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A BIOLOGICALLY-BASED SYSTEM FOR WINTER PRODUCTION OF FRESH-MARKET TOMATOES IN SOUTH FLORIDA

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Abstract. **A three year-experiment was conducted at two locations near Homestead, Florida to evaluate the feasibility of using a biologically-based system for winter production of fresh-market tomatoes (*Lycopersicon esculentum* Mill.) in south Florida fields with light to moderate infestations of the root-knot nematode (*Meloidogyne incognita* [(Kofoid and White) Chitwood], and yellow nutsedge (*Cyperus esculentus* L.). The system consisted of a cropping rotation in which nematode-resistant cover crops [cowpea (*Vigna unguiculata* (l.) Walp. cv. Iron Clay), velvetbean (*Mucuna deeringiana* (Bort.), Merr.) and sunn hemp (*Crotalaria juncea* L. cv. Tropic Sun)] were followed by a nematode-resistant tomato (*Lycopersicon esculentum* Mill.) crop. There were two cover crop treatments (cowpea and velvetbean) and a standard methyl bromide/chloropicrin (MC-33) treatment in 2000/01. A third cover crop treatment using sunn hemp was added in 2001/02. In 2003/04, two cover crop treatments (velvetbean and sunn hemp), a fallow (no cover crop), and a MC-33 treatment preceded by a summer sorghum sudangrass cover crop were used. Biomass production by the velvetbean, cowpea, and sunn hemp crops averaged 14.8, 8.5, and 11.6 Mg·ha^{-1}, respectively. Suppression of root-knot nematode (*Meloidogyne incognita*) by the cover crops could not be rigorously determined because of very low or low density nematode populations. Marketable tomato yields in all treatments and in all years were above average annual yields in Miami-Dade County. Yields were highest in 2003/04 because the crop was healthy and favorable prices encouraged eight harvests. In contrast, yields were low in 2001/02 due to a heavy infection by foliar pathogens. In 2000/01, there was no significant difference in extra-large fruit yield among the treatments but the MC-33 treatment had a higher yield of large fruits than the cowpea and velvetbean treatments, thus resulting in a higher total marketable yield than both cover crop treatments. The total marketable yield in the velvetbean treatment was next highest. In 2001/02, the cowpea treatment had a significantly higher yield of extra-large fruits than the MC-33 and the velvetbean treatments and significantly higher total marketable yield than all other treatments. In 2003/04, equal marketable yields in all fruit-size grades occurred in the sorghum sudangrass/MC-33, velvetbean, and sunn hemp treatments and these were significantly higher than in the fallow treatment. Economic analysis showed that all treatments resulted in positive net returns in all years. Returns in 2003/04 were the highest of all study years due to high yields and high market prices. Among the cover crops, sunn hemp produced the highest tomato yields and net returns of all treatments over the two years it was used.**

Beginning about one-half century ago, production of vegetables in tropical and sub-tropical areas such as Florida became progressively more dependent on prophylactic chemical fumigation of soils to protect crops from soil-borne plant pests and diseases. In fact, during the past three decades almost 100% of acreage planted to tomato (*Lycopersicon esculentum* Mill.) and pepper (*Capsicum* spp.) in Florida has been prophylactically fumigated each year. Methyl bromide/chloropicrin mixture (MC-33) became the dominant material used for soil fumigation because it has been both economical and effective over a broad spectrum of pests. Indeed, VanSickle et al. (2000) predicted that without MC-33, tomato production in Miami-Dade County would cease. The decision by the Montreal Protocol Parties (www.mbao.org/mbrqa.html) to phase-out the manufacture, sale and use of methyl bromide in developed countries has caused scientists not only to search for alternative fumigants but also to investigate ways of producing high value vegetable crops without soil fumigation.

The search for potential solutions to the imminent void that will be created by the loss of methyl bromide has taken several directions including chemical, biological, and cultural, as well as combinations of two or more alternatives. The chemical alternatives include the use of soil fumigants such as the mixture of 78.3% 1-3 dichloropropene and 16.5% chloropicrin (Telone C-17) (Eger, 2000; Gilreath et al., 1995), metam sodium (McMillan et al., 1998a; Pinkerton et al., 1996), and methyl iodide (McMillan et al., 1998b). Cultural alternatives include heat treatments such as soil solarization (Chellemi et al., 1997, 1999; Stapleton and Devay, 1995), hot water treatment (Noling, 2000), and a combination of soil solarization and fumigation (Gilreath et al., 2000). Biocontrol of root-knot nematode by single-spore isolates of *Pasteuria penetrans* (Thorne) Sayre and Starr has been proposed (Kaplan et al., 1995). Likewise, *Acremonium butyri* (van Beyma) W. Gams, *Chaetomium globosum* Kunze, *Gliocladium roseum* Bainer, *Trichoderma hamatum* (Bonorden) Bainier, and *Zygorrhynchus moelleri* Vuill fungi have been reported to reduce the populations of *Fusarium*, *Penicillium*, and *Mucor* when applied to compost in a soilless culture planted into tomatoes (Sivapalan et al., 1994). Finally, microbial pathogens that have been reported to be effective against nematodes include the bacteria *Pasteuria penetrans* and *Bacillus thuringiensis* Berliner (DuFour et al., 1998).

