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Fresh-market Tomato Production in a Low-input Alternative System Using Cover-crop Mulch

Aref A. Abdul-Baki[1]
Vegetable Laboratory, Plant Sciences Institute, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, MD 20705

J.R. Teasdale
Weed Science Laboratory, Plant Sciences Institute, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, MD 20705

R. Korcak
Fruit Laboratory, Plant Sciences Institute, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, MD 20705

D.J. Chitwood and R.N. Huettel
Nematology Laboratory, Plant Sciences Institute, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, MD 20705

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***Abstract.* A low-input sustainable agricultural system for the production of staked, fresh-market field tomatoes (*Lycopersicon esculentum* Mill.) is described. The system uses winter annual cover crops to fix N, recycle leftover nutrients, produce biomass, and prevent soil erosion throughout the winter and spring. Yields of tomato plants grown in hairy vetch (*Vicia villosa* Roth), crimson clover (*Trifolium incarnatum* L.), and rye (*Secale cereale* L.) plus hairy vetch mulches were higher than those grown in the conventional black polyethylene (BP) mulch system in 2 of 3 years. Fruit were heavier with the plant mulches than with BP mulch. Eight weeks after transplanting, N levels in tomato leaves were higher with plant than with BP mulch, although the plant mulch plots received only 50% of the N applied to the BP plots. The cover crops had no effect on populations of five phytoparasitic nematode species.**

Vegetable production in the United States depends on high-input systems to maximize yield and product quality and to achieve low production costs that keep U.S. products competitive in international markets (Shennan, 1992). Management practices in these systems depend heavily on using commercial fertilizers (Power, 1987), black polyethylene (BP) mulch (Abdul-Baki et al., 1992; Hochmuth et al., 1986; Schales, 1989), and tillage (Jamnick and Klindt, 1985).

Nitrogen from synthetic sources is essential in these high-input systems to maintain fertility levels, especially on soils of low fertility. In the mid-Atlantic states, the general recommendation for fresh-market tomatoes ranges from 80 to 200 $kg \cdot ha^{-1}$ for soluble N applied several times throughout the production season through a trickle system (Rutgers Cooperative Extension, 1994). Many farmers, however, apparently apply N in excess of the recommended rates. Consequently, nitrates from N fertilizer sources have been a major contaminant of surface and groundwater in 17 states of the United States (Meisinger et al., 1991; National Research Council, 1989).

Polyethylene mulches are primarily used to reduce competition by weeds (Teasdale and Colacicco, 1985) and to raise soil temperatures early in the production season (Ashworth and Harrison, 1983). Results of a national survey showed that 85,000 ha of mulch were used in the United States for growing vegetables during 1988 and that 87% of this plastic mulch was low-density, nondegradable, BP mulch (Schales, 1989). Nondegradable polyethylene mulches cost about $1250/ha to buy, lay, and dispose (Kelly et al., 1995).

Tillage enhances soil erosion, particularly on sloping lands (Jamnick and Klindt, 1985), and stimulates the germination of weed seeds. As a result, conservation tillage is being widely adopted for field crop production. These three production components (N, polyethylene mulch, and tillage) comprise a significant portion of the production costs for conventional large-scale production of fresh-market tomatoes.

There is a growing demand for alternative cultural practices, with an emphasis on reducing off-farm input of labor and chemicals. One such alternative, which would circumvent the need for a synthetic source, polyethylene mulch, and tillage, is using winter annual legume cover crops in a vegetable crop rotation (Abdul-Baki and Teasdale, 1993). The purpose for which the cover crop is to be used dictates the selection of the species and its subsequent management (Decker et al., 1992). An ideal cover crop in a sustainable vegetable production rotation should fix, immobilize, and recycle N. It also should produce a large quantity of biomass that can serve as an effective mulch and a source of essential nutrients to be used by the following vegetable crop (Hargrove and Frye, 1987; Hoyt and Hargrove, 1986; Shelton and Bradley, 1987; Somda et al., 1991).

