, 1980). Pesticides and fertilizer nutrients were applied in accordance with extension service and soil test recommendations. Cotton was planted before May 15 each year and harvested in October. Additional details regarding this experiment were reported by Camp et al. (1990).

Tensiometers were installed at various depths and locations relative to the row each year. Tensiometer readings were generally recorded three times each week and were serviced as required. Rainfall was measured on site using either a tipping-bucket or weighing-type recording rain gauge. Yield data were analyzed using analysis of variance (ANOVA) and means were separated by computing a least significant difference (LSD) and contrasts (SAS, 1990).

RESULTS AND DISCUSSION

Maize experiment

Total rainfall and irrigation amounts between planting and crop maturity for 1985-1987 are included in Table 1. Daily rainfall and irrigation amounts during the growing season for these years are included in Figure 3. Rainfall was much higher in 1985 (274 mm) than in 1986 (161 mm), when one of worst droughts of this century occurred during the growing season. Seasonal irrigation amounts were much higher in 1986 because of the drought, which was particularly severe early in the growing season. Rainfall in 1987 (202 mm) was intermediate between the other two years as were the irrigation amounts. There were differences in the amount of irrigation required by the two tube placements but neither consistently required the greater amount of irrigation. In 1986, the

Table 1. Seasonal rainfall and irrigation amounts for three water management treatments with maize in a southeastern USA Coastal Plain soil (Précipitations saisonnières et apports d'eau pour trois traitements en gestion d'eau pour le maïs dans la plaine côtière au Sud-Est des Etats-Unis).

Microirrigation treatment	Seasonal rainfall or irrigation (mm)						
	1985		1986		1987		Mean
AF*	331	(40)#	387	(56)	373	(56)	364
ER	331	(40)	425	(56)	348	(52)	368
Rainfall	274	(35)	161	(27)	202	(26)	212

* Treatment codes are defined as follows : ER = every-row tube placement and AF = alternate furrow tube placement.

\# Number of rainfall or irrigation events during the season.

