SEQUENTIAL CROPPING OF VEGETABLES USING PLASTIC MULCH, TRICKLE IRRIGATION, AND SOIL FUMIGATION

by

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INTRODUCTION

Increased production costs for vegetable crops have caused production practices to favor more intensive culture. The evolution of this concept has presently reached the level of practicing sequential cropping utilizing plastic mulch, trickle irrigation, and soil fumigation, conducted on the same site in one season. These combined practices distribute costs over two crops in one season season thus serving to offset the high costs and risks incurred. Research on intensive culture of vegetables has been conducted in Georgia on sandy soils with high frequency rates of irrigation and supplemental nutrition (5). High value crops with associated production problems could possibly be economically grown by utilizing such a combination of production practices.

Cabbage production in southwest Virginia has been curtailed because of infestations of *Plasmodium brassicae* Wor., clubroot. The profitability from producing a single cabbage crop does not warrant the expense of soil fumigation for controling this fungus (11). The objective of the research reported in this paper was to assess the use of sequential cropping of cabbage and a second vegetable, utilizing plastic mulch, trickle irrigation, and soil fumigation in Virginia on silt loam soil.

Chapter II

MATERIALS AND METHODS

Experiments were conducted at the Viginia Tech Horticulture Research Farm in Blacksburg, on a Lodi silt-loam soil, during the spring and summer growing seasons of 1980 and 1981. The experimental design was a split-split plot, including four replications of all possible combinations of with and without soil fumigation as main plots, trickle irrigation as subplots, and 1.5 mil black plastic mulch as sub-sub plots. Beds were 6.1 m x 0.91 m, 10 cm high, and 1.52 m apart. Irrigated treatments received municipal water through one (Bi-wall) trickle line per bed, placed 5 cm deep, laid in the center of the bed. The trickle lines had holes every 30 cm and the rate of water application was 1.9 liter/min/30 m at 1.1 kg/sq cm pressure. These treatments were irrigated at 50% field capacity determined by soil moisture blocks placed 15 cm deep. Moisture blocks were calibrated by using a soil moisture desorption curve. Enough water was applied to restore the soil to field capacity during each irrigation. Beds were fumigated under plastic after broadcasting, and incorporating 84 kg N, 96 kg P, and 139 kg K per ha to a depth of 15 cm. Subsequent N was applied through the trickle system and sidedressed on non-irrigated plots at equivalent rates. Calcium nitrate was the N source for all treatments both years. At transplanting 56 kg/ha of 20N-8.6P-16.6K was injected through the trickle system and placed on the non-irrigated plants as a starter solution. Prior to planting, plastic was removed from the plus soil fumigation/minus plastic mulch plots. All plant material was cut at ground level after harvesting the first crop for both experiments.

Experiment I, 1980

First Crop. Prior to the April 18 planting date, fertilizer was broadcast and incorporated. Fumigated treatments received a mixture of 98% methylbromide and 2% chloropicrin (brom-o-gas) fumigant at 258 kg/ha. Cabbage transplants were set 46 cm apart in the row with two rows 46 cm apart on each bed. Additional N was supplied at 28 kg/ha at 14 and 28 days after planting. Cabbage harvest was conducted on July 7.

Second Crop. On July 10, tomato transplants were set 46 cm apart in a single row per bed. Supplemental N was applied at 67 kg/ha at 4 weeks and 22 kg/ha at 8 weeks after planting. Tomato harvest was conducted from August 22 to September 6.

Experiment II, 1981

First Crop. Plots were prepared as in 1980 and fumigated with a 67% methylbromide and 33% chloropicrin (Terr-o-gas 67) fumigant at the rate of 393 kg/ha. On May 18, cabbage transplants were set 30 cm apart in the row, with two rows 46 cm apart per bed. Additional N was applied similarly to the first crop in 1980. Cabbage harvest was conducted July 31.

Second Crop. Broccoli transplants were set on August 16, 46 cm apart in the row with two rows 46 cm apart per bed. Plants were set regardless of the location to the decapitated cabbage plants. Supplemental N was applied at 56 kg/ha two weeks after planting. Broccoli harvest was conducted from September 15 to October 22.