Winter annuals have been used for some time in rotations of some major field crops (Hoyt, 1987; Hoyt and Hargrove, 1986). However, incorporating winter annual legumes into vegetable production rotations has received limited interest (Ashworth and Harrison, 1983; Shennan, 1992; Stivers and Shennan, 1991). Our purpose was to evaluate winter annual cover crops that would fit into a low-input tomato production system and to compare these cover crops with standard noncover crop practices.

Materials and Methods

Experiments were conducted over 3 years (1992 to 1994) on the North Farm of the Beltsville Agricultural Research Center, Beltsville, Md. The field has a Keyport fine sandy loam, Aquic Hapludult, clayey, mixed, mesic soil, with a 2% slope. Fresh-market tomato cultivars suited to staked culture were grown: 'Sunny' in 1992 and 'Sunbeam' from 1993 to 1994. In the first year, five mulches (Horto paper, BP, hairy vetch, crimson clover, and a combination of hairy vetch and rye) were compared to bare soil (no mulch). In the second year, hairy vetch, crimson clover, and BP were compared to bare soil. Hairy vetch and BP mulch were compared on larger plots in the third year. By the third year, the intent was to develop a single mulch system for in-depth analysis (data not presented). Hairy vetch has proven to be the most reliable cover crop under Maryland conditions (Holderbaum et al., 1990).

The mulch treatments were arranged in a randomized complete-block design with two blocks. There were six mulch treatments in 1992, four in 1993, and two in 1994. Each treatment in each block had two subplots along the same row in 1992, two to four subplots on adjacent rows in 1993, and six subplots on two adjacent rows in 1994. Treatments were separated by a single bed covered with BP mulch. In 1994, each mulch treatment consisted of four beds in which the outer bed on each side served as a border row and the inner two rows were used for data collection. Each subplot consisted of 15 tomato plants. Analysis of variance was performed on the tomato data sets in 1992 and 1993, and if the experimental error did not differ significantly from the subplot (sampling) error, these errors were pooled.

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[1]To whom reprint requests should be addressed.

The tests with tomato were part of a larger experiment containing other crops in 1994. The 1994 analysis of variance included crops as one factor and mulches as a second factor but only the data for tomato are presented.

Field preparation and seeding for all the cover crop mulch treatments were performed in September and included plowing, disking, and preparing raised beds, 1.50 m center to center and 15 cm high. No lime or K was incorporated at this time. A Brillion seeder (Brillion Iron Work, Brillion, Wis.) was used to sow seeds at 45, 28, and 84 $kg\cdot ha^{-1}$ for hairy vetch, crimson clover, and rye, respectively.

The cover crops grew ≈15 cm in the fall. Growth resumed by late March. At mowing time, the heights of hairy vetch, crimson clover, and rye were 1.5, 1.7, and 0.6 m, respectively. A 1-m-square sample of biomass was taken from each of the two replications, representing each cover crop treatment, for nutritional analysis. The material was oven-dried at 70C for 1 week, ground, and used to assess nutrient composition.

Cover crops are killed either by plowing under to serve as green manures in a conventional tillage system or by desiccating with herbicides to serve as a mulch in a no-tillage system. We introduced mowing to provide an alternative to herbicide application for converting the cover crop into a mulch. On the same day the tomatoes were transplanted, cover crops were mowed with a high-speed flail mower (Hesston Corp., Oregon, Ill.) 5 cm above the bed surface without disrupting the soil to form a uniform layer of residue several cm thick. At the time of mowing, vetch was vegetative, crimson clover was at the early flowering stage, and rye was approaching the milk stage.

The three noncover crop treatments consisted of BP (1.5 m wide, 2.5×10^{-2} mm thick) mulch, Horto paper (a brown biodegradable paper; Mellingers, North Lima, Ohio), and bare soil (no mulch). Beds were formed and the mulches were laid 1 week before transplanting. The BP mulch was laid by machine and Horto paper mulch was laid by hand. One trickle irrigation line (Turbo Tape, San Diego) (2.5×10^{-1} mm thick; 30-cm emitter spacing; 350 $liters\cdot h^{-1}$ per 100-m line) was buried in each bed 5 cm below the soil surface and 10 cm away from the plants.