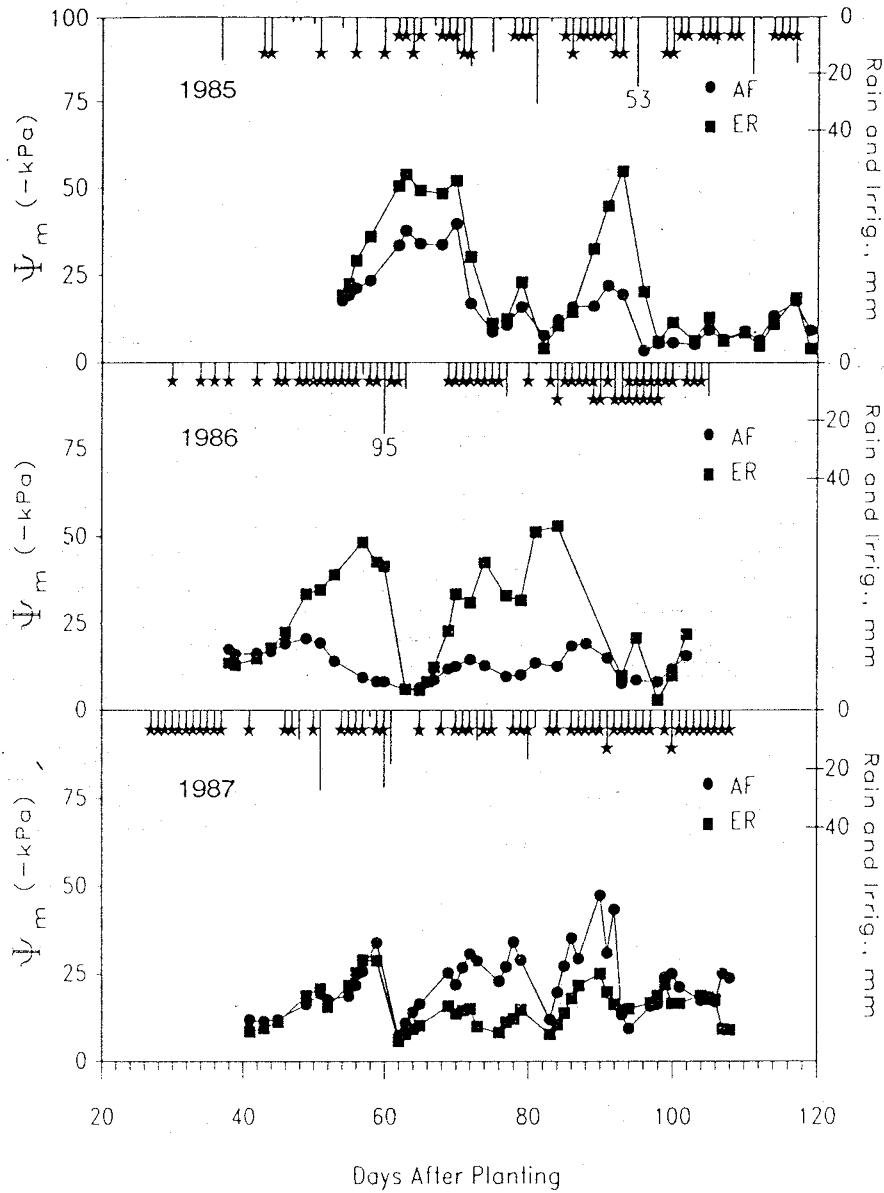

Figure 3. Mean soil water potential at the 0.30-m depth for locations farthest from microirrigation tubing in a maize experiment during 1985-87. ER = every-row treatment and AF = alternate-furrow treatment, and stars indicate daily irrigation events (Potentiel hydrique moyen à la hauteur de 0,30 m pour les lieux qui sont très loin des installations du système de micro irrigation, dans une expérimentation (1985-87) impliquant le maïs)

ER treatment required 38 mm more irrigation than the AF treatment, but in 1987 the AF treatment required 25 mm more.

Tensiometer data indicate that SWP was generally maintained within the desired range (Figure 3). The ER treatment was the driest treatment for the first two years and the AF treatment was slightly drier in the last year. Analyses of these data showed consistent differences in wetting patterns between the two tube placements (Camp et al., 1987).

To be feasible for agronomic crops, microirrigation laterals must be durable enough to function after either repeated installation and removal operations, with associated damage by equipment and insects, or long-term burial, which normally accelerates emitter plugging. Subsequent to the maize experiment, the irrigation system was used for two years (1988-89) in a vegetable experiment (Camp et al., 1989a) and for another three years (1990-92) in another maize experiment. Although slight damage to laterals was caused by tillage equipment and soil samplers, no serious problems were observed. A few cases of minor rodent and insect damage were observed. There has been no evidence of serious emitter plugging or any degradation in water delivery rate. However, preventive treatments using chlorine and acid have been implemented periodically.

Maize grain yields for all three years are included in Table 2. In 1985, all yields were high and there were no significant differences in yields among the treatments. In 1986, grain yields were significantly lower for the AF treatment, which 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, maize on the row farthest from the irrigation lateral was shorter and had a lighter green color. This condition might be attributed to small root systems located farther away from irrigation emitters during extremely dry soil conditions that caused low water availability in the root zone. Plant biomass data confirmed the difference in plant size, but nutrient concentrations in whole

Table 2. Maize grain yields for two microirrigation tube placements in a southeastern USA Coastal Plain soil (Rendement de grain de maïs pour deux installations de tuyaux de micro irrigation dans la plaine côtière au Sud-Est des Etats-Unis)

Microirrigation treatment	Maize grain yield (Mg/ha)			
	1985	1986	1987	Mean
AF*	13.1 a#	9.8 b	11.4 a	11.4
ER	12.9 a	11.4 a	12.4 a	12.2

* Treatment codes are the same as defined in Table 1.

\# Means within a column followed by the same letter are not significantly different by LSD at $P \leq .05$.

plant samples were sufficient (within established sufficiency range) for the seven nutrients analyzed. This suggests that small plant size and lighter green color were caused by low water availability in the root zone, and that low water uptake limited plant growth. This period of early stress probably caused the reduced grain yield measured for the AF treatment in 1986. There was no significant difference in grain yield for tube placements in 1987.

In the parallel treatment to the ER treatment, where the tube was installed about 0.30 m below each row, maize yields were not significantly different from those for the ER treatment any of the three years of the experiment (Camp et al., 1989b). This demonstrates the feasibility of subsurface installation of microirrigation tubing for acceptable maize growth and yield.