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The development of vegetable cultivars with resistance to soil-borne pathogens and plant parasitic nematodes has been steadily progressing (Scott, 1998), and disease and nematode resistant cultivars are likely to be key technologies in vegetable production systems that do not involve soil fumigation. In 1968, 'Walter', a cultivar resistant to *Fusarium oxysporum* f. sp. *lycopersici* race 2, and in 1976, 'Flora-Dade', a cultivar resistant to both Verticillium wilt and Fusarium wilt races 1 and 2 were released from the Tropical Research and Education Center, Homestead, Fla. (Scott, 1998). More recent releases include 'RTF 6153', resistant to Verticillium wilt race 1, to Fusarium wilt races 1 and 2, and to *Stemphyllium* gray leaf spot (Scott, 2004), 'Solar Fire', resistant to Fusarium races 1, 2 and 3 and to Verticillium wilt race 1 (Scott, 2003), and 'Sebring', resistant to Fusarium races 1, 2 and 3 and to Verticillium wilt race 1 (www.rogersadvantage.com).

Introducing genetic resistance to root-knot nematodes into cultivars of vegetables has been successful in 'Sanibel', 'Sun jay', 'Clemente', 'Cisco', 'Shady Lady', and other tomato cultivars, and in 'Charleston Bell', 'Carolina Wonder' and other pepper cultivars (DuFour et al., 1998). Likewise, several cultivars of leguminous and grassy cover crops have been identified as non-hosts or resistant to root-knot nematodes (McSorley, 2000; McSorley et al., 1994; Peet, 1996; Yepsen, 1984). Some of these nematode-resistant host plants thrive well in tropical climates and include sunn hemp (*Crotalaria juncea*) (McSorley, 1999; Wang et al., 2002b), *Dolichus lablab* L. (Araya and Caswell-Chen, 1997), velvetbean (*Mucuna deeringiana*) (Kloepper et al., 1991; Rodriguez-Kabana et al., 1992a,b; Vargas-Ayala and Rodriguez-Kabana, 2001; Vincente and Acosta, 1987; Weaver et al., 1998), castor bean (*Ricinus communis* L.), cowpea (*Vigna unguiculata* cv. Iron Clay), and American jointvetch (*Aeschynomene americana* L.) (McSorley, 1999). Nematode resistant grasses include oat (*Avena sativa* L.), sorghum (*Sorghum bicolor* (L.) Moensch) and bahiagrass (*Paspalum notatum* Flueggé) (Rodriguez-Kabana et al., 1989).

On the alkaline limestone-derived soils in Miami-Dade County, yellow nutsedge (C*yperus esculentus* L.), is a potentially devastating weed pest in plastic mulch covered tomato and pepper beds, but purple nutsedge (*C. rotundus* L.), is of lesser importance. These two species readily penetrate the plastic mulch. However, our experience has shown that moderate densities of these shade-intolerant nutsedge species can be sufficiently weakened by dense plantings of a cover crop so that subsequently applied plastic mulch is quite effective in suppressing such nutsedge populations. Spiny pigweed, purslane, parthenium, ragweed, nightshade and various grasses, which are annually recurring problems, can also be controlled by a dense cover crop stand followed by application of plastic mulch on the raised bed. On the other hand, all of these weed species must be controlled in the aisles between beds by application of S-metolachlor and metribuzin or other herbicides.

There are significant differences in species of plant-parasitic nematodes typically found in Florida's sandy soils and those found in the calcareous soils in the southeastern Florida (McSorley et al., 1985). Sandy soils are often inhabited by the sting nematode (*Belonolaimus longicaudatus* Rau), the awl nematode (*Dolichodorus heterocephalus* Cobb), and stubby-root nematodes (*Paratrichodorus* spp.), which can affect tomato and pepper, but these species are not prevalent in southeastern Florida soils. However, the root-knot nematode, *Meloidogyne incognita* [(Kofoid & White) Chitwood], is among the most common and important nematode pests of all major vegetable crops and causes economic losses on both soil types.

