Sequential Cropping for Vegetable Production using Microirrigation on Sandy Soils in Southwestern Florida

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Summary. Combinations of various vegetable crop species grown in multiple-cropping sequences using microirrigation on a sandy soil were evaluated for production potential and changes in normal cultural management. An initial fall-season fresh-market tomato crop was followed immediately by a winter-season crucifer crop (cauliflower, broccoli, or cabbage), which was followed by a spring-season cucurbit crop (cucumber, zucchini squash, or muskmelon). Studies were conducted over a 3-year period in southwestern Florida. Results showed that when cropping sequences were compared on a basis of a derived relative value index (RVI), the sequence of tomato-cauliflower-zucchini squash significantly outperformed other sequences. Several management concerns particular to the production system (crop residue removal and interference, plastic mulch deterioration and damage, and weed control) were identified and discussed. The potential savings when cropping sequences are compared to individual crop production resulted in net savings (dollar savings less additional production costs) that ranged from \$565 to \$1212/acre (\$1396 to \$2993/ha) and \$614 to \$1316/acre (\$1516 to \$3251/ha) for the 1986-87 and 1988-89 seasons, respectively.

The adoption of microirrigation for vegetable production in southern Florida has not been widespread for a number of reasons. This region receives an average annual rainfall of 53 inches (1350mm), which is concentrated during the months of June through September, when limited vegetable production occurs. With this amount of precipitation, it may be assumed that irrigation is not necessary, but such is not the case for two important reasons. First, much of the vegetable production occurs on soils that consist of >90% sand and have very low water-holding capacities. Second, Florida's favorable climate permits market advantages of high-value crop production during the late-fall to late-spring season. These crops require irrigation to ensure maximum production levels and to protect high investments of up to several thousands of dollars per acre per production season.

Seepage subirrigation, the predominant irrigation method, uses water table control to provide water continuously to the crop. This system developed because of favorable soil conditions, a readily available and abundant water supply, and its low investment and operating costs. In recent years, as competition for the use of water resources has increased, the system has been criticized increasingly for its low application efficiency (30% to 40%).

Microirrigation has been available for many years, but grower acceptance has not been widespread. Some previous work has been conducted in Florida on double-cropping of vegetables for a seepage-irrigated crop (Everett, 1978; Kalmbacher et al., 1982), primarily targeted at use of residual fertilizer remaining after the removal of an initial crop. Clough et al. (1990) demonstrated advantages of multiple-cropping vegetables with microirrigation compared to overhead irrigation.

Competition among municipal, industrial, and agricultural interests for the use of water continues to escalate in Florida. Fear of severe restrictions on future allocations of water for agricultural production has caused increased interest in using systems that provide for water conservation without affecting yield potential adversely. Improved management of existing systems to increase application efficiencies has occurred, as well as an increased interest in the use of alterna-

tive irrigation systems such as microirrigation, which have application efficiencies of 85% to 95%. When compared with seepage irrigation, microirrigation requires a totally different approach toward irrigation management, causing reluctance on the part of producers to make a change. In addition, as with most business enterprises, the economic implications of a change in any system must be positive for the change to occur voluntarily. In most cases, it has not been demonstrated that the use of microirrigation increases production over the use of the conventional seepage subirrigation system (Csizinszky and Stanley, 1984; Csizinszky et al., 1986). Thus, the additional costs of materials and management may not be overcome by increased production. However, as mentioned earlier, the concern over possible future water use restrictions, as well as a genuine desire on the part of most growers to conserve and protect water resources vital to their livelihood, has resulted in a greater number of producers seriously considering use of microirrigation.

The economic feasibility of using microirrigation could be improved if one or both of the following occur: 1) increase the production potential such that it outweighs the increased costs of owning and operating the system, or 2) spread the cost of owning and operating the system over multiple crops, thus decreasing the cost on a per-crop basis. However, increasing the production potential by using microirrigation has not been demonstrated. There may be some improvement of production potential through the use of fertigation by providing nutrients to a crop according to its needs at particular growth stages, and possibly lengthening the production season if the market conditions remain favorable. The focus of this paper considers southwestern Florida's favorable climate, which allows multiple-cropping on the same beds, thus spreading the costs of microirrigation over more than one crop. It was under these assumptions that this appeared to be a highly viable approach, and that the following study was planned and conducted.