Cotton experiment

Seasonal rainfall and irrigation amounts for both irrigation treatments and the RAIN treatment during 1988-1990 are included in Table 3. Daily rainfall and irrigation amounts during the growing season in these years are shown in Figure 4. Growing-season rainfall ranged from 544 mm in 1988 to 313 mm in 1990. Although there were six more rainfall events in 1989, seasonal rainfall was 59 mm lower than in 1988. Seasonal rainfall was computed for the period from planting to two weeks prior to first harvest. In 1990, when seasonal rainfall was least, more irrigation was required for both irrigation treatments.

Tensiometer measurements indicate that there were no consistent differences in SWP for the two tube placements. Although the rainfall amount during the growing season was greatest in 1988, soil at the 0.30-m depth appeared to be somewhat drier than in other years, as shown for the two tube placements in Figure 4. There were significant fluctuations, both within years and between

Table 3. Seasonal rainfall and irrigation amounts for three water management treatments with cotton on a southeastern USA Coastal Plain soil (Précipitations saisonnières et apports d'eau pour trois traitements en gestion d'eau pour le coton, dans le plaine côtière au Sud-Est des Etats-Unis)

Water management	Seasonal rainfall or irrigation (mm)			
treatment	1988	1989	1990	Mean
AF*	90 (9)#	25 (3)	115 (11)	77
ER	95 (9)	30 (3)	129 (11)	85
Rainfall	544 (50)	485 (56)	313 (33)	447

* Treatment codes are the same as defined in Table 1.
\# Numbers in parentheses refer to the number of irrigation or rainfall events during the growing season.

