Intercropping Systems for Tomatoes within a High Tunnel

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Additional Index Words: Lettuce, basil, companion crops, relay intercropping, polyculture, monoculture, relative yield total,

Summary: High tunnels are low-cost, plastic-covered, solar heated greenhouses that are used to protect and extend the traditional growing season of many horticulture crops. Tomatoes (*Lycopersicon esculentum* Mill.) produced within a high tunnel are 4-5 weeks earlier than field tomatoes in the central Midwest. However, many other warm and cool season crops can be produced successfully using high tunnels. Tomatoes were intercropped with lettuce (*Lactuca sativa* L.), and basil (*Ocimum basilicum* L.) within a high tunnel during a nine-month season in 2002 and 2003. In addition to being planted concurrently with tomatoes, lettuce was relay intercropped with tomatoes one month after seeding the lettuce. The effects of intercropping on fruit size, quality, and total marketable yield was compared to monoculture systems of the same crops. Intercropped tomatoes showed no significant reduction in yield when compared to monoculture tomatoes. Lettuce yields were reduced when concurrently intercropped, but not when relay intercropped. The *Relative Yield Total* (RYT), a measure of intercropping productivity, was 1.40 – 1.83 indicating that it would require 40 to 83% more land for separate monoculture plantings of tomatoes, lettuce and basil to produce a yield equivalent to the intercropping planting within the high tunnel. Intercropping tomatoes with other vegetables in high tunnels increases output per unit area and enables growers to take full advantage of the high tunnel environment.

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There is increasing interest in the use of high tunnels for producing high-value, locally grown fruits and vegetables. High tunnels are solar-heated, polyethylene-covered greenhouses that are used to protect crops from the environment while lengthening the traditional growing season. Many horticultural crops can be grown successfully within a high tunnel, and early yield and quality usually exceeds field-grown crops of the same cultivars (Jett and Read, 2003). In the central Midwest, tomatoes are often perceived to be the highest value warm season vegetable that can be produced within a high tunnel.

Intercropping, growing of more than one crop in the same area either in a row or as a mixture of plants, is not widely practiced in field production of vegetables in the Midwest. Abundant land has never required growers to maximize land use in the central Great Plains. High tunnels, however, are amenable to intercropping. The relatively small area of a high tunnel (a commercial high tunnel is $\approx$ 2500-3000 ft^2) permits intensive culture of the protected crops. Furthermore, it may be more productive to grow a mixture of several crops simultaneously within a stationary high tunnel rather than construct a mobile high tunnel and move it over different crops during the growing season. In addition to mixed or row intercropping, relay intercropping may be used within the high tunnel. Specifically, relay intercropping is the growing of two or more crops simultaneously during part of the life cycle of each crop (Vandermeer, 1989). This intensive crop system is highly productive when land resources are limited and the production season of several high value crops overlap (Harwood and Plucknett, 1981). The objective of this research was to evaluate the efficacy

of intercropping tomatoes with specific cool and warm season vegetables within a high tunnel.

Materials and methods

Tomato transplants were grown in the University of Missouri Horticulture Greenhouses six weeks prior to being transplanted into high tunnels during 2002 and 2003. The tomatoes (cv. 'Merced') were seeded in 1020 germination flats (20"x 10" x 2") (8.10 cm x 4.01 cm x 0.94 cm), and upon development of the first true leaves, were transplanted into 606 deep insert containers (2.71 cm x 2.07 cm x 1.28 cm deep) (Hummert Intl., St. Louis, MO). The tomato plants received a weekly application of 20N-20P-20K water-soluble fertilizer (200 ppm N), after being transplanted into the 606 containers. The tomatoes were also top dressed with a 14N-14P-14K Osmocote slow release fertilizer (3-4 month analysis) prior to being transplanted in the tunnels.