The specific objectives of this study were to: 1) evaluate the potential of extended use of microirrigation installations through use of continuous cropping systems (double- or triple-cropping schemes) by determining

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those cropping schemes that offered the highest potential for success; and 2) identify any changes in standard cultural management practices that result from the use of this cropping system.

This study was conducted at the Gulf Coast Research and Education Center (GCREC), IFAS, Univ. of Florida, Bradenton, during a 3-year period from Aug. 1986 through May 1989. However, production data are presented only for the 1986-87 and 1988-89 seasons. During the 1987-88 season, no data were collected due to equipment failures. The study was designed to investigate cropping sequences initiated in the fall and followed immediately by a winter crop, which in turn was followed by a spring crop. The specific crops included fresh-market tomatoes as the initial the fall crop, followed by a winter crucifer crop (cauliflower, broccoli, or cabbage), by a spring cucurbit crop (cucumber, zucchini squash, or muskmelon). The experimental design was a split-split plot with four replications, which enabled evaluation of both double- and triple-cropping situations, and enabled analysis of the effect that the previous crop had on the following crop for all sequences.

The influence that the type of microirrigation tubing had on crop production also was investigated by using two types of tubing. They were: 1) an in-line emitter tubing (Netafim Typhoon, Netafim Irrigation Inc., 10 E. Merrick Rd., Valley Stream, NY 11580), designed for multiple seasons of use with a 20-inch (50-cm) emitter spacing; and 2) a thinner dual-chambered tubing (Chapin Twin-Wall, Chapin Watermatics, 740 Watertown, NY 13601) with a 12-inch (30-cm) emitter spacing primarily designed for single-season usage. Evaluation of performance included clogging potential and endurance of materials over the extended period of time.

The soil was an Eau Gallie fine sand (sandy, siliceous, hyperthermic Alfic Haplaquod). Because this soil has a very low water-holding capacity and because microirrigation has limited ability to prepare the field adequately for bedding (Stanley and Clark, 1988), seepage subirrigation was used when necessary to prepare the land for bedding, and for initial transplant establishment, when required. Irrigation rates were determined using a Class A

evaporation pan for potential evapotranspiration estimates, and tensiometers were installed in the plots to monitor soil moisture status. Irrigation amounts were recorded to determine water use at specific periods of the growing season. Three weeks of seepage irrigation was needed to initiate the crops in Fall 1986, while none was needed for the 1988 fall season because of abundant rainfall.

Crops were grown on raised beds that were fumigated with methyl bromide at 132 lb/acre (148 kg-ha⁻¹) for initial disease, weed, insect, and nematode control and covered with 1.25mil white plastic mulch. No additional soil fumigants were applied for the second and third crops. Beds were spaced 54 inches (137 cm) apart center-to-center. In the 1986-87 season, N and K fertilizers were applied 50% in dry form and 50% injected through the tubing for the initial tomato crop. Phosphorus fertilization was applied 100% preplant in dry form. The seasonal fertilizer rate was 4, 2, and 8 lb (1.8, 0.9, and 3.6 kg) of N, P₂O₅, and K₂O, respectively, per 100 ft (30.5 m) of row length. Subsequent crucifer and cucurbit crops received N and K fertilization 100% in liquid form injected through the tubing.

Periodic sampling for nutrient content in plant tissue and the soil was carried out throughout the cropping sequences to monitor nutrient status to

prevent deficiencies from developing. Crop yields were determined for quality and quantity for each crop within each sequence. To compare crop sequences quantitatively for degree of success, a relative value index (RVI) was developed based on an average per-unit value (derived from historical economic information) and individual crop yields for each individual crop sequence. This was not an attempt to describe the relative profitability of each sequence, but simply to provide a means a comparison among cropping sequences.