A combination of crop rotation and genetic resistance is currently hypothesized to be the only major management tool available (other than methyl bromide) that is effective and economical in fields where mixed populations of *Meloidogyne* spp. and *Heterodera glycines* Ichinohe occur (Rodriguez-Kabana et al., 1990, 1998; Weaver et al., 1993). This led us to hypothesize that in soils that are lightly to moderately infested with root-knot nematodes, the use of nematode-resistant cover crops preceding the vegetable crop will allow production of an economic crop without soil fumigation provided that the fields are kept free of weeds that serve as hosts to nematodes.

Materials and Methods

Field experiments were conducted for three years (fall/winter of 2000/01, 2001/02 and 2003/04) at Homestead, Fla. In the first two years, the experiments were conducted at the Tropical Research and Education Center (TREC), University of Florida, Homestead, and in the third year at Pine Island Farms (PIF), a commercial vegetable production farm about 20 miles northeast of TREC. The soil at TREC is Krome, a very gravelly loam (loamy-skeletal, carbonatic hyperthermic lithic Udorthents) consisting of about 33% soil and 67% pebbles (>2 mm). The soil at PIF is Opalocka - Rock Outcrop Complex (sandy, siliceous, hyperthermic lithic Udorthents). The experiment in 2000/01 consisted of three treatments: two cover crop treatments, 'Iron Clay' cowpea and velvetbean (cultivar not specified), and one methyl bromide/chloropicrin (MC-33) treatment at 392 kg ha^{-1} which contained 330 $g \cdot kg^{-1}$ chloropicrin (Helena Chemical Co., Florida City, Fla.). In 2001/02, 'Tropic Sun' sunn hemp was added to the 2000/01 treatments as a third cover crop treatment. Each year the fields were disked three times and raised beds 15-cm high were formed. The experiments were laid out in a randomized complete block design. Each treatment was applied to three raised beds each 13.5-m long by 1.8-m wide (center-to-center). A distance of 5-m separated the various treatments. Plots 6-m long were randomly designated from the middle row for yield determination. There were four replications per treatment in each year. In order to suppress weeds in the aisles between the raised beds, S-metolachlor, and metribuzin were incorporated into the soil after the beds had been formed. If needed, one or more additional in-season applications of metribuzin were made. Fallow plots were maintained weed-free by rototilling.

In 2003/04, the experiment at PIF consisted of four treatments—sunn hemp, velvetbean, an MC-33 soil fumigation treatment following a summer sorghum sudangrass cover crop, and a fallow treatment which was kept weed free. The field was disked as in the previous two years and the raised beds were formed as described earlier. The experiment was laid out in a randomized complete block design with four replications. Each treatment consisted of a double-bed 26-m long with plants spaced 0.6-m within the row. Because of some differences in management practices and dates of various operations from year to year, some imposed by the grower, each year will be described separately.

Year 2000/01. Rhizobium-treated seeds of the leguminous cover crops and sorghum sudangrass were seeded in mid-June using a no-till seeder (Tye no-till drill, AGCO Corp., Lawrenceville, GA). Seeding rates for cowpea and velvetbean were 112 kg·ha^{-1} and 34 kg·ha^{-1}, respectively. The cover crops received no fertilizer during the growing season. They were flail-mowed on 16 Aug. Above-ground samples of biomass were taken and biomass yield was determined. The beds were reseeded and biomass samples were taken again for biomass determination before the crops were flail-mowed on 12 Oct. 2000. The cover crop residues were incorporated into the soil using a spader (Imants Heavy Duty, Imants USA/Autrusa Co., Perkeomenville, Pa.) during the second week of October During the first week of December 2000, dry fertilizer (6N-2.6P-10K) was applied at the rate of 1123 kg·ha^{-1} for the MC-33 treatment and 392 kg·ha^{-1} for the two cover crop treatments. The fertilizer was banded 25-cm on each side of the bed center and rototilled into the soil for all treatments. The beds were then reformed. Immediately thereafter, MC-33 was injected into the appropriate beds at 392 kg ha^{-1}, and two drip lines and white-on-black plastic mulch were laid on all beds. Nematode-tolerant 'Sanibel' tomato seedlings were transplanted into the beds on 19 Dec. 2000. Beginning 15 Jan. 2001, an additional 180 kg·ha^{-1} of N was applied as liquid 4N-0P-6.6K to all treatments through the drip lines twice a week starting at a rate of 1 kg N/ha·day^{-1}, and beginning 8 Feb. 2001, it was increased to 3.6 kg N/ha·day^{-1} up to the first harvest. The rate was thereafter reduced to 1 kg N/ha·day^{-1} up to one week before the final harvest. This made a total of 247 and 214 kg N/ha for the MC-33 and the cover crop treatments, respectively. Due to low prices during that season, only two tomato harvests were made, one harvest on 30 Mar. and the other on 13 April.