Chapter III

RESULTS AND DISCUSSION

There were no interacting effects ($P > 0.05$) among variables on marketable yield in this study. Individual treatment effects are presented in Table 4 of the appendix; however only the main effects of trickle irrigation, plastic mulch, and soil fumigation are discussed below.

3.1 TRICKLE IRRIGATION

Individual and combined crop yields were increased both years with trickle irrigation (Table 1). During both years the first crop received rather uniformly distributed rainfall throughout the growing season whereas the second crop did not (Figure 1). Large amounts of rainfall during the 1981 cabbage growing season created a situation in which the mulched plots required considerably more irrigation water than the non-mulched plots to maintain the soil at 50% field capacity (Table 2). Water runnoff created by the plastic probably limited the rain water from reaching the soil-root zone in the plastic mulched plots.

Even though the trickle irrigated cabbage in 1980 received only slightly more water than the non-irrigated plots in 1981, they did yield between 13 to 24 MT/ha

Table 1. Influence of trickle irrigation, plastic mulch, and soil fumigation on marketable yield of double cropped vegetables, 1980 and 1981.

	1980 Yields (MT/ha)[y]			1981 Yields (MT/ha)		
Variable	Cabbage	Tomato	Total	Cabbage	Broccoli	Total
Trickle Irrigation						
+with	43.4	10.7	54.1	60.5	2.2	62.7
-without	29.4	6.3	35.6	23.7	0.5	24.2
	**[z]	**	***	***	***	***
Plastic Mulch						
+with	38.7	10.8	49.5	42.0	1.5	43.5
-without	34.0	6.2	40.2	42.3	1.1	43.4
	NS	**	*	NS	NS	NS
Fumigation						
+with	37.3	8.5	45.8	41.3	1.5	42.8
-without	35.4	8.6	44.0	42.9	1.2	44.1
	NS	NS	NS	NS	NS	NS

[z]Levels of significance: *, **, *** - 0.05, 0.01, 0.001.
[y]MT/ha times 0.446 = Tons/acre.