Five-week-old tomato plants were transplanted into the plots by hand immediately after mowing in 1992 and by using a Holland punch-type planter (Holland Co., Holland, Mich.) in 1993 and 1994. The Holland punch-type planter opened holes 10 cm wide and 10 cm deep in the soil, dropped the transplant, and pressed the soil and mulch around it. Tomatoes were planted during the second week of May in each of the three years. Following planting, the trickle irrigation lines were laid on the surface of the beds that comprised the plant mulch treatments; the emission pores were directed downward and were held in position with U-shaped wires at 6-m intervals along the row and a 10-cm distance from the plants.

Management practices of the tomato crop were typical of those used in growing staked fresh-market tomatoes (Abdul-Baki et al., 1992). The plants were not pruned. They were staked and supported by three tiers of twine to avoid fruit contact with soil. Water was supplied as needed to maintain a soil water level close to field capacity. Tensiometers were installed at random locations in the row of various mulch treatments to estimate irrigation requirements. Each drip line was provided with an on–off switch valve that allowed regulating the delivery of water and fertilizer to individual beds and prevented leakage of fertilizers from one bed to another.

A preplant soil test revealed a high P level (840 $kg\cdot ha^{-1}$). At planting, Peter's plant starter ($9N–45P_2O_5–15K_2O$; Grace Sierra Horticultural Products Co., Milpitas, Calif.) was delivered to plants through the transplanter at 0.28 kg fertilizer/100 liters water. Subsequent applications of N were in the form of NH_4NO_3 delivered through the trickle system at 112 kg N per mulched hectare per growing season for the bare soil, Horto paper, and BP mulches and half that for the cover-crop mulch treatments. The fertilizer was applied weekly for 14 weeks in equal portions starting 10 days after planting.

Postemergence weed control consisted of applying 4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one (metribuzin) at 0.56 $kg\cdot ha^{-1}$ and 2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one (sethoxydim) at 0.22 $kg\cdot ha^{-1}$ as required for the particular mulch treatment. Insects and pathogens were monitored using the integrated pest management system of the Univ. of Maryland, College Park. The field was scouted three times a week and pesticides were applied as recommended.

Changes in populations of five phytoparasitic nematode genera in the soil under each mulch treatment were monitored and included the root-knot (*Meloidogyne*), the lesion (*Pratylenchus*), the stunt (*Tylenchorhynchus*), the spiral (*Helicotylenchus*), and the lance (*Hoplolaimus*) nematodes. Soil samples were removed with a 2.0×25-cm soil probe; each sample consisted of a 20-core composite. Samples were collected on 24 May (early count), 11 July (midseason count), and 9 Sept. (late count). Vermiform nematodes were extracted from 100-ml subsamples of soil with centrifugal flotation (Jenkins, 1964), identified to genus, and counted on a stereomicroscope.

Yields of 15 tomato plants per replication were estimated by harvesting every 2 to 4 days at the breaker to pink stages from early July to the second week of September. Early fruiting was defined as fruit harvested during the first 2 weeks of the harvest season. Average fruit weight was determined in 1992 on three consecutive harvest dates (8, 11, and 14 Aug.) made in the midseason.

Table 1. Biomass production and macronutrient analysis of cover crops in Beltsville, Md., harvested the second week of May.

Year	Cover crop	Biomass ($t\cdot ha^{-1}$)	Macronutrients ($kg\cdot ha^{-1}$) N	P	K
1992	Hairy vetch	4.95 a[z, y]	188 a	30.2 a	154 a
	Crimson clover	4.22 a	120 c	16.9 b	137 a
	Hairy vetch + rye	5.91 a	151 b	28.5 a	159 a
1993	Hairy vetch	4.36 b	167 a	26.6 a	136 a
	Crimson clover	5.68 a	162 a	22.8 a	185 a
1994	Hairy vetch	5.18	197	31.6	161

[z]Values are averages of four subsamples of the biomass collected.
[y]Values followed by the same letter within columns are not significantly different according to the least significant difference test at $P \leq 0.05$.