Year 2001/02. As in 2000/01, the experiment was laid out in a randomized complete block design with four replications. Rhizobium-treated seeds of cowpea, velvetbean and sunn hemp were seeded on 9 May. Seeding rates for cowpea and velvetbean were as in the previous year and for sunn hemp it was 56 kg·ha^{-1}. On 13 July, the cowpea was flail-mowed at ground level and the sunn hemp was flail-mowed at 25 cm above ground level to induce profuse branching (Abdul-Baki et al., 2001). Residues from the first mowing were left to decompose in the field. The cowpea plots were reseeded on 18 July 2001. Subsequently, on 1 Oct., all three cover crops were flail-mowed and incorporated into the soil. As in the previous year, biomass samples were taken from each treatment before mowing, dried, and total biomass determined. In mid-October the raised beds were reformed and 1235 kg·ha^{-1} of 6 N-2.6 P-10 K fertilizer was applied and rototilled into the soil of all treatments. Two drip lines were installed into each bed, MC-33 was applied to the appropriate treatment as before and the beds were immediately covered with polyethylene mulch. Five-week-old seedlings of 'Leila', a nematode-susceptible cv. were transplanted into the beds on 9 Nov. 2001. As in 2000/01, an additional 180 kg·ha^{-1} was applied as liquid 4N-0 P-6.6 K to all treatments through the drip line, resulting in a total application of 247 kg N ha^{-1} for all treatments. Three harvests were made: 6 Feb., 5 and 25 Mar.

Year 2003/04: The experiment in the third year was conducted at PIF, a commercial production farm described by the grower to have moderate-to-high nematode population densities. Two cover crop treatments were velvetbean and sunn hemp. Two additional treatments were fallow (no cover crop or soil fumigation), and sorghum sudangrass followed by MC-33. This last treatment is commonly used by large-scale conventional growers in south Florida. The cover crops (including sorghum sudangrass, which was part of the MC-33 treatment) were seeded on 9 June and an irrigation system was installed to deliver water as needed. Seeding rate for sorghum sudangrass was 45 kg·ha^{-1} and for the other cover crops, as in previous years.

The fallow plots were kept weed free. On 22 Aug. 2003 the cover crops were prematurely plowed under before the biomass samples could be taken. Fertilizer was applied to all treatments as N6-P6-K12 at an N rate of 247 kg·ha^{-1} and incorporated into the soil. The beds were reformed and MC-33 was injected into the appropriate beds as in previous years. Two drip lines and white-on-black plastic mulch were laid on all beds. On 11 Nov., five-week-old seedlings of 'RTF 6153' (Rogers Seed Co., Greenboro, N.C.) were transplanted. Additional liquid fertilizer (N13-P0-K46) was applied twice-a-week for five weeks starting at fruit set at a rate of 8 kg per application thus bringing the N application to a total of 300 kg·ha^{-1}. All other cultural practices were the same as in the previous two years.

Eight on-vine-ripe fruit harvests were made at the breaker to pink stages between 17 Feb. and 31 Mar. The last harvest included unripe marketable fruits. The fruits were graded in accordance with Florida Tomato Committee standards (Brown, 2000) and separated into extra-large, large, and medium. Market prices during that year were favorable even for medium-size fruits. All cultural operations were done by the grower in the same manner he managed the rest of his large-scale tomato field. Pesticides were applied according to standard growers' practices (Maynard and Olson, 2000).

Nematode and root health evaluation. Root-knot nematode gall ratings were evaluated on 250 cm^3 soil samples taken at three time intervals during the 2003/04 production season: before seeding the cover crops; before transplanting the tomatoes; and at the end of tomato harvest. Likewise, tomato root health was determined at the end of harvest by examining root necrosis caused by root rot (primarily *Rhizoctonia solani* Kühn), and gall formation by the root-knot nematode. Five randomly selected plants were taken from each replication for evaluation. In each case a 0 to 5 scale was used as proposed by Taylor and Sasser (1978) for evaluating nematode density and by Coyler (1988) for root rot.