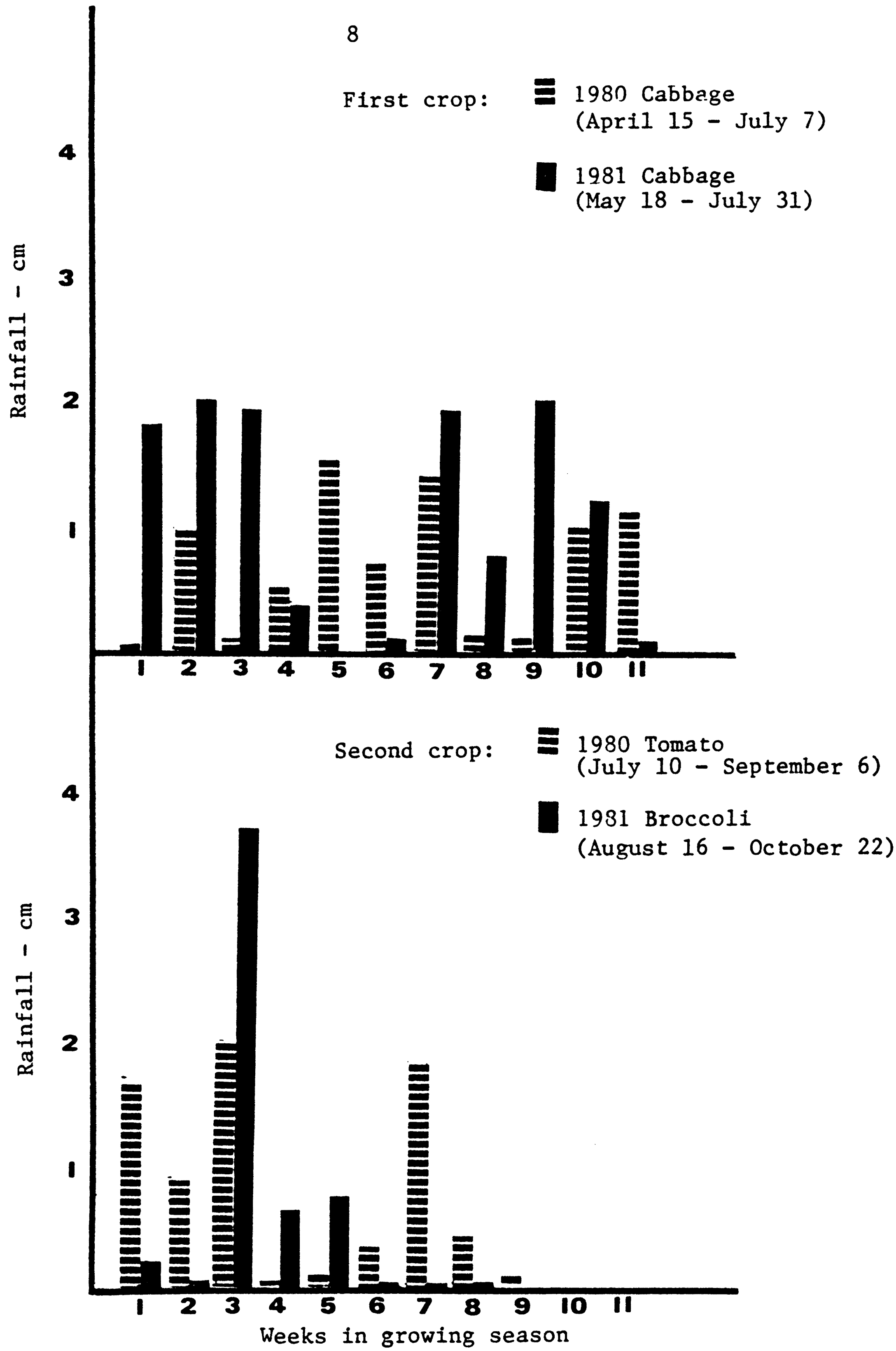

Figure 1. Rainfall amount and distribution, 1980,1981.

Table 2. Amount of irrigation water applied and rainfall per crop, 1980 and 1981.

Water Source	First crop 1980 Cabbage	First crop 1981 Cabbage	Second crop 1980 Tomato	Second crop 1981 Broccoli
Irrigation Water (cm)				
+PM[z]	9.1	14.7	6.1	8.8
-PM	11.6	9.8	7.8	6.7
Rainfall (cm)	7.3	15.7	7.2	7.3
Total Water (cm)				
+PM	16.4	30.4	13.3	16.1
-PM	18.9	25.5	15.0	14.0
Growing Season	80 days	74 days	70 days	40 days

[z]PM = plastic mulch.

greater. It is recognized that many factors might have differed between the 1980 and 1981 growing season; never-the-less trickle irrigation appears to be a superior water source than rainfall. Undoubtedly, irrigation affected growth and yield by maintaining soil moisture above 50% field capacity. In addition, trickle irrigation has the added advantage over other irrigation methods of applying water and nutrients near the root system thus conserving these substances (10).

3.2 PLASTIC MULCH

There were no yield responses to plastic mulch except for tomato and total yields in 1980 (Table 1). Despite the onset of cool weather late in the 1980 growing season which slowed plant development, yields of the irrigated and mulched tomato treatments reached the state averages (1). Tomatoes have been proven to respond well to plastic mulch (4,6). Cabbage and broccoli, both cole crops, did not respond to the plastic mulch. Since they are cool-season crops apparently plastic mulch was of no real benefit, particularly when combined with trickle irrigation. Plastic mulch has been shown to only slightly increase yields for cool season cole crops in Florida (2,3). Cole crops grown at the latitude and elevation of this study may very well respond differently to mulch.

3.3 SOIL FUMIGATION

Although the methylbromide fumigants used are known to control clubroot organisms (11), there was no effect from soil fumigation, indicating that deleterious soil organisms were not present in the soil or the fumigant was not effective.

To be effective sequential cropping of vegetables in southwest Virginia will require early spring planting. If soil fumigation is to be used with sequential cropping in this area, weather conditions must be right and the soil must be well-drained to accomodate early tillage and soil preparation. In 1980, good weather and soil conditions permitted early fumigation and the cabbage was planted on April 18. Planting of cabbage in 1981 was delayed until May 18 because weather conditions would not permit fumigation. Once fumigation was performed a minimum of 7 days was required for the fumigant to dissipate before planting was possible. Since planting and harvest of cabbage was delayed in 1981, the second crop, broccoli, had to be planted beyond the recommended planting dates. Although the 1981 broccoli only had a 40 day growing season, trickle irrigation promoted some head development thus avoiding total crop failures.