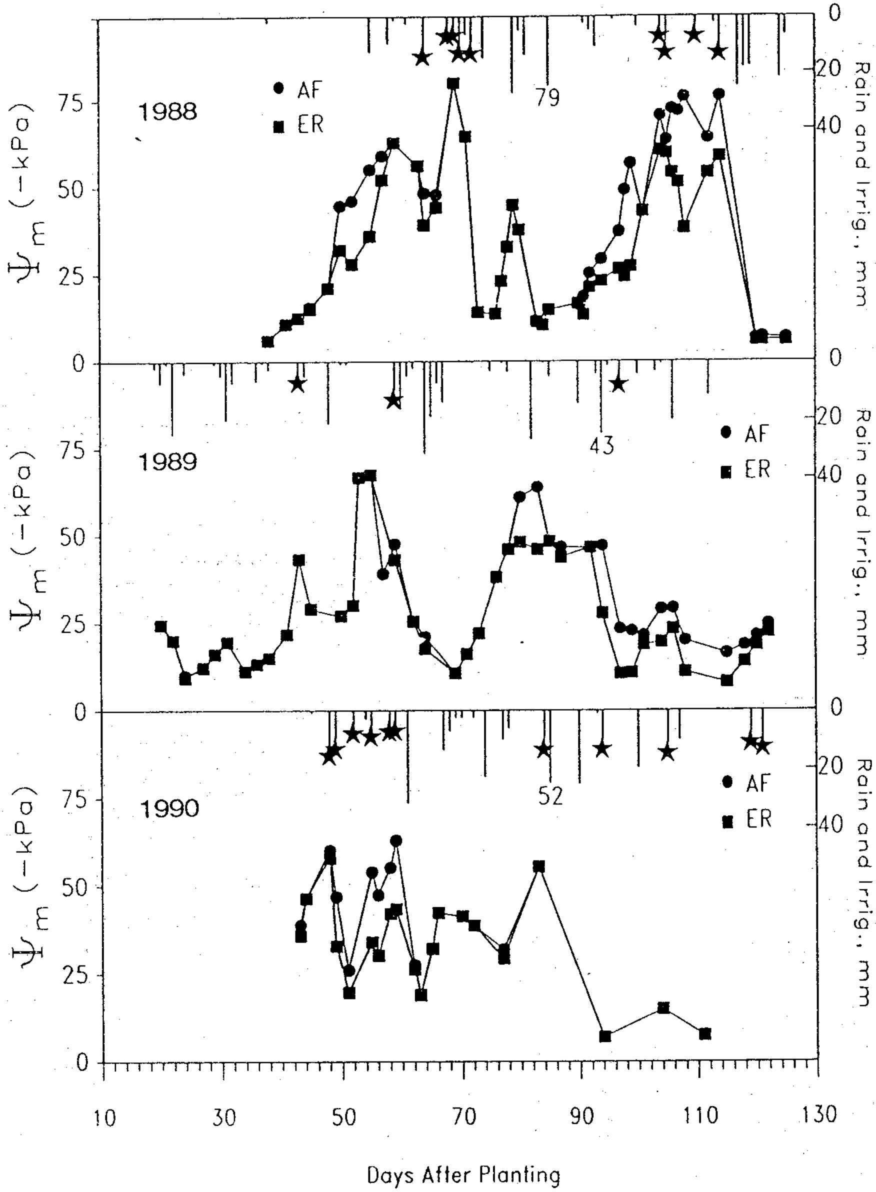

Figure 4. Mean soil water potential at the 0.30-m depth in the row for a cotton experiment during 1988-1990. ER = every-row treatment and AF = alternate-furrow treatment, and stars indicate daily irrigation events (Potentiel hydrique moyen de la hauteur de 0,30 m dans la ligne dans une expérimentation 1988-1990 qui implique le coton)

treatments, but there were no consistent patterns. The large variation in rainfall and irrigation amounts among years did not cause a major difference in SWP, indicating that both tube placements provided an adequate soil-water environment for good cotton growth and yield.

Cotton lint yields for all treatments and years are included in Table 4. All yields in 1988 were above 975 kg/ha and the ER treatment had significantly higher yields than the RAIN treatment. Statistical evaluation of yields using contrasts indicated a significant effect (P<.06) for tube placement. Cotton lint yields for all treatments in 1989 were lower than those measured in 1988. Although there were numerical differences in yields among treatments, none were statistically significant. The relationship between irrigation amount and cotton yield was less evident in 1989. Cotton yields for all treatments in 1990 were similar to those in 1989. Again, there were relatively small numerical yield differences among irrigation treatments, but none were statistically significant at $P \leq .05$. Although rainfall in 1990 was 170-230 mm less than in the two previous years and 115-192 mm of irrigation was applied, there was no significant difference in yield between the RAIN treatment and irrigation treatments. Analysis by contrasts indicated no significant difference between the two tube placements.

Table 4. Cotton lint yields for three water management treatments in a southeastern USA Costal Plain soil (Rendement en charpie de coton pour trois traitements en gestion d'eau dans une plaine côtière au Sud-Est des Etats-Unis)

Water management treatment	Cotton lint yield (kg/ha)			
	1988	1989	1990	Mean
AF*	1090 ab#	880 a	765 a	910
ER	1220 a	860 a	870 a	985
Rainfall	975 b	810 a	825 a	870

* Treatment codes are the same as defined in Table 1.
\# Means followed by the same letter within a column are not significantly different by LSD at $P \leq .05$.

Irrigation systems

The use of microirrigation systems with the alternate-furrow tube placement should result in significant reductions in initial system cost (estimated at about 30%) and reductions in operational costs when compared to higher-pressure systems such as some center-pivot sprinkler systems and travelling-gun systems popular in the southeastern USA. Also, it appears that microirrigation systems can be used for several years, either when installed on the soil surface and removed each year or when installed permanently in the soil below the tillage zone (Tollefson, 1985; Phene et al., 1987; and Camp et al., 1989a,b). The combination of reduced system cost, reduced operational cost, and increased system longevity should make microirrigation a profitable alternative to sprinkler systems in humid areas where the need for irrigation is extremely variable, both within a growing season and among years. However, the availability of an irrigation system permits the grower to manage crop production for maximum profit without concern for inadequate soil water or yield-reducing plant stress caused by short- or long-term droughts. Another capability of the microirrigation system is the application of fertilizer nutrients and some pesticides at very low rates and at high frequencies, which more closely matches the requirement, particularly for plant nutrients. For coarse-textured soils in areas where high-intensity rainfall can occur, this system provides the potential for significant improvement in nutrient and pesticide efficiency as well as a greatly decreased probability of degrading the quality of surface and ground waters.

