Evaluation of Conservation Tillage and Cover Crop Systems for Organic Processing Tomato Production

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SUMMARY. Field experiments were conducted in 2000 and 2001 in Meridian, Calif. to evaluate the effects of cover crop mixtures and reduced tillage on yield, soil nitrogen (N), weed growth, and soil moisture content in organic processing tomato (*Lycopersicon esculentum*) production. The trial was set up as a randomized complete-block design with eight treatments consisting of a 2 × 3 (cover crop × tillage) factorial design, a fallow control (F) and a single strip-till (ST) treatment. Cover crop mixtures were either legumes (L), common vetch (*Vicia sativa*), field pea (*Pisum sativum*) and bell bean (*Vicia faba*), or those legumes with

grasses (GL), annual ryegrass/triticale (*Lolium multiflorum*/*xTriticosecale*) in 2000; cereal rye (*Secale cereale*)/triticale in 2001. Tillage treatments included an incorporation of the cover crop at planting (IP), a delayed incorporation (DI) (17 to 19 days after planting), and no-till (NT). Due to regrowth of the annual ryegrass in 2000, tomato fruit yields in 2000 were reduced by 50% to 97% within all GL treatments. However, regrowth of the cover crop was not a problem in 2001 and yields were not different among treatments. Total percent weed cover was 1.6 to 12.5 times higher in NT than IP treatments in 2000 and 2.4 to 7.4 times higher in 2001 as weed pressure was mainly affected by tillage practices and less by cover crop type. In 2000, available soil N was 1.7 to 9.4 times higher in L than GL treatments and was significantly influenced by tillage, but there were no treatment effects in 2001 due to a 60% reduction in weed pressure and minimal or no cover crop regrowth. Soil moisture content did not differ between treatments in either year. These results demonstrate the importance of appropriate selection and termination of cover crops for their successful adoption in organic conservation tillage systems.

California produces over 90% of the processing tomatoes in the U.S. (U.S. Dept. of Agriculture, 2002). Though most of these tomatoes are grown conventionally, since the early 1990s growers were beginning to dedicate a portion of their acreage to the production of organic processing tomatoes (Klonsky et al., 1994). This conversion is linked to California's expanding organic vegetable industry. In the 1990s, a statewide increase in demand for organically grown vegetables resulted in a doubling of certified crop acreage from 1992 to 1997 and an increase in certified sales of over 30% (Klonsky and Tourte, 1998). Sales of organic tomato products, such as paste, tomato sauce, and salsa, also grew at an estimated annual rate of 15% to 20% (Food Marketing Institute, 2001).

Due to restrictions on the use of agrichemicals, organic production depends more on tillage and cultivation than conventional production to manage soil fertility and weeds. To maximize the N mineralization of cover crops or other organic amendments, growers incorporate them into the soil by discing several weeks before planting. For weed control, in-season mechanical

and hand cultivation are used, rather than herbicides. These additional tillage operations can increase total operating costs up to \$250/ha (\$101/acre) (Clark et al., 1999).

Aside from the cost, there are also long-term consequences to the soil and environment from tillage. Every year, organic growers go to great efforts to increase soil organic matter (SOM), an important indicator of soil health (Gaskell et al., 2000; Ismail et al., 1994). However, every tillage operation exposes more SOM to microbial degradation and oxidation (Reicosky, 1996). Increased microbial activity can mineralize the humus reserves in the soil and lead to substantial losses of SOM in the form of carbon dioxide (CO₂) (Schlesinger, 1985). This paradox between tillage and SOM not only undermines growers' desire to improve soil health, but also contributes to the increase in atmospheric CO₂ and its related greenhouse effect (Lal et al., 1999; Post et al., 1990).

Many growers are examining the benefits of conservation tillage (CT) for maintaining SOM. CT, defined by the Soil Science Society of America (1987) as "a tillage or tillage and planting combination which leaves 30% or greater cover of crop residue on the surface", has been shown to reduce crop production costs and increase SOM (Phillips et al., 1997; Uri, 2001). However, most CT research has been done using agronomic crops in conventional farming systems. Growers question whether such systems are even applicable in an organic setting where the incorporation of organic amendments is important, the use of herbicides is prohibited, and most of the crops are vegetables.

Recent research has presented new possibilities for CT in organic systems, including new strategies for mechanically killing winter cover crops and planting or transplanting into residue without tillage (Creamer et al., 1995; Gaskell et al., 2000; Kuepper, 2000). These studies include work by Abdul-Baki and Teasdale (1997) in Maryland with transplanted tomatoes in mechanically killed hairy vetch (*Vicia villosa*) and forage and by Morse (2000) in Virginia with organic broccoli (*Brassica oleracea* group *italica*) produced in high-residue, no-till systems.

We examined the benefits of CT and cover crop mixtures in the production of organic processing tomatoes in California to identify key management

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strategies that reduce inputs and improve the long-term fertility of organic fields in the irrigated, Mediterranean climates of the western U.S.

Experiments were conducted in the same commercial organic field in 2000 and 2001 near Meridian, Calif. (lat. 39°04'38.6"N, long. 121°50'57.9"W) on a Nueva loam (fine-loamy, mixed, thermic Fluventic Haploxerolls). The field was certified organic in 1998 and, since 1997, cover crops and compost at 10.09 t·ha⁻¹ (4.5 ton/acre) have been incorporated into the soil every year. Previous crops have included wheat (*Triticum aestivum*), blackeye peas (*Vigna unguiculata*), safflower (*Carthamus tinctorius*), pinto beans (*Phaseolus vulgaris*), and field corn (*Zea mays*). The field has a history of high weed densities which have been managed through crop rotation and timely cultivation.

The trial was set up as a randomized complete-block design with five blocks (reps) and eight treatments: six in a 2 × 3 (cover crop × tillage) factorial arrangement, a fallow control (F), and a single strip-till (ST) treatment. Plots within blocks contained three beds and each bed measured 1.5 × 30.5 m (5 × 100 ft). Cover crop mixtures were either pure legumes (L) (common vetch, field pea, and bell bean), or those legumes with grasses (GL) (annual ryegrass/triticale in 2000; cereal rye/triticale the 2001). Tillage operations included an incorporation of the cover crop at planting (IP), a delayed incorporation (DI), and no-till (NT).

Cover crops were sown on 25 Nov. 1999 and 12 Oct. 2000 on the surface of pre-shaped 5-ft raised beds, using a Schmeiser vineyard drill (Schmeiser Manufacturing, Fresno, Calif.). Before bed shaping and planting the cover crop in 1999, compost from cow manure containing 2% N was surface applied and incorporated in all plots at 10.09 t·ha⁻¹. Compost was also surface applied on 24 Mar. 2001 at the same rate to all plots, however it was done after the killing of the cover crop and only incorporated in the IP and F treatments. Cover crop mixture seeding rates were: 1) 28.0 kg·ha⁻¹ (25 lb/acre) each of vetch, pea, and bell bean, and 56.0 kg·ha