Table 2. Total marketable yield, early yield, and average fruit weight of fresh-market tomatoes growing under different mulches.

Cultivar/mulch	Total marketable yield ($t\cdot ha^{-1}$)	Early fruiting ($t\cdot ha^{-1}$)	Avg fruit wt (g)
	1992		
Sunny			
Bare soil (no mulch)	33.7 b[z]	4.0 bc	157 b
Horto paper	31.5 b	4.6 b	140 b
Black polyethylene	46.3 b	9.9 a	153 b
Crimson clover	71.7 a	1.4 d	200 a
Hairy vetch	91.6 a	1.7 cd	191 a
Rye + hairy vetch	81.8 a	1.2 d	202 a
	1993		
Sunbeam			
Bare soil (no mulch)	77.4 b	10.0 b	
Black polyethylene	88.0 ab	14.9 a	
Crimson clover	93.1 a	7.8 bc	
Hairy vetch	95.8 a	7.3 c	
	1994		
Sunbeam			
Black polyethylene	64.6 b	15.8 a	
Hairy vetch	93.2 a	2.8 b	

[z]Mean separation within columns and years by protected least significant difference test at $P \leq 0.05$.

Nutrient analysis of the tomato leaves was performed on samples taken at 8 weeks after planting from two replications of each treatment. Ten uppermost fully developed leaves of similar physiological age were washed in 0.1% sodium lauryl sulfate solution, rinsed with deionized water, forced-air-dried at 70C overnight, and ground to pass through a 0.6-mm sieve opening. Analysis of P, Ca, Mg, K, Mn, and B was performed by plasma emission spectroscopy and total N by Kjeldahl (Baker et al., 1964).

Results

All cover crops produced a high quantity of biomass that provided a uniform, dense layer of mulch in each year (Table 1). Hairy vetch had higher percent N in its biomass compared to the other cover crops. Its total N content ranged from 167 to 197 kg•ha^{-1} and was higher than that for crimson clover in 1992. Crimson clover contained more K than hairy vetch in 1993 but less P than the other cover crops in 1992. The tomato plants grown with plant mulches yielded more than those from the other treatments, including the standard BP mulch, in every year except 1993 (Table 2). The same trend was apparent in 1993, but results were not statistically significant at $P \leq 0.05$. Furthermore, the 1992 data showed that average fruit weight for the plant mulch plots was higher than that for the other treatments. The main advantage of the BP mulch was enhancement of early fruiting.

The leaves of tomato plants grown with BP mulch senesced earliest in all years. Consequently, the harvest season with hairy vetch was ≈3 weeks longer than with BP, and the harvest during these 3 weeks was ≈40% of the total yield (Fig. 1).

Analyses of the tomato leaves showed an increase in leaf N with all cover crops compared to the other mulch treatments and bare soil over all 3 years (Table 3). The N concentration of plants grown under BP or Horto paper in 1992 was suboptimal (Reuter and Robinson, 1986).

In 1992, tomato leaf P varied among treatments, with leaves from rye plus hairy vetch mulch containing more than those grown with BP mulch (Table 3). The hairy vetch mulch led to significantly higher leaf P concentrations than BP mulch in 1994, while there were no significant differences among treatments in 1993. Foliar K differed among treatments similar to leaf P. Both foliar P and K concentrations were within adequate crop requirement levels (Winsor and Adams, 1987).

Foliar Mg concentrations were not affected by treatment in 1992, highest with crimson clover mulch in 1993, and higher with BP mulch in 1994. In general, foliar Mg concentrations were adequate for tomato (Winsor and Adams, 1987).