Four high tunnels were constructed in March, 2002 at the University of Missouri Bradford Research and Extension Center in Columbia, MO. Each high tunnel was covered with a single layer of greenhouse grade, 6 mL plastic polyethylene (K-50, Klerk's Plastic Manufactures, Inc., Richburg, South Carolina). The dimensions of each high tunnel are 20 ft wide x 36 ft long x 12 ft high (6m x 11m x 3.6m) with bows spaced 4 ft (1.2m) apart. Temperature and humidity were managed by rolling-up the 5 ft-high (1.5m) sidewalls or removing the endwalls. Sidewall vents were rolled-up if ambient temperatures were $\geq$ 60°F (22°C). Soil at the University of Missouri Bradford Research and Extension Center is a fine Mexico silt loam, montmorillonitic, mesic Mollic Endoaqualf previously under fescue sod. Additional topsoil classified as Haynie course silt

loam was also used to amend the existing soil. Using a tiller mounted to a small tractor, the two soils were mixed and incorporated to a depth of approximately 8 in. (25 cm), resulting in a final pH of the mixed soil of 6.9. After the raised beds were shaped and prepared for planting, a pre-plant application of 13N-13P-13K granular fertilizer was applied at the rate of 9 lbs/1000ft^2 (4.1kg) as a top dress. A weekly application of calcium nitrate ($CaNO_3$), (15.5% N; 19% Ca), was applied via the drip irrigation system at the rate of 1.l lbs/1000ft^2 (0.5 kg) for all crops. The tomatoes were fertigated commencing 2 weeks after transplanting through harvest.

Intercropping Tomatoes: To evaluate intercropping a vegetative, shallow-rooted vegetable with a fruiting, deep-rooted vegetable, tomatoes were intercropped with leaf lettuce. 'Merced' an early-season, determinate tomato cultivar and 'Red Salad Bowl' leaf lettuce, were chosen as companion crops. Tomato transplants were planted into raised beds with each plant spaced 24" (0.6 m) apart and beds spaced 4 ft. (0.9 m) apart. The tomatoes were staked and trellised using the modified Florida Weave System with 3-4 supporting strings, approximately 6 in (15 cm) apart.

All plantings were on a 10 in. (25 cm) high raised bed, and each plot was 30 in wide x 96 in long (76 cm wide x 2.2 m long) without plastic mulch. Each row was irrigated with one ¾ in. (0.6 cm) diameter plastic drip tube and drippers spaced on-center 12 in (30 cm) apart (T Systems Inc., San Diego, CA). Irrigation was scheduled based on a tensiometer placed 12" (30 cm) deep in each bed. All treatments received the same volume of water and fertilizer regardless of the planting treatment. Preplant and drip fertilization was applied based on recommended fertilization practices for monoculture tomatoes.

Intercropping Lettuce: Lettuce (cv. 'Red Salad Bowl') was direct seeded by hand in 2 rows per bed on April 6, 2002 and March 15, 2003. Each row was 12 in. (30 cm) apart, and the lettuce was thinned to approximately 1 in. (2.5 cm) between plants 2 weeks after emergence. Tomatoes were transplanted immediately after the lettuce emerged between the two parallel rows of lettuce. For the relay intercropping treatment, lettuce was direct seeded one month earlier (February 15) than the tomatoes were transplanted (March 15). Monoculture plots of both tomatoes and lettuce were planted to compare with the intercropping treatment. Two layers of a light-weight row cover (AG-19; Agribon Inc., Mooresville, NC) was applied to each bed from seeding and remained on the plants through mid-April of each year. To increase fruit size and accelerate harvest, each tomato plant was pruned at anthesis by removing the axillary shoots, leaving one shoot just below the first flower cluster resulting in two fruiting stems per plant.

Tomatoes were harvested at full red color and graded according to USDA grade standards (USDA, 1991). Dry weights of the tomato plants in each treatment were also taken to compare the effects of the intercrop on overall plant growth. 'Merced' tomatoes were removed by cutting the plants off at the soil line on August 20, 2002 and on July 21, 2003.

Lettuce was multiple-harvested as a loose-leaf approximately 5 in. (12.7 cm) long. Harvest was terminated as the lettuce plants began to bolt in mid June. Nitrate levels were monitored for each lettuce treatment using a hand-held Cardy Nitrate Meter (Spectrum Technologies, Plainfield, IL). On May 1, 2003, fresh sap was extracted from 30 lettuce petioles per treatment and nitrate levels recorded.