Statistical Analysis. Data were analyzed statistically using analysis of variance (ANOVA) and Duncan's multiple range test using SAS (Version 8.1, SAS Inst., Inc., Cary, N.C.).

Results and Discussion

Cover crop biomass. Biomass data for 2000/01 and 2001/02 appear in Table 1. In 2003/04, the cover crops were disked and plowed about one month before they reached the optimum termination stage and before biomass samples could be taken. Velvetbean biomass in both years 2000/01 and 2001/02 was consistently high (14.3 and 15.4 Mg·ha^{-1}). Cowpea biomass fluctuated between high (10.6 Mg·ha^{-1}) in 2000/01 and moderate (6.3 Mg·ha^{-1}) in 2001/02. Because of delayed seeding, sunn hemp biomass in 2001/02 fell in between that of velvetbean and cowpea. All three leguminous cover crops were selected to serve two main purposes: firstly to fix N and recycle other nutrients in order to reduce the input of synthetic fertilizer; secondly to suppress plant-parasitic nematodes including root-knot nematode. Based on these two properties, N input from commercial sources could be substantially reduced and soil fumigation could be eliminated, thus significantly reducing production cost and protecting

Table 1. Biomass of cover crops in 2000/01 and 2001/02 prior to mowing and incorporating into soil before tomato transplanting.

Year	Treatment	First mowing[z]	Second mowing	Total
		Biomass dry wt (Mg ha^{-1})		
2000/01	MC-33	—	—	—
	Velvetbean	7.0 a[y]	7.5 a	14.3 a
	Cowpea	7.8 a	2.8 b	10.6 b
2001/02	MC-33	—	—	—
	Velvetbean	—	15.4 a	15.4 a
	Cowpea	4.4 c	1.9 c[z]	6.3 c
	Sunn hemp	5.7 b	5.8 b	11.6 b

[z]Biomass of the first and second mowing in 2000/01 represent two consecutive cover crop plantings whereas biomass from 2001/02 cover crops represents two mowings from a single cover crop except for the cowpea treatment that was seeded twice.
[y]Values in same column followed by the same letter are not significantly different ($P \le 0.05$) according to Duncan's multiple range test.

the environment. Unfortunately, neither expectation was properly met. A delay of almost two months between killing the cover crops and transplanting the tomatoes during the hot, humid fall season was long enough to allow the biomass to decompose and an appreciable part of the N to mineralize and leach from the soil before the tomato plants could use it. As a result, commercial NPK fertilizer was applied at the full rate (at an N rate of 250 to 300 kg·ha^{-1}) normally applied by the growers for growing tomatoes conventionally in south Florida. Nitrogen provided by the cover crops (about 2.5% of the dry biomass) added to N applied as commercial fertilizer was much more than the total N recommended in any state for growing tomatoes. For example, this sum is far above the average of 160 to 180 kg·ha^{-1} recommended for growing tomatoes in the Mid-Atlantic States (Maryland Coop. Exten., 2003). It is possible that higher N rates are needed in the high pH soils of south Florida because ammonia volatilization in high pH soils occurs at a high rate (Fenn and Hossner, 1985) and growers tend to over-irrigate, which causes nutrient loss through leaching and reduces yields (Li et al., 1998; Wang et al., 2002a).

Unfortunately the field at TREC where we conducted our research in 2000/01 and 2001/02 had almost no root-knot nematodes, although it had been used for growing vegetables for several years without any soil fumigation. However the overall density of the root-knot nematode population at PIF was higher than at TREC. Nematode numbers in all treatments (Table 2) were higher at tomato harvest time than at the other earlier sampling date, which is normally the case, the nematode population at PIF on all sampling dates remained fairly low and never reached an economic threshold in any of the treatments at any soil sampling date. The grower had been fumigating the soil with MC-33 every year before planting tomatoes probably because this field has a history of infection with *Fusarium solani* race 3.

It is likely that many growers fumigate their fields regularly at the beginning of the planting season without determining if soil-borne pathogen, nematode and nutsedge populations are high enough to require soil fumigation. In order to limit soil fumigation only to fields where one or more of these populations are high enough to inflict economic losses, growers should monitor their fields before planting the crop to determine whether such a treatment is needed.