Crops with similar growth intervals to fruit harvest were chosen for this study to afford similar amounts of water to be applied for each individual crop within each growing season. Only cabbage grown as a second crop in the sequence (1986-87 season) required a 3- to 4-week-longer growing period. This longer period for cabbage caused a delay in the transplanting of the third crop that followed it. This delay prompted the substitution of a shorter-season cabbage variety in the 1988-89 season, which allowed equal-season lengths with the other winter-season crops. Some difficulty in establishing the spring cucurbit crops due to the loss of transplants from an unexpected freeze in early Mar. 1989 caused an extension of the final crop 2 to 3 weeks beyond that of the 1986-87 season. About 0.14 to 0.15 inches/day (0.37 to 0.38 cm/day) of water was applied

Table 1. *Effect of microirrigation tubing and previous crop on yield of individual crops within sequences (1986-87 and 1988-89 seasons).*

Crop	Tube effect			Previous crop		
	Marketable wt	Marketable no.	Avg wt	Marketable wt	Marketable no.	Avg wt
<i>1986-87 Season</i>						
Tomato	**	**	NS	---	---	---
Cabbage	NS	NS	NS	---	---	---
Cauliflower	NS	NS	NS	---	---	---
Broccoli	NS	NS	NS	---	---	---
Zucchini	NS	NS	NS	**	**	NS
Cucumber	NS	NS	NS	*	*	NS
Muskmelon	NS	NS	NS	*	*	NS
<i>1988-89 Season</i>						
Tomato	NS	NS	NS	---	---	---
Cabbage	NS	NS	NS	---	---	---
Cauliflower	NS	NS	NS	---	---	---
Broccoli	NS	NS	NS	---	---	---
Zucchini	NS	NS	---	NS	NS	---
Cucumber	NS	NS	---	*	*	---
Muskmelon	NS	NS	NS	NS	NS	NS

*, **, NS Significantly different between treatments at P = 1% or 5% or not significant, respectively.

to all crops in the 1986-87 season, while the water applied in the 1988-89 season ranged from 0.15 to 0.19 inches/day (0.38 to 0.48 cm/day). When compared to the 1986-87 season, more microirrigation was used (much of the increase occurring during the spring season), but no seepage irrigation was required due to very wet initial conditions in the fall. Overall, $\approx 25\%$ more water was applied during the 1988-89 season.

The effect of tubing type and previous crop on yield is shown in Table 1. A significant effect of tubing type was observed only with the 1986-87 season's initial tomato crop, when the tomatoes irrigated by closer-spaced (23-cm) dual-chambered tubing significantly out-yielded the crops irrigated with the wider-spaced (56-cm)

tubing. The type of tubing did not affect the average fruit size significantly.

The effect of the previous crop (second crop in each sequence) had on yields (marketable numbers and weight) of the third crop of the sequences (Table 1) was significant for all of the cucurbit crops (1986-87 season). Additional analyses showed that the effect was only significant when the third crop followed the cabbage crop, which as mentioned earlier, because of its longer growing season, caused a delay in planting of the following crop. There was no significant previous-crop effect on average marketable weight for any cucurbit crop. A similar evaluation for the 1988-89 season revealed no significant yield differences among tubing types for all crops; the only significant

effect of a previous crop was with the cucumber crop following cauliflower, in which some slight decrease in production was detected. The use of a shorter-season cabbage variety eliminated the previous-crop effect measured in the 1986-87 season for the reasons discussed earlier.

Table 2 contains the results of using the RVI described earlier as a means of comparing the performance of the nine cropping sequences. Crop RVI is derived from multiplying the individual crop yield by the unit RVI for each individual crop within each sequence. Totalling the RVIs for each crop within each sequence results in a sequence RVI. Mean separation of the sequence RVIs showed close agreement of sequence performance between seasons. The combination of tomato-cauliflower-zucchini had a significantly higher sequence RVI than any other sequence. Sequences that included cabbage as a second crop (except when zucchini was the third crop in the 1988-89 season) were generally the lowest overall performers. Once again, since the cabbage variety was changed to one with a shorter season (in the 1988-89 season), its detrimental effect on the delay of the transplanting of the spring season crop was minimized, eliminating the effect of delayed transplanting on production.