Tomatoes Intercropped with Basil: Basil (cv. 'Lettuce leaf') was seeded in 72 cell Pro-Trays on June 7, 2002 and June 2, 2003, and the basil transplants were relay planted July 1st 2002 and 2003 with existing 'Merced' tomatoes after the lettuce harvest was finished. Two rows of basil, spaced 12 in. (30 cm) between rows and 15 in. (38 cm) between plants were intercropped with the tomatoes in the center. Each plot comprised an area of 20 ft^2.

The basil was allowed to grow from 6-12 in. (15-30 cm) before harvest commenced. Basil was harvested by cutting approximately ¼ in. (0.64 cm) above a lower internode on the stem of the each plant (Youger-Comaty, 1994). As the season progressed, care was taken not to include any lignified tissue that may have developed at the base of the basil stem. Harvest of basil ended in mid-October each year, and the plants were removed from the plots.

The 'Merced' tomatoes were replaced with 'Sunchief', an early-season, determinate slicing tomato in 2002 and 'Sweet Olive', a determinate grape tomato in 2003. Prior to planting, soil tests were taen in the intercropping planting area. Following the results of the soil tests, 1.1 lbs/1000 ft^2 (0.5 kg) of 13N-13P-13K granular fertilizer was applied each year.

The 'SunChief' tomato transplants were relay intercropped with 'Lettuce Leaf' basil July 29, 2002 and the 'Sweet Olive' tomato was planted August 3, 2003 within established basil beds. A double layer of rowcover (AG-19, Agribon, Mooresville, North Carolina; 0.55 oz/yd^2) was applied on the first frost date of each year (October 11, 2002 and October 20, 2003). The rowcover remained over the tomatoes (or basil) until final harvest on November 20, 2002 and November 22, 2003.

When measuring the production potential of intercropping, the area required to produce a monoculture crop and its yield potential are compared to production of the intercropped planting. Relative yield totals (RYT) were used to evaluate production gain when using an intercropping system (Schultz et al., 1982).

(1) $RYT = P_1/M_1 + P_2/M_2 = RY_1 + RY_2$

P_1 and P_2 are the yields of two crops in polyculture, and M_1 and M_2 are the yields of each crop in a monoculture system. Schultz et al. (1982/83) recognized the importance of the economic value of the crops grown when comparison of the two cropping systems was evaluated.

Each of four high tunnels served as a replication for all experiments. Treatments were randomized within each replication, and analysis of variance (ANOVA) was performed on the data.

Results and discussion

High tunnels increased the average daily temperatures by 10-14°F (Figure 1). From late March through mid April, ambient daily temperatures average 50°F (9.8°C), while high tunnels maintain temperatures ≈ 63°F (17°C).

Intercropping: Tomatoes/Lettuce. Previous evaluation of 'Merced' tomato had indicated it to be a high yielding, early-season cultivar that performs well within a high tunnel (Jett and Read, 2003). Tomato harvest began on June 22, 2002 and June 19, 2003. Harvest continued until July 19, 2002 and July 16, 2003. Flowering of tomatoes was observed on April 24, 2002 and April 21, 2003. Intercropping tomatoes with lettuce did not delay the date of first harvest of tomatoes in either year (Figure 2).

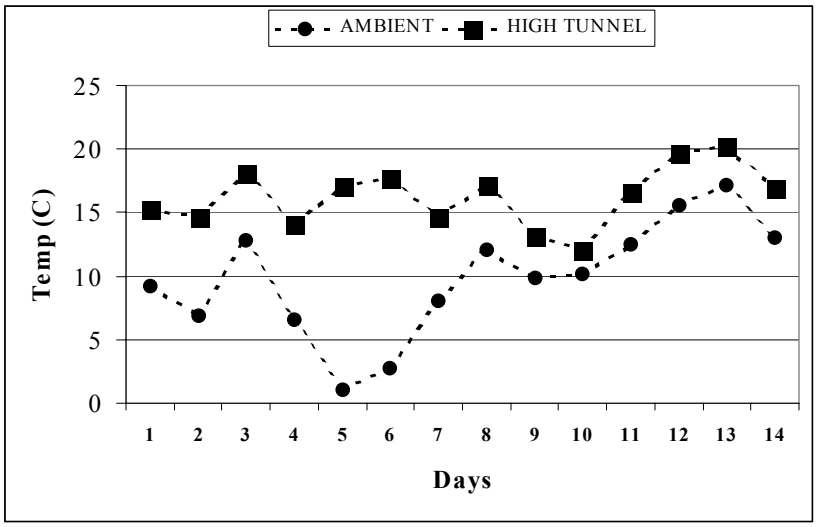

Figure 1. Average daily temperature within a high tunnel compared with ambient temperature (3/30/02-4/12/02). °F= 1.8 (°C) + 32.