CONCLUSIONS

Microirrigation provides the potential for improved irrigation in humid areas. The feasibility of this system was demonstrated using the results of two experiments with two agronomic crops common in humid areas. These results indicate that less-than-optimum irrigation system design can provide acceptable yields in areas where growing-season rainfall is generally adequate but its distribution produces significant drought periods many years. For the total of six years covered by these two experiments, significant yield reduction occurred in only one year for the alternate-furrow tube placement. Additionally, the yield reduction for that year was only about 10%, which may be an acceptable risk when one considers both the magnitude of yield loss and the probability of occurrence. Because of the difference in water requirements for maize and cotton, the risk would probably be greater for maize than for cotton, particularly when critical growth periods and the ability of the crop to recover from periods of drought stress during these periods are considered.

The reduced system cost and potential savings in operational costs because of lower operating pressures and lower power requirements make microirrigation with alternate-furrow tube placement a viable irrigation system choice for agronomic crops in many humid areas. Installation of microirrigation tubing in the soil below the tillage zone reduces the cost of installing and removing the tubing each year but increases the potential for emitter plugging by plant roots and biological agents. However, additional data (not reported here) indicates the potential for satisfactory performance of subsurface tube placement for periods of 8-10 years, which provides attractive savings in both material and operational costs. Microirrigation systems also offer the opportunity for low application rates and precise placement of fertilizer nutrients, which will frequently result in better fertilizer use efficiency and reduced leaching to ground water.

REFERENCES

Baker, D. N., J. R. Lambert, and J. M. McKinion. 1983. GOSSYM: A simulator of cotton crop growth and yield. Tech. Bull. 1089. S. C. Agr. Exper. Stn., Clemson Univ., Clemson, SC.

Bucks, D. A., L. J. Erie, O. F. French, F. S. Nakayama, and W. D. Pew. 1981. Subsurface micro irrigation management with multiple cropping. Transactions of the ASAE 24(6):1482-1489.

Camp, C. R., W. J. Busscher, and E. J. Sadler. 1987. Wetting patterns for line-source trickle emitters. ASAE Paper No. 87-2524, Am. Soc. Agr. Engr., St. Joseph, MI.

Camp, C. R., J. T. Garrett, W. J. Busscher, and E. J. Sadler. 1989a. Micro-irrigation management for vegetables in a humid area. ASAE Paper No. 89-2589, Am. Soc. Agr. Engr., St. Joseph, MI.

Camp, C. R., E. J. Sadler, and W. J. Busscher. 1989b. Subsurface and alternate-middle micro irrigation for the southeastern Coastal Plain. Transactions of the ASAE 32(2):451-456.

Camp, C. R., W. M. Thomas, and C. C. Green. 1990. Scheduling irrigation for cotton. Proc. Third Nat'l. Irrig. Symp., ASAE Pub. No. 04-90, Phoenix, AZ, Oct. 28-Nov. 1, pp. 275-280.

Campbell, R. B., W. J. Busscher, O. W. Beale, and R. E. Sojka. 1988. Soil profile modification and cotton production. Proc. Beltwide Cotton Production Research Conference, New Orleans, LA, pp. 505-509.

French, O. F., D. A. Bucks, R. L. Roth, and B. R. Gardner. 1985. Micro and level-basin irrigation management for cotton production. Drip/Micro Irrigation in Action, Proc. Third International Drip/Micro Irrigation Congress 2:555-561. ASAE, Nov. 1985, Fresno, CA.

Lemmon, H. 1986. COMAX: An expert system for cotton crop management. Science 233:29-33.

Phene, C. J., K. R. Davis, R. B. Hutmacher, and R. L. McCormick. 1987. Advantages of subsurface irrigation for processing tomatoes. Acta Horticulturae 200:101-114.

Sammis, T. W. 1980. Comparison of sprinkler, micro, subsurface, and furrow irrigation methods for row crops. Agron. J. 72:701-704.

SAS Institute Inc. 1990. SAS/STAT Users Guide, Version 6. SAS Institute Inc., Cary, NC.

Tollefson, S. 1985. The Arizona System: Drip irrigation design for cotton. Drip/Micro Irrigation in Action. Proc. Third International Drip/Micro Irrigation Congress 1:401-405. ASAE, Nov. 1985, Fresno, CA.