3.4 PRODUCTION COSTS

Double cropping decreased production costs by 35% compared to conventional single cropping systems (Table 3). Trickle irrigation, plastic mulch, taxes and insurance when distributed over two crops represented 100% savings. Savings on fertilizer, machinery and equipment was approximately 35%. Figures such as these show the value of multiple cropping when costs savings are considered.

Table 3. Production costs estimates for conventional versus multiple cropping systems.

Production inputs[z]	Production costs ($/ha)[y]			
	Conventional[x]			Multiple cropping
	Cabbage	Tomato	Total	Cabbage followed by tomato
	$/ha			
Plants	430	716	1,146	1,146
Machinery & equipment	1,712	1,366	3,078	1,976
Pest management	178	615	793	793
Fertilizer	343	343	686	425
Trickle irrigation	1,235	1,235	2,470	1,235
Plastic mulch	647	647	1,294	647
Taxes, insurance	247	247	494	247
Total	4,792	5,169	9,961	6,469

[z]Does not include fumigation, labor, harvesting, and marketing costs.

[y]Costs according to O'Dell (1982).

[x]Assumes spacing would be equal for both crops if grown on separate site.

Chapter IV

CONCLUSIONS

The use of trickle irrigation has increased the yields of the crops grown when season totals are compared (Table 1). Annual totals of both crops show an advantage of plastic mulch only in 1980 and no effect of soil fumigation with the crops grown in this study. Possibly other varieties or crops would maximize the use of this system. If soil borne organisms were a problem, fumigation would be necessary and plastic mulch would therefore be useful to contain the fumigant when applied.

Considering the variability of yield responses for the second crop, sequential cropping proved to have a beneficial effect both years on the annual combined totals of crops per ha. This is indicative of the advantages of sequential cropping concerning the compensation for possible crop losses on one of the two crops grown (7,9).

Based on this study sequential cropping is a worthwhile method of minimizing the risks involved in producing vegetable crops. This practice when performed in conjuction with trickle irrigation, plastic mulch, and soil fumigation (where needed) can increase annual productivity and net return per ha in Virginia. Careful attention must be directed to varietal selection and sequence of planting. Timing is also critical, especially in the shorter growing season of western Virginia.

Chapter V

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Appendix A

TABLE 4. INFLUENCE OF TRICKLE IRRIGATION, PLASTIC MULCH, AND SOIL FUMIGATION ON MARKETABLE YIELD OF VEGETABLES.

Table 4. Influence of trickle irrigation, plastic mulch, and soil fumigation on marketable yield of double cropped vegetables, 1980 and 1981.

Treatments[z]			1980 Yields (MT/ha)			Relative Yield Response (% of Total)	1981 Yields (MT/ha)			Relative Yield Response (% of Total)
T	P	F	Cabbage	Tomato	Total		Cabbage	Broccoli	Total	
X	X	X	45.3a[y]	13.1ab	58.4a	97	57.2a	3.0a	60.2a	93
X	X		45.7a	14.3a	60.1a	100	61.0a	1.9ab	62.9a	97
X		X	46.4a	9.1bc	55.5a	92	60.7a	1.9ab	62.6a	96
X			36.1ab	6.4c	42.5b	71	63.2a	1.8ab	65.0a	100
	X	X	31.3b	6.8c	38.1b	63	24.7b	0.4bc	25.1b	39
	X		32.5b	9.1bc	41.6b	69	24.9b	0.2c	25.8b	40
		X	26.2b	4.9c	31.1b	52	22.6b	0.5bc	23.1b	36
			27.4b	4.3c	31.7b	53	22.6b	0.2c	22.8b	35

[z] T = trickle irrigation, P = plastic mulch, F = soil fumigation.
[y] Mean separation within columns by Duncan's multiple range test, 5% level.