Intercropped tomatoes exhibited no significant reduction in yield or average fruit size when intercropped with lettuce relative to monoculture tomatoes (Table 1). Relay intercropping also did not significantly lower marketable yield or average fruit size of tomatoes within a high tunnel in 2003 (Table 1). Yield of relay planted tomatoes was ≈ 15% higher than monoculture tomatoes (Table 1). Over 70% of all marketable fruit was graded as US No. 1 with both monoculture and intercropped treatments (Table 2). Thus, intercropping did not significantly lower fruit quality.

Four weeks after transplanting tomatoes, harvest of the February-seeded lettuce commenced (Figure 3). Relay intercropping did not delay time to first harvest or reduce marketable lettuce yields relative to monoculture lettuce. February-seeded lettuce was harvested 57 days after seeding while March-seeded lettuce was harvested 43 days after seeding. However, seeding lettuce in mid-February resulted in a harvest 14 days earlier than March-seeded lettuce (Figure 3). Marketable yields of February-seeded/relay intercropped lettuce were

not significantly lower than March-seeded/monoculture lettuce (Table 3). However lettuce seeded immediately before the tomatoes were transplanted (i.e., intercropped) had a significantly lower marketable yield (Table 3). Relay cropping tomatoes into an existing lettuce crop is a superior choice because it results in a cropping system with a longer harvest window for lettuce.

Peak tomato harvest was not affected by intercropping or relay cropping (Figure 2). By the third harvest (early July) tomatoes had the highest yields regardless of planting treatment. Generally tomatoes require 40-60 days from flowering to vine-ripe harvest (Jett, 2004). Tomatoes harvested in early July were fruit produced from flowers initiated and pollinated in mid to late May. Both monoculture and intercropped lettuce exhibited a peak harvest level at approximately the same time (61 days after tomato transplanting) (Figure 2). The tomatoes began flowering approximately 40 days after transplanting. As the tomatoes began to initiate and develop fruit, lettuce yields were declining. Tomatoes were able to initiate reproductive growth without significant competition by lettuce since lettuce yields were declining after May 15.