Foliar Ca and Mn were affected little by treatments throughout the three years (data not shown) but were within optimal ranges for tomato (Reuter and Robinson, 1986). Foliar B concentration was similar for all treatments in 1992, ranging from 44 to 48 µg•g^{-1}. Foliar B levels, however, were significantly lower with all mulches compared to BP mulch in 1993 and 1994. For example, in 1994, foliar B concentrations were 50 and 32 µg•g^{-1} with BP and hairy vetch mulches, respectively.

Populations of the five most common phytoparasitic nematode genera started low early in the growing season and remained below the levels that would cause economic losses to the tomato crop (Table 4). Furthermore, there was no significant increase in the population of any of the five species in the hairy vetch treatment relative to the bare soil or BP treatment.

Discussion

We present a low-input, alternative system for fresh-market tomato production. This alternative system is based on the realization that sustainability on the farm is achieved and maintained through production practices that

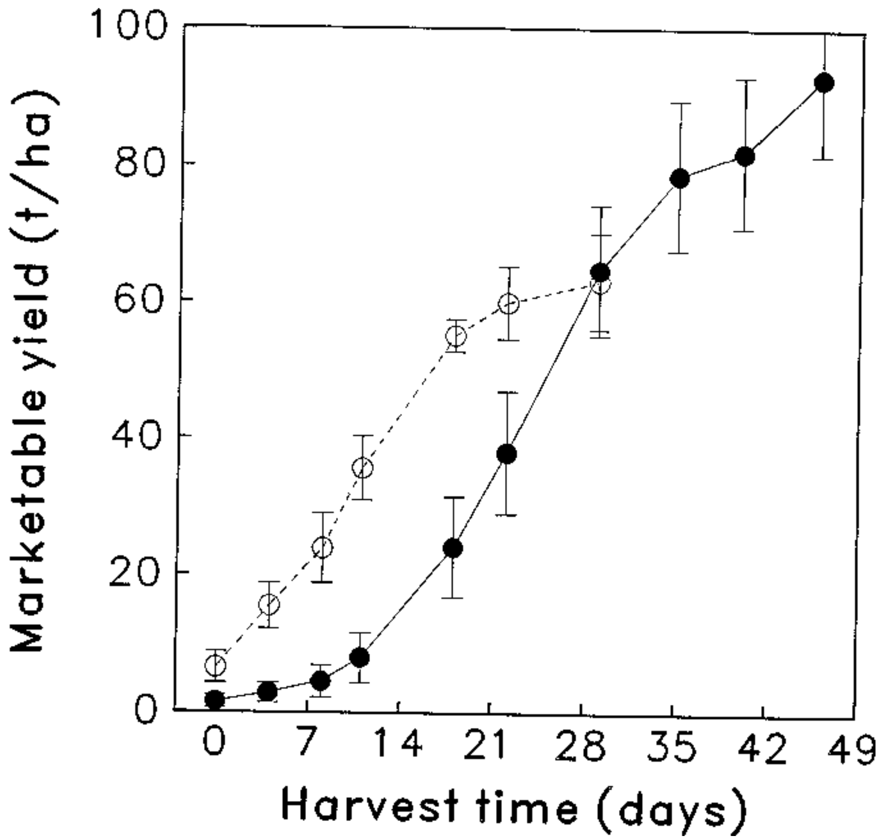

Fig. 1. Cumulative yield of 'Sunbeam' fresh-market tomato grown with black polyethylene (open circles) and hairy vetch (closed circles) mulches, 1994.

Table 3. Macronutrient composition of tomato leaf samples taken 8 weeks after field-planting fresh-market tomatoes grown under different mulches over 3 years.