Appendix B

LITERATURE REVIEW

B.1 MULTIPLE CROPPING

Multiple cropping has been practiced in many parts of the world over the past few centuries. Development of this concept has not reached the interests of the commercial agriculture research community until recently (29). Agricultural practices utilizing this concept have been limited to low level equilibrium farming in other countries of the world, typically located in tropical areas (1,29). Sequential cropping is an application of multiple cropping implying the production of two or more crops on the same site in one year (1).

Plant growth factors are intensified by the practice of multiple cropping. Factors such as moisture, nutrition, soil characteristics, seasonal variations, and their limitations require careful coordination with crops to be grown, in what sequence, and how to grow them (1,29). Multiple cropping increases the importance of space and time utilization factor. The biological dynamics of multiple cropping generally maximizes crop productivity, water and nutrient use efficiency during a growing season (1).

B.2 PLASTIC MULCH

Plastic film mulches are being used extensively in the production of vegetable crops (4,14,17,21). Plastic mulching has proven to increase root development, decrease nutrient leaching, increase soil temperature, improve soil structure, provide weed control, retain soil moisture, and allow for uniform distribution of water (4,17). Using such mulches, particularly black plastic mulch, creates a new dimension for vegetable production.

B.3 TRICKLE IRRIGATION

Since its inception by Syncha Blass 40 years ago in Israel, trickle irrigation has accompanied technilogical advances in agriculture and is now well established in the U.S. (18,33). The use of trickle irrigation as the name implies involves the use of low volumes of water at low preasures to provide water directly to the rooting zone of the plant (12). Frequency of applications and volume of water varyaccording to soil, environmental, plant, and cultural characteristics. Water applications at frequent intervals have been recommended with trickle irrigation on light soils (6,7,8,11,12,21,31). Recently using such quantities of water so often have been found to be excessive. Root development and water movement are controled and limited to a large extent by trickle irrigation, particularly when in conjuction with plastic mulch (3,7,8,9,11,12,31). Bucks et al. (5) determined that irrigations as frequently as every 3 days decreased yields on a clay loam soil. Earl and Jury (9) found that soils without excessively high hydraulic conductivity, created better growth responses at weekly intervals. Based upon this information, irrigation at 50% field capacity seems suitable for heavier soils (19,24,25). Such a frequency allowed ample root development and decreased surface evaporation of the water applied. Csizinsky and Overman (8) indicated that the placement of one tube per bed was sufficient to provide water to grow vegetables with increased yields.

Another dimension developed by the use of trickle irrigation has been the injection of soluble fertilizers through the system. The system itself limits the type and quantity of fertilizers to be applied but when performed properly, increased yields and quality have been the results (5,9,25,31). Bar-Yosef (3) indicated that to determine the rate of fertilizer injection depends upon 3 parameters; a) the plants daily uptake rate of nutrients, b) the relationship between uptake rate and nutrient concentration in the soil solution, and c) the plants daily water requirement. Variation of requirements during plant growth stages and environmental changes throughout the season are implemented.

B.4 SOIL FUMIGATION

Control of certain soil borne insects, diseases and weeds can be attained through the use of soil fumigation. These materials (fumigants) when injected into the soil are toxic to the organisms which impare the growth and development of the desired crop. Limitations to soil fumigation are primarily moisture and temperature. Fumigation in the fall has been found to be preferable over spring treatments (15,23). This maximizes the responses to fumigation. McCarter et al. (23) determined that annual fumigation is warranted to alleviate any reinfestation of detrimental organisms. Also, a number of soil fumigants due to their volatility must be covered. The use of plastic mulch for this purpose is often performed and in fact increases the efficacy of the fumigation when left on throughout the season (18).

B.5 COMBINING SEQUENTIAL CROPPING, PLASTIC MULCH, TRICKLE IRRIGATION, AND SOIL FUMIGATION

Vegetable production costs have increased. Growers seek to improve productivity and offset the costs and risks involved by using methods to intensify their cultural practices. Such demands have led to the intensification of vegetable production by using trickle irrigation, soil fumigation, and plastic mulches together (18). Further demands and risks have proven it necessary to carry this technique further and apply sequential cropping to this system. This distributes the pre-planting cost of more than $2570 per ha over two or more crops (10,14,18). Hayslip et al. (14) indicated that plastic mulches are in good condition after the first crop and cause the rentention of much residual fertilizer. Plastic mulch combined with trickle irrigation provides a means by which supplemental fertilization for subsequent cropping is possible. This maximizes crop productivity and continued efficiency of water and fertilizer usage.