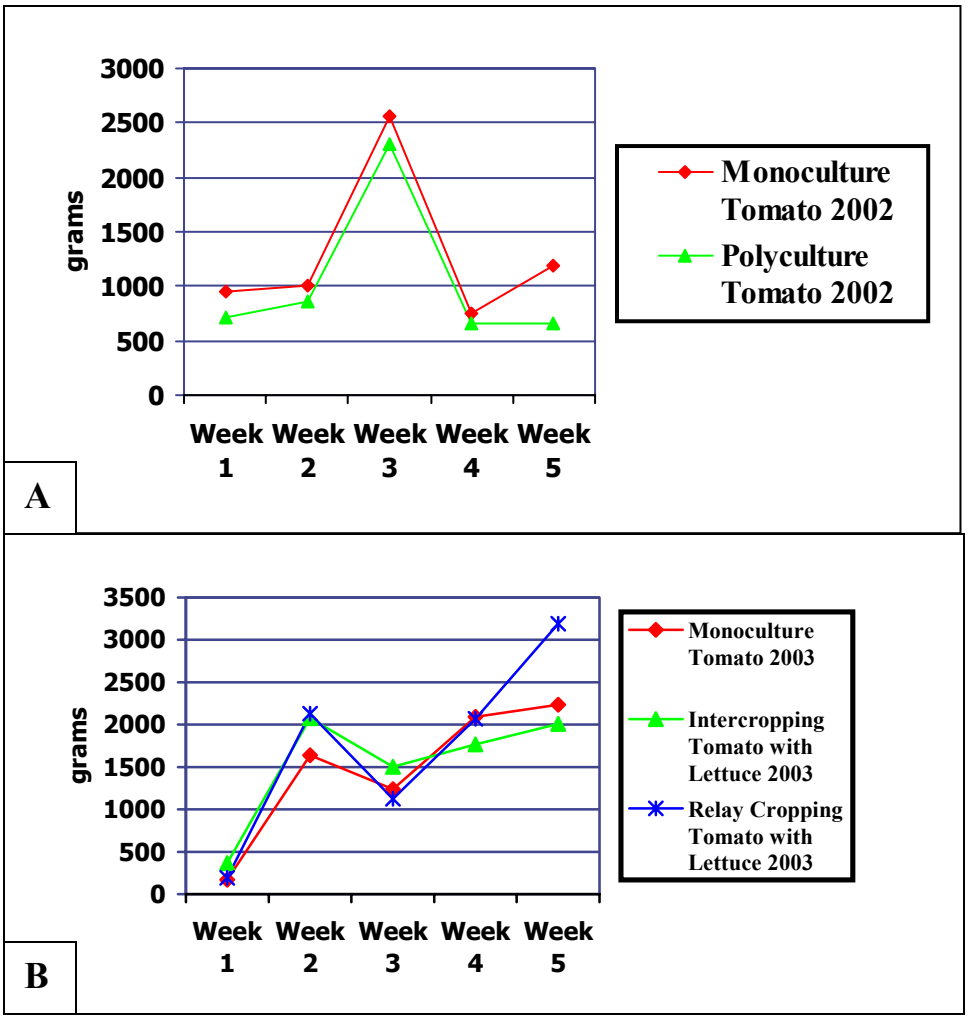

Figure 2. Tomato harvest as affected by planting treatment in 2002 (A) and 2003 (B).

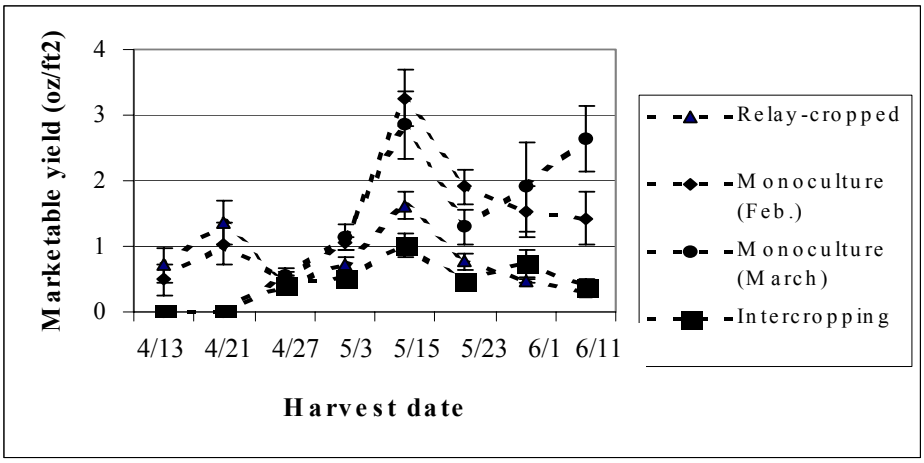

Figure 3. Lettuce harvest as affected by planting treatment (2003).

Table 1. Effects of intercropping tomatoes with lettuce on marketable tomato yield.

Planting treatment	Total yield[z] (lbs/plant)	Average fruit wt. (oz.)	Total yield[z] (lbs/plant)	Average fruit wt. (oz.)
	2002	2002	2003	2003
Monoculture Tomato	11.9a	7.6a	16.6ab	7.3a
Intercropping Tomato with Lettuce	10.4a	7.5a	17.0ab	6.8b
Relay Cropping Tomato with Lettuce	NA[y]	NA	19.2a	7.0b

[z]Duncan's Multiple Range Test. Means within a column followed by the same letter are not significantly different ($P \leq 0.05$). [y]NA=not available. [x]Lbs/ft^2

Lettuce did not accumulate high levels of NO_3 nitrogen regardless of the planting treatment (Figure 4). Monoculture lettuce did have significantly higher levels of nitrates relative to the intercropped planting. Since all treatments received nitrogen based on requirements for tomatoes, this was expected. However the levels were not excessive.