Major changes in production practices will require changes in associated management practices. This system differs from other multiple-cropping systems in that it is essentially a continuous cropping system for a 9-month period involving three different crop types. Along with the problems that were experienced during the 1987-88 season, other specific management concerns were identified. They included: 1) the need for complete crop residue removal and disposal between crops; 2) the need to minimize interference of remaining plant residue with transplanting subsequent crops; 3) protection of plastic mulch from deterioration and mechanical damage; 4) special attention to clogging prevention when using microirrigation systems; and 5) increased weed control requirements.

It was very important that the crop residue from the previous crop be removed as quickly as possible to facilitate the seeding or transplanting of the following crop. This problem was particularly evident with the initial

Table 2. *Yield comparisons for all crop sequences (1986-87 and 1988-89 seasons).*

Crop sequence ^a			Yield (units/acre) ^b			Crop RVI ^c			Sequence RVI ^c
C-1	C-2	C-3	C-1	C-2	C-3	C-1	C-2	C-3	
1986-87 Season									
TO	MU	ZU	1123	859	761	1123	781	1278	3182 a ^v
TO	BR	ZU	1123	392	648	1123	537	1088	2748 b
TO	MU	CU	1123	859	731	1123	781	665	2569 b
TO	MU	CN	1123	859	211	1123	781	380	2284 c
TO	BR	CU	1123	392	605	1123	537	545	2205 c
TO	CA	ZU	1123	482	401	1123	308	673	2104 cd
TO	BR	CN	1123	392	167	1123	537	300	1960 de
TO	CA	CU	1123	482	387	1123	308	352	1783 ef
TO	CA	CN	1123	482	87	1123	308	157	1588 f
1988-89 Season									
TO	MU	ZU	2084	470	602	2084	428	1010	3522 a
TO	BR	ZU	2084	237	598	2084	324	1004	3412 b
TO	CA	ZU	2084	349	527	2084	223	885	3192 c
TO	MU	CU	2084	470	542	2084	428	493	3005 d
TO	BR	CU	2084	237	655	2084	324	596	3004 d
TO	MU	CN	2084	470	267	2084	428	480	2992 d
TO	CA	CU	2084	349	597	2084	223	543	2850 e
TO	BR	CN	2084	237	223	2084	324	402	2810 e
TO	CA	CN	2084	349	250	2084	223	450	2757 e

^aC-1, C-2, and C-3 correspond to the first, second, and third crop of the indicated cropping sequence, respectively.

^bYields are the average of four replications. Crop abbreviations and yield units, and Unit Relative Value Index (RVI) based on average market value (using TO = 1.00), are shown below:

Crop	Abbreviation	Weight per unit of yield, lb (kg)		Unit RVI (per unit of yield)
Tomato	TO	25	(11.3)	1.00
Cauliflower	MU	25	(11.3)	0.91
Cabbage	CA	53	(24.0)	0.64
Broccoli	BR	25	(11.3)	1.37
Muskmelon	CN	100	(45.4)	1.80
Cucumber	CU	55	(25.0)	0.91
Zucchini	ZU	42	(19.0)	1.68

^cCrop RVI = Unit RVI $\times$ yield (units/acre).

^dSequence RVI is the total of crop RVIs for an individual sequence.

^eMeans within a column for each season followed by the same letter are not significantly different at $P \leq 0.05$ using Duncan's multiple range test.

tomato crop, since the crop residue as well as the wooden stakes and string used for tying the crop needed to be removed. The second crops in the sequence were harvested as whole plants and trimmed outside the field to facilitate removal of residue after the crop was finished.

Even though most of the crop residue can be removed, some always remained, which often interfered with the seeding or transplanting of the following crop. This was usually only a problem when punched holes in the plastic from the previous crop were used for planting the next crop, and was really more of a nuisance than a significant problem, although it is something that must be considered. It was found advantageous to reuse the existing holes from the previous crop when possible to minimize damage to the plastic mulch and tubing. There may be benefits from a study to determine the degree that crop residues can be tolerated by a following crop (with regard to the costs of crop residue removal) based on a cost-benefit analysis. Additionally, regrowth of a prior crop and the remaining residue after harvest tended to interfere with the planting and growth of the subsequent crop.