Variables affecting yield and grade. Yields and grades for 2000/01, 2001/02, and 2003/04 appear in Tables 3, 4 and 5, respectively. There were several variables during the three production years that affected yield and grade, and ultimately net returns. These included: location, cultivar, disease severity, and prices. Higher yields at PIF in 2003/04 than at TREC in 2000/01 and 2001/02 may be, in part, attributed to higher fertilization rates, better soil, and cultivar selection. With regard to cultivar, 'Sanibel'—a nematode-resistant cultivar was used in 2000/01; 'Leila', a nematode-susceptible cultivar was used in 2001/02, and 'RTF 6153'—an indeterminate disease-resistant cultivar was used in 2003/04. As for infection by foliar diseases, 2001/02 was the most severe year. During the growing season, heavy dew formation during many nights facilitated the destruction of a large-portion of the surface area of the foliage by Alternaria leaf blight (*Alternaria solani* [Ellis & Martin]) and by target spot (*Corynespora cassicola* [Berk. & MA Curtis]). In contrast, infection by pathogens was low in 2000/01 and 2003/04. Finally, prices were very low in both 2000/01 and 2001/02. Only two harvests were made in 2000/01 and three in 2001/02. In contrast, prices were favorable in 2003/04 for vine-ripe tomatoes sold at local markets. Consequently, eight harvests were made in that year. Because of differences in these major variables from year to year, and because a major objective was to compare yields among treatments, we chose to limit the comparisons among treatments only to those within the same year as presented below:

Yields and grades of 2000/01 and 2001/02 harvests. The number of harvests per crop depended largely on prices and the health of the plants. In both 2000/01 and 2001/02, market prices of picked-mature green tomatoes during the two seasons were poor. So, only extra-large and large fruits comprised total marketable yields (Tables 3 and 4). In both years, total marketable yield of extra-large and large fruits in every treatment were above the 39.3 Mg·ha^{-1} average for Miami-Dade County which also included the medium grade together with the extra large and large grades in the reported yields.

In 2000/01, total extra-large fruits per season from MC-33, cowpea, and velvetbean were equal, whereas yield of large fruits was highest in MC-33 and lowest in cowpeas (Table 3). In all treatments, the ratio of extra-large to large fruits was

Table 2. Effects of cover crops and soil fumigant on root-knot nematode (*Meloidogyne incognita*) densities prior to treatment, before tomato transplanting, and after tomato harvest, and on root health after harvest at Pine Island Farms in 2003/04.

Treatment	Root-knot nematodes No./250 cm^3 soil			Root-knot nematode gall rating after tomato harvest	Root-rot rating after tomato harvest
	Before treatment	Before tomato transplanting	After tomato harvest		
Velvetbean	13.8 a[z]	10.4 a	59.9 a	2.7 a[y]	0.27 a[x]
Sunn hemp	12.8 a	12.2 a	72.1 a	3.2 a	0.38 a
Fallow	19.2 a	10.6 a	68.1 a	3.2 a	0.20 a
MC-33	11.7 a	9.8 a	61.8 a	3.6 a	0.13 a

Table 3. Yields of extra large, large, and total marketable 'Sanibel' tomatoes grown under conventional and cover cropping systems at the Tropical Research and Education Center during 2000/01.

	Treatment		
Harvest and Grade	MC-33	Cowpea	Velvetbean
First harvest (H1)	Yield (Mg ha^{-1})		
Extra-large	28.64 a^z	25.30 a	28.13 a
Large	19.20 a	13.10 b	19.40 a
Total marketable	47.84 a	38.40 b	47.53 a
Second harvest (H2)			
Extra-large	3.74 a	3.52 a	3.15 a
Large	25.00 a	19.30 b	18.10 b
Total marketable	28.74 a	22.82 b	21.25 b
Total (H1+H2)			
Extra-large	32.38 a	28.82 a	31.28 a
Large	44.20 a	32.40 c	37.50 b
Total marketable	76.58 a	61.22 c	68.78 b

^{z}Values within the same row followed by the same letter are not significantly different (P ≤ 0.05) according to Duncan's multiple range test.

very high (59-66% of total marketable) in the first harvest and continued to be moderately high (13-15% of total marketable yield) in the second harvest, reflecting a vigorous and healthy crop.

Yields of large and total marketable fruits in 2001/02 were considerably lower than in 2000/01 in all treatments (Table 4). Marketable yields with the MC-33, cowpea and velvetbean treatments were 44, 22, and 35% lower in 2001/02 than in 2000/01, respectively. Likewise, reductions in extra-large fruit yields in the MC-33 and velvetbean treatments were 11 and 15%, respectively. These reductions in both large and total marketable yields in 2001/02 were attributed to high incidence of foliar pathogens. The cowpea treatment in 2001/02 yielded significantly higher extra-large and total marketable fruit than the MC-33 and the velvetbean treatments in contrast to 2000/01 in which MC-33 exhibited significantly higher total marketable yield than the cowpea and velvetbean treatments.