Year, cultivar, and mulch	Macroelement (% dry wt) N	P	K	Mg
1992				
Sunny				
Bare soil (no mulch)	2.3 b[z]	0.49 ab	2.55 ab	0.44 a
Horto paper	2.2 b	0.49 ab	2.23 b	0.42 a
Black polyethylene	1.9 b	0.48 b	2.24 b	0.33 a
Crimson clover	2.7 a	0.51 ab	2.78 ab	0.33 a
Hairy vetch	3.2 a	0.54 ab	3.00 a	0.33 a
Rye + hairy vetch	3.0 a	0.60 a	3.18 a	0.36 a
1993				
Sunbeam				
Bare soil (no mulch)	3.8 b	0.51 a	3.3 b	0.39 c
Black polyethylene	3.8 b	0.54 a	4.06 a	0.46 b
Crimson clover	4.4 a	0.55 a	4.01 ab	0.52 a
Hairy vetch	4.5 a	0.55 a	3.74 ab	0.45 bc
1994				
Sunbeam				
Black polyethylene	2.9 b	0.44 b	2.95 b	0.56 a
Hairy vetch	3.7 a	0.61 a	4.28 a	0.49 b

[z]Mean separation within columns by least significant difference test at $P \leq 0.05$.

Table 4. Changes in phytoparasitic nematode populations during the growing season as affected by mulch type.

		Root knot (*Meloidogyne*)			Lesion (*Pratylenchus*)			Stunt (*Tylenchorhynchus*)			Spiral (*Helicotylenchus*)			Lance (*Hoplolaimus*)		
		Time of season[z]			Time of season[z]			Time of season[z]			Time of season[z]			Time of season[z]		
Mulch	Year	E	M	L	E	M	L	E	M	L	E	M	L	E	M	L
Bare soil	1992	---	---	---	---	3	5	---	2	3	---	12	140	---	---	---
	1993	8[y]	0	0	7	2	38	18	4	0	0	17	30	0	51	42
Horto paper	1992	---	---	---	---	1	1	---	5	6	---	0	3	---	---	---
	1993	8	0	0	7	1	1	18	6	3	0	6	84	---	---	---
Crimson clover	1992	---	---	---	---	3	7	---	4	25	---	6	363	---	---	---
	1993	0	0	0	6	0	79	2	4	14	15	0	6	4	21	7
Black polyethylene	1992	---	---	---	---	2	10	---	5	24	---	9	55	---	---	---
	1993	0	0	0	6	0	79	2	4	14	15	0	6	4	21	7
	1994	0	0	0	4	16	142	56	18	210	165	105	206	4	2	0
Hairy vetch	1992	---	---	---	---	3	4	---	2	13	---	15	212	---	---	---
	1993	20	0	0	14	4	40	3	11	1	8	22	18	8	55	8
	1994	0	0	0	91	7	0	32	0	16	4	42	88	21	28	11

[z]E = early, M = middle, and L = late season sampling.
[y]Number of nematodes per 100-ml soil sample. Each number is the average of two to four replications.

reduce soil losses, maintain high soil fertility, lower production costs, conserve nonrenewable resources, and maintain yield and product quality. The alternative system offers all these advantages by growing hairy vetch as a winter annual cover crop during the off-seasons of the vegetable rotation. Biomass production in these experiments was similar to that reported by others (Hoyt, 1987). When mowed, the plant mulches formed an effective layer of organic residue that suppressed the growth of weeds, released nutrients to the tomato crop, and improved soil fertility and water-holding capacity. The ultimate choice of hairy vetch as a cover crop was based on several years of testing winter annuals in the humid, eastern United States. The results of these tests consistently showed that hairy vetch was most tolerant to low temperatures and fixed more N than other legumes (Holderbaum et al., 1990). Furthermore, hairy vetch was effective in suppressing early weeds (Teasdale, 1993; Teasdale and Mohler, 1993).

Among the many advantages of the alternative production system are the elimination of polyethylene plastic mulches and the reduction in use of commercial fertilizers and herbicides. Eliminating these three inputs lowers production cost by about $1850/ha. The only added cost is that of hairy vetch seed (about $36/ha) and mowing of the cover crop (Kelly et al., 1995).