Another problem that became evident as the season progressed was the deterioration of the plastic mulch and its susceptibility to mechanical damage. This was a devastating problem, primarily because the loss of plastic cover caused dehydration of the bed. The soil was extremely low in water-holding capacity, and when dry exhibited a hydrophobic characteristic that restricted lateral water movement away from the microirrigation emitter. This, in turn, affected the establishment of transplants of following crops severely. The 1.25-mil plastic mulch tended to become brittle, break down, and deteriorate too quickly to maintain coverage throughout the cropping sequence. Since the same plastic mulch is used three times longer than normal, the use of a heavier plastic (≥ 1.5 mil) may lessen the likelihood of this problem. This loss of mulch cover can affect the weed control, which can increase the need for the use of herbicides. Although plastic mulch deterioration was experienced in all seasons, the 1987-88 season resulted in almost complete breakdown of the plastic because environmental conditions were not

Table 3. *Estimated additional costs*, dollar savings, and net savings for vegetable multiple cropping sequences, 1986-87 and 1988-89.*

Crop sequence ^a	1986-87			1988-89		
	Additional cost	Dollar savings	Net savings	Additional costs	Dollar savings	Net savings
			(\$/acre)			
TO-MU-ZU	(106)	740	634	(115)	804	689
TO-BR-ZU	(101)	740	639	(110)	804	694
TO-MU-CU	(106)	1298	1192	(115)	1409	1294
TO-MU-CN	(106)	671	565	(115)	729	614
TO-BR-CU	(101)	1298	1197	(110)	1409	1299
TO-CA-ZU	(92)	747	655	(100)	811	711
TO-BR-CN	(101)	671	570	(110)	729	649
TO-CA-CU	(92)	1304	1212	(100)	1416	1316
TO-CA-CN	(92)	677	585	(100)	736	636

*Data for cost and savings determination from Taylor and Smith (1989).

^aTO = tomato, MU = cauliflower, CA = cabbage, BR = broccoli, CN = muskmelon, CU = cucumber, ZU = zucchini.

significantly different from the other seasons, the breakdown may have been due to a poor manufacturing process.

As stated earlier, nematode and disease control were achieved through the fumigation of the mulched beds prior to transplanting the initial tomato crop. Although no problem was observed in this study, there are strong possibilities that injection of a pesticide through the tubing between crops may be required to maintain suppression of nematode populations or other soil-borne pests. Because each crop was followed by a different crop species, the degree of nematode problems may have been decreased. However, in cropping sequences that include the same crop grown for two consecutive seasons, build-up of harmful nematode populations may occur (Overman and Mislevy, 1984). Nematode control can be effective using application of pesticides through microirrigation tubing (Overman, 1982; Overman and Price, 1983).

We found a high feasibility for using multiple-cropping sequences with microirrigation in southwestern Florida. There does appear to be some flexibility in choosing the most economically advantageous crops. A spring zucchini crop was very successful. Based on the experiences of using both a long- and short-season cabbage crop (during the second crop, winter), it appears to be desirable to schedule maturity of all crops as early as possible to avoid delay in transplanting or seeding the following crop.

Production costs, dollar savings, and net savings associated with each

cropping sequence are compared to production of individual crops (Table 3). Additional costs result from the additional labor required to remove crop residues from the first and second crops and a slight increase in herbicide costs between crops. Dollar savings result from reduced field preparation, plastic mulch, tubing, fumigant, lime, irrigation, and land rent. Net savings from using a cropping sequence ranged from \$565 to \$1212/acre (\$1396 to \$2993/ha) and \$614 to \$1316/acre (\$1516 to \$3251/ha) for the 1986-87 and 1988-89 seasons, respectively. The greatest net savings were associated with the crop sequences that included a cucumber crop. The large savings resulted primarily from not incurring expenses for plastic, fumigant, field preparation, and land rent. The net savings are simply the net dollar amount that would be realized above added production costs associated with each cropping sequence. Individual growers would need to evaluate their yields, production costs, and available market price for these commodities to determine which cropping sequence is most profitable.

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