Table 4. Yields of extra large and total marketable 'Leila' tomatoes grown under conventional and cover cropping systems at the Tropical Research and Education Center during 2001/02.

	Treatment			
Harvest and Grade	MC-33	Cowpea	Sunn hemp	Velvetbean
First harvest (H1)	Yield (Mg ha^{-1})			
Extra-large	19.67 a^z	16.82 ab	15.52 ab	13.05 b
Large	5.70 a	3.30 b	4.30 ab	3.40 b
Total marketable	25.37 a	20.12 b	19.82 b	16.45 b
Second harvest (H2)				
Extra-large	7.54 b	15.14 a	13.86 a	12.14 a
Large	3.70 b	5.20 a	7.70 a	9.20 a
Total marketable	11.24 b	20.34 a	21.56 a	21.34 a
Third harvest (H3)				
Extra-large	1.58	2.38	1.74	1.42
Large	4.60	5.30	7.00	5.60
Total marketable	6.18	7.68	8.74	7.02
Total (H1+H2+H3)				
Extra-large	28.79 b	34.34 a	31.12 ab	26.61 b
Large	14.00 b	13.80 b	19.00 a	18.20 a
Total marketable	42.79 c	48.14 ab	50.12 a	44.81 bc

^{z}Values within the same row followed by the same letter are not significantly different (P ≤ 0.05) according to Duncan's multiple range test.

Yield and grade of 2003/04 harvest. It is not unusual for growers to make on the spot decisions based on market prices. In 2003/04, the price of green-picked tomatoes was poor whereas the price of vine-ripe tomatoes to meet the needs of the local market was favorable. So the collaborating grower decided to pick vine-ripe and market locally. The healthy crop and the local demand for vine-ripe tomatoes supported the decision of harvesting eight times. Breaker to pink stage tomatoes were harvested every five days and the fruits were graded into extra-large, large, and medium (Table 5).

Total tomato yields of sorghum sudangrass/MC-33, velvetbean, and sunn hemp treatments were higher than those in the previous two years based on the grower's records. Yield differences among these three treatments in 2003/04 were not significant in total marketable yield, extra-large, large or medium grades. However, total marketable and large fruit yield yields with all three treatments were significantly higher than in the fallow treatment. The highest extra-large fruit yield occurred with the sunn hemp treatment.

Keeping the land fallow in summer is one of the common practices of vegetable growers in south Florida. Another frequent practice is to grow sorghum sudangrass in summer, plow it under in the fall, and apply MC-33 before planting the tomatoes. The rationale behind this practice is to have the sorghum sudangrass intercept nutrients that are left in the soil at the end of the previous growing season and recycle them, as well as to add some organic matter to the soil at a minimal management cost. While these two objectives contribute to conservation of nutrients and improvement of soil, the high C/N value in sorghum sudangrass tends to tie up any available N and render part of it unavailable to the subsequent crop (Clark et al., 1994, 1997). However, the sorghum sudangrass, which was part of the MC-33 treatment, did not reduce the yield probably because the treatment received very high rates of commercial N fertilizer.

Economic Assessment. Net returns, defined as the difference between gross returns and total cost, with the MC-33 treatments and the cover crop systems are shown in Table 6. The budget used for the tomato systems studied was a modification of a recent budget for the MC-33 system published by Smith (2000). Preharvest production costs included fertilizer, chemicals, seed, labor, equipment use (operation, maintenance, fuel, and depreciation), other materials (including

Table 5. Yields of extra large, large, medium, and total marketable 'RTF 6153' tomatoes grown under conventional and cover cropping systems at the Pine Island Farms during 2003/04.

	Treatment			
Grade	Sorghum sudan/MC-33	Velvetbean	Sunn hemp	Fallow
	Yield (Mg ha^{-1})			
Extra-large	56.58 ab^z	55.59 ab	66.15 a	45.06 b
Large	25.32 a	24.42 a	23.09 a	15.98 b
Medium	5.40 a	5.11 a	4.02 a	4.64 a
Total	87.30 a	85.42 a	93.26 a	65.68 b

^{z}Values within the same row followed by the same letter are not significantly different (P ≤ 0.05) according to Duncan's multiple range test.

Table 6. Economic summary of tomato production under alternative cover crop systems, in years 2000/01, 2001/02, 2003/04 (in $·ha^{-1}, rounded to the nearest $10).