Table 2. Effects of intercropping tomatoes with lettuce on tomato quality[z].

Planting treatment	US No. 1 (lbs/plant)	US No. 2 (lbs/plant)	US No. 3 (lbs/plant)
		2002	
Monoculture Tomato	8.9a	2.5b	0.9c
Intercropping Tomato with Lettuce	8.1a	2.1b	0.7c
		2003	
Monoculture Tomato	11.4a	1.2b	1.7b
Intercropping Tomato with Lettuce	13.3a	2.2b	1.5b
Relay Cropping Tomato with Lettuce	15.1a	1.6b	2.5b

[z]Duncan's Multiple Range Test. Means within each grade class followed by the same letter are not significantly different (P≤0.05).

Table 3. Effects of intercropping lettuce with tomatoes on lettuce yields[z].

Planting treatment	Lettuce yield (oz/ft^2)	
	2002	**2003**
Monoculture Lettuce (February-seeded)	NA	11a
Relay Cropping Tomato with Lettuce	10a	6bc
Monoculture Lettuce (March-seeded)	11a	10ab
Intercropping Tomato with Lettuce	6b	4c

[z]Duncan's Multiple Range Test. Means within a column followed by the same letter are not significantly different (P≤0.05).

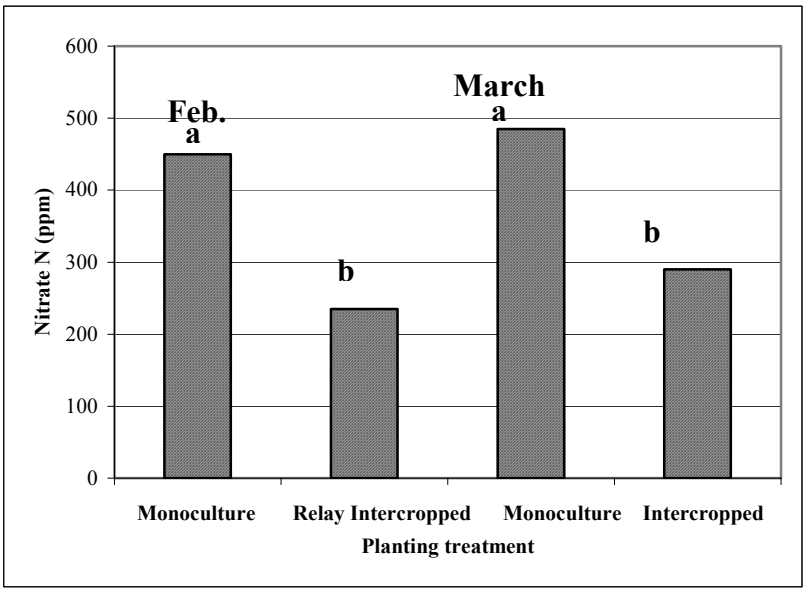

Figure 4. Monoculture lettuce had significantly higher NO_3 nitrogen levels relative to intercropped lettuce.

Relay Intercropping Tomatoes/Basil. 'Lettuce Leaf' basil followed the 'Red Salad Bowl' lettuce crop within each high tunnel. Basil harvest began on August 28, 2002 and August 16, 2003 and was harvested four times with harvest terminating on October 23, 2002 and October 26, 2003.

The spring-planted 'Merced' tomato crop was replaced with either 'SunChief' tomatoes in 2002 or 'Sweet Olive' grape tomatoes in 2003 for fall harvest. The tomatoes were relay planted into existing beds of basil or planted without a companion crop.

The grape tomato cultivar chosen was a short-season, determinate cultivar that did not compete significantly with the basil. Intercropping with a determinate, slicing tomato significantly lowered basil yield in 2002, but intercropping did not reduce marketable yields of basil in 2003 (Figure 5). As observed with spring-

planted slicing tomatoes, intercropping did not significantly reduce marketable tomato yields relative to monoculture plantings (Figure 5). Intercropping did not delay the date of first tomato harvest or average fruit weight per plant.