As a mulch, BP has a unique advantage over plant mulches because it warms the soil early in the growing season and hastens earlier fruit maturity. In areas where earliness commands a premium price, this property can be economically important. However, this advantage often is not the case in the mid-Atlantic states where market demand early in the season is well met by produce from growers located farther south. Often, prices for fresh-market field tomatoes in Maryland during the past 3 years were highest between mid-August and early October (Kelly et al., 1995). During this period, harvest from tomatoes grown under polyethylene mulch ceased, whereas tomatoes planted at the same time in hairy vetch mulch remained in full production. Our results over 3 years, under Beltsville conditions, show that a significant portion of the total tomato yield from the hairy vetch mulch plots was harvested during the latter part of the season when production from the BP plots was nearly complete (Fig. 1).

Yield comparisons between the hairy vetch and the BP treatments show three major differences: the yields in the hairy vetch were higher in 2 of 3 years (Table 2), the harvest period was longer (Fig. 1), and yields fluctuated much less from year to year. These yield increases with the hairy vetch over the BP system may not be achievable in other locations; they may be representative of locations characterized by hot summer climates, such as that in Beltsville. Similar results may be unachievable in northern states because of factors relating to a shorter growing season.

The enhanced tomato yields in this study may have resulted from two temperature-related growth factors that favorably altered the plant-mulched plots. First, presumed high soil temperatures favor rapid mineralization of the leguminous crops, thus releasing ample N. Second, the longer growing season associated with delayed senescence extended the harvest period of tomatoes grown in plant mulches. Overall, hot, humid, summer climates, such as those encountered in Beltsville, are ideally suited for the legume-mulched systems. However, these data may not apply to other growing locations.

Tomatoes in the plant-mulched plots contained more leaf N than those from bare soil, BP mulch, or Horto paper (Table 3), which was achieved with one-half the N input applied to all noncover crop mulches and bare soil. In 1992 and 1994, the N mineralized from the legume mulches and possibly other factors raised the N uptake level in the legume-mulched plots into the sufficiency range, resulting in a large increase in tomato yield.

Depending on the intended end use, fruit weight can be a component of fruit quality that affects the market value of the product (U.S. Dept. of Agriculture, 1994). The heavier fruit obtained with all cover-crop-mulched plots, compared to those mulched with BP or paper likely adds to the marketing value of the product and, consequently, to profits. Furthermore, the price of tomatoes during the last 3 weeks of the season was higher than that in early and midseason, contributing to higher profits from tomatoes grown in hairy vetch (Kelly et al., 1995).

Although soil P status was high, plants grown in the cover crops, particularly hairy vetch in 1994, had a significantly better P status than those in BP mulch. The higher K concentration in plants grown in hairy vetch in 1994, compared to those grown with BP, may be the result of recycling this nutrient by hairy vetch. The lower Mg status of these plants, however, was probably due to the suppressive effect of a K $\times$ Mg interaction shown by Winsor and Adams (1987).

The tendency of leaf tissue B concentrations to be lower with plant mulches compared to BP mulch may have a long-term implication. Legumes, in general, have a high B requirement (Mengel and Kirby, 1987). The release rate of B used by the cover crops and the mobility of soil B in these cropping systems are unknown; thus, supplemental B may be necessary.

Concern about changes in populations of phytoparasitic nematodes in the soils of the various mulch treatments during the growing season was prompted by the fact that certain legumes, including hairy vetch, are moderately susceptible hosts of nematodes (Powell, 1990). Under favorable conditions, nematode populations may increase, especially if cover-crop legumes become part of the vegetable crop rotation. However, our data showed no significant build-up in populations of any of the five major nematode genera in any of the treatments. Their population levels appeared low early in the season and remained within the safe range in all the mulched plots. The cold winters in the mid-Atlantic region from 1991 to 1994 may have kept the population under control.

We recommend hairy vetch as a low-input alternative agricultural system for the production of fresh-market tomatoes. The system uses fall planting of hairy vetch as part of the vegetable crop rotation to fix N and add organic matter to the soil. Vetch is then converted into a plant mulch by mowing, thus eliminating the need for polyethylene mulches, preplant herbicides, or cultivation. Tomato yields in the hairy vetch system were higher in

2 of 3 years, and fruit were heavier than those produced with BP, paper, or no mulch. The proposed system likely also lowers production cost and is applicable to small- and large-scale tomato production.

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