Year	Production system	Gross returns per fruit size[z] XL	L	M	Total	Cost Pre-harvest	Harvest & marketing	Total	Net returns
2000/01	MC-33	25580	31020		56600	16490	23180	39670	16930
	Cowpea	22730	22740		45470	14920	18520	33440	12030
	Velvetbean	24710	26320		51030	14900	20820	35720	15310
2001/02	MC-33	22660	9970		32630	16490	12990	29480	3150
	Cowpea	27080	9620		36700	15060	14530	29590	7110
	Velvetbean	21000	12780		33780	15030	13560	28590	5190
	Sunn hemp	24550	14030		38580	15190	15460	30650	7930
2003/04	SS/MC-33	57380	23440	4760	85580	18000	26560	44560	41020
	Fallow	45700	14800	4090	64590	15750	19980	35730	28860
	Velvetbean	56370	22610	4510	83490	15850	25900	41750	41740
	Sunn hemp	67080	21380	3550	92010	16070	28370	44450	47560

[z]Gross returns are based on the following prices received for 11.4 kg (25-lb) cartons: 2000/01: size XL—$9.00, size L—$8.00; 2001/02: size XL—$9.00, size L—$8.00; 2003/04: size XL—$11.50, size L—$10.50, size M—$10.00

plastic mulch and string), and land rental. One notable preharvest cost was the fumigant in the MC-33 system. In 2000/01 and 2001/02, this cost $1,544/ha, and in 2003/04 the price had risen to $2,162/ha. In the cover crop systems there were additional costs for seeds, seeding, and mowing. All other preharvest costs were the same for all treatments. Labor for picking, hauling, and packing in all systems was accounted for with the costs for harvesting and marketing, which also included containers, use of hauling and packing equipment, sales and organizational fees. Annual input costs were adjusted by the USDA-National Agricultural Statistics Service's agricultural input price index (www.usda.gov/nass/graphics/data/paid.txt). Weekly Miami Terminal market prices for tomatoes were obtained from the USDA's Agricultural Marketing Service (www.ams.usda.gov/fv/mnprice.htm), and averaged over the harvest season. In 2000/01 and 2001/02, prices for 11.4-kg (25-lb) cartons of extra-large and large "vine ripes" were $9.00 and $8.00, respectively. In 2003/04, prices for extra-large, large, and medium size vine ripes were $11.50, $10.50, and $10.00, respectively.

In all years, every treatment produced positive net returns (Table 6). In 2000/01, the range of net returns was from $16,930/ha down to $12,030/ha, while in 2001/02, the range was from $7,930/ha down to $3,150/ha. In 2003/04, the range was considerably higher, from $47,820/ha down to $28,860/ha. In 2001/02 and 2003/04, extra-large fruits were responsible for the majority of revenue. Yield and market price determined the magnitude of returns. Net returns in 2001/02 were much lower than in 2000/01, due in part to greatly reduced yield of large size tomatoes, even though yield of extra-large sized fruit did not change drastically and market prices were the same. In 2003/04, market prices had increased 22% from 2001/02 for extra-large tomatoes and 31% for large fruit. Coupled with a substantially increased yield in both of those size categories and the additional harvest of medium sized fruit, net returns in 2003/04 were by far the greatest of the three study years. While all returns were positive, cover crop systems were less profitable than the MC-33 system in 2000/01, but in 2001/02 and 2003/04 cover crop systems were more profitable than the MC-33 system. Among the cover crops, sunn hemp appeared to produce the best results. In years when the sunn hemp treatment was used, it brought the highest net returns of all treatments.

Use of cowpea, sunn hemp, and velvet bean cover crop systems appears promising. It is encouraging to obtain marketable tomato yields from these cover crop treatments that are equal to or better than those obtained with MC-33. In addition to the favorable economic results obtained here, cover crops offer several advantages to growers, and the environment that have not been quantified in the economic calculations presented here, and are not available with the MC-33 system. These benefits include the addition of organic matter to the soil, which enhances soil fertility and biological activities of soil microorganisms, and improves water and nutrient holding capacity and water use efficiency (Brandi-Dohrn et al., 1997; Karlen and Doran, 1991; Wang et al., 2005). Not using fumigants also contributes to greater biological activity in the soil, and improved soil ecosystem functioning. We recognize that the tests were not performed in soils with high nematode populations that would provide a rigorous challenge to the cover cropping systems. Therefore we suggest that additional experiments in the future be carried out in soils more heavily infested with major pathogen, nematode and weed populations than the soils of the present experiments.

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