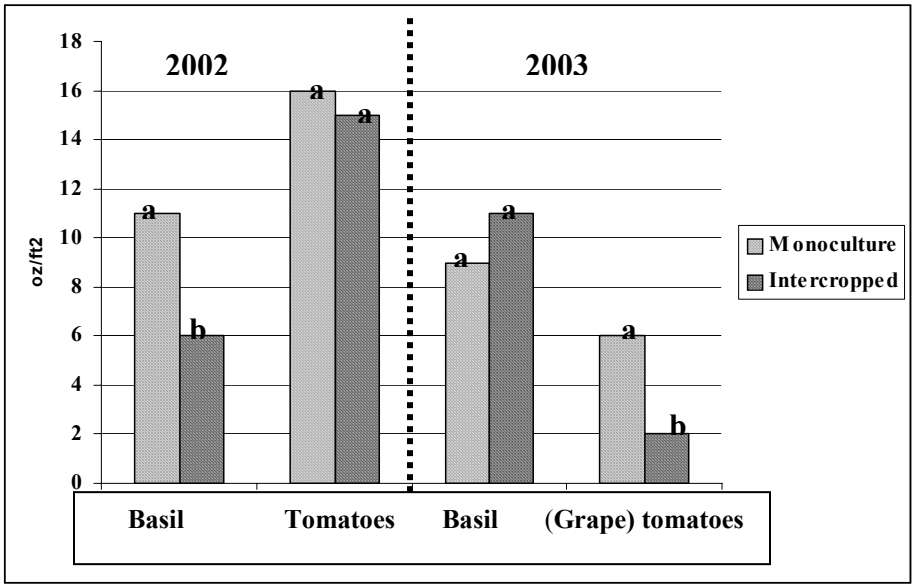

Figure 5. Effects of intercropping tomatoes with basil. Grouped bars with the same letter within each year are not significantly different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Relative Yield Total: The suitability of intercropping 'Merced' tomato with 'Red Salad Bowl' lettuce can also be determined by calculating the Relative Yield Total (RYT). A RYT that exceeds 1 is a suitable intercropping choice.

2002: The average weight of intercropped lettuce is 7 oz/ft^2 (2478 g/m^2) (Table 3). The intercrop value can then be divided by the average yield of a lettuce crop grown in a monoculture system. The average yield value for monoculture lettuce was 11 oz/ft^2 (3441 g/m^2). Thus, the relative yield for lettuce is 0.52. The same procedure can be applied to the average yield of tomatoes resulting in a relative yield of 0.88 (Table 2). The result is a Land Equivalency Ratio or Relative Yield Total of 1.40 for the intercropping combination. Intercropping lettuce with tomatoes is 40% more efficient than growing the two crops individually in the

same area within the high tunnel (Figure 6).

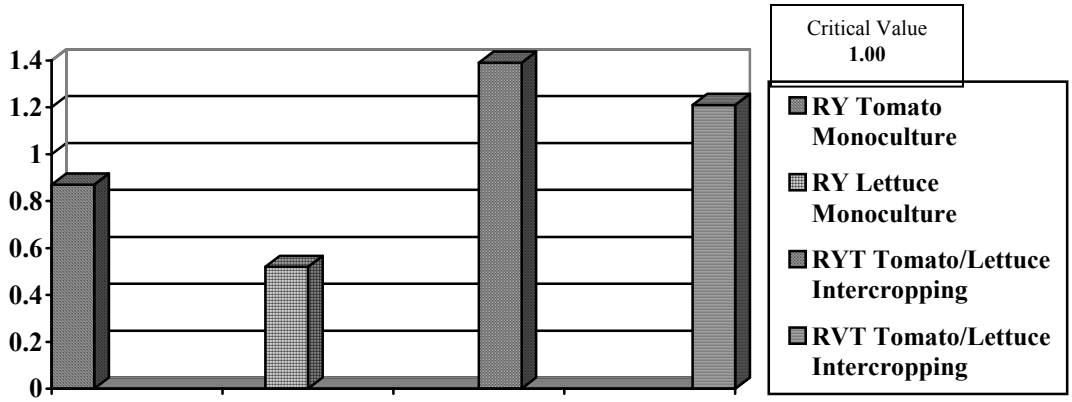

Figure 6. Relative Yield and Relative Yield Total of tomato and lettuce intercropping within a high tunnel (2002).