Trickle irrigation has some limitations in application of rather immoble elements such as phosphorous may not be suitable for trickle irrigation in the quantities required to sustain sequential cropping. Associated problems with salt accumulation in the soil may also become prevalent (5).

Reinfestation of the soil by pathogens can occur(14,18). If this reinfestation is of any consequence, additional fumigation is required. Hayslip et al. (14) investigated the use of a tractor mounted implement designed to apply fumigants under established beds covered with film mulches. Overman (30) found that application of fumigants through the trickle system could be a feasible solution.

Any number of problems primarily assiciate with production techniques are encountered when using the combination of multiple cropping with plastic mulch, trickle irrigation, and soil fumigation. Timing is critical due to the length of the growing season limiting the crops to be grown and time required for site preparation. Removal of the first crop and planting over the remaining stubble is an additional factor.

Plasmodium brassicae Wor., clubroot, has been an age old problem of producing cole crops. Control of this organism has been achieved through soil fumigation with methyl-bromide (34). Yet, the profitability of producing cole crops does not warrant the expense involved in fumigation. Sequential cropping may offset these costs by incorporating trickle irrigation, and plastic mulch in addition to soil fumigation. Sequential crops may include cole crops or another crop such as tomatoes.

Cszinsky and Overman (8) found that one drip tube per twin rows of broccoli on one bed was sufficient to sustain a crop and increase yields. On clay loam soils, Bucks et al. (5) Showed that too frequent irrigation via a trickle system would reduce yields. Irrigation at less frequent intervals - ie. at 50% field capacity or slightly greater - should be preferable for cole crops on silt loam soils (5,28). Maurer (22) reported that irrigation at near field capacity improved yields but this was without plastic mulch and trickle irrigation. Cabbage plants develop through four major growth stages; a) young seedling, b) transition stage, c) head enlargement, and d) mature plant stage (27). This is also applicable to broccoli and therefore critical moisture requirements occur during head formation and enlargement (22).

To insure maximum production of cole crops supplemental nitrogen is recommended until the middle stages of growth with a more constant supply of phosphorous and potassium (13,28). Spacing of cabbage plants in the row was found to be most productive at 30 cm (20).

Tomatoes have problems associated with soil borne pathogens (15). Control of these pathogens can be obtained through soil fumigation as is also possible for cole crops.

Root distribution and nutrition of tomatoes is dramatically altered by trickle irrigation. Coordination of frequency and quantity of water and nutrients will increase yields dramatically (18,25,31,32). Persaud et al. (31) found that tomato production was most successful with 50% N injected and 50% broadcast. Tomato response to trickle irrigation was best at 50 % field capacity on silt loam soils (18,25).

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SEQUENTIAL CROPPING OF VEGETABLES USING PLASTIC MULCH, TRICKLE IRRIGATION, AND SOIL FUMIGATION

by

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(ABSTRACT)

Successive cropping of two vegetable crops grown on the same site in one season utilizing trickle irrigation, plastic mulch, and soil fumigation was performed in two separate experiments. In 1980, cabbage (*Brassicae olericea* L. var capitata cv. Market Prize) was followed by tomato (*Lycopersicon esculentum* Mill cv. Pik Red). In 1981, cabbage was followed by broccoli (*Brassicae oleracea* L. var italica cv. Green Duke). Double cropping increased the annual productivity of the research plots both years and decreased production costs by 35% compared to conventional single cropping systems. Early spring planting of the first crop was essential for economic production of the second crop. Trickle irrigation increased yields of all crops grown and was the factor most responsible for yield response both years. Black plastic mulch increased yields of tomato and total yields in 1980 but cole crops showed no significant yield response to mulch either year. No difference in crop yield resulted from soil fumigation either year. Increased production costs have caused growers to seek improved methods to offset risks and costs involved. Trickle irrigation can reduce the risks involved in producing vegetables and is particularly suited to multiple cropping on plastic mulch.