2003. If the same procedures are applied to the 2003 season using the relay cropping system (Tables 1 and 3) the result is a RYT of 1.61, largely due to the relay cropping system out yielding the monoculture tomatoes (Table 1)

Although several planting and harvest dates are included within this study, including four different crops, one can calculate the RYT for all crops to evaluate the output of the intercropping system. The average yield of the two tomato cultivars was added together for each treatment providing an overall average yield for the season. Likewise, average yields of 'Red Salad Bowl' leaf lettuce and 'Lettuce Leaf' basil were combined. The following calculation was used to determine the RYT for this intercropping study:

$$RYT = (P_{\text{lettuce \& basil}}/M_{\text{lettuce \& basil}}) + (P_{\text{tomato1 \& tomato2}}/M_{\text{tomato1 \& tomato2}})$$

When the relative yield of each crop was totaled, the RYT was equal to 1.40, or the intercropping treatment was 40% more efficient use of the high tunnel environment when compared to a monoculture system of all crops individually in 2002 (Figure 6). In 2003, the combined RYT of both tomato crops and the lettuce/basil was 1.83, indicating that intercropping was ≈ 80% more

efficient within a high tunnel relative to monoculture production of each crop (Figure 7).

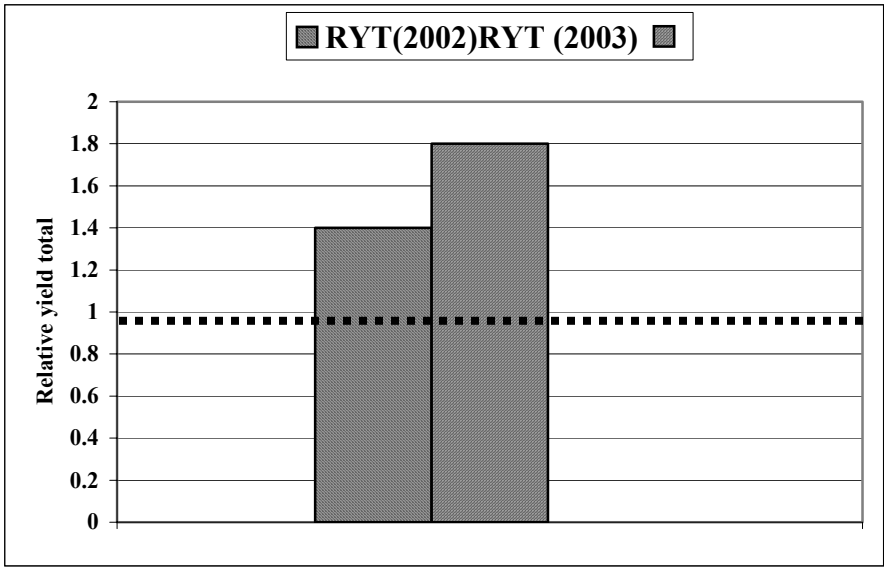

Figure 7. Combined Relative Yield Total (RYT) for all crops produced within a high tunnel.

Conclusions

High tunnels enable growers the opportunity to produce many high-value crops within a calendar year. Intercropping further enhances the benefits of the high tunnel by producing diverse vegetable crops that have overlapping production and marketing cycles within a given year. Thus a producer who wishes to establish and market lettuce from February through mid-June can successfully relay intercrop with tomatoes without a significant reduction in marketable yield of either crop. Later, warm season vegetables or herbs such as basil can be relay intercropped with tomatoes with success

The protected environment within the high tunnel avoids or prevents many pest outbreaks that would normally occur within the field environment in the Central Midwest. Intercropping increases biodiversity, and by combining high

tunnel production with intercropping may provide growers with even greater protection from pests.

Not all intercropping systems will be successful within a high tunnel. Although tomatoes are highly profitable within a high tunnel, it is critical to choose an intercropping combination that maximizes relative yield of each companion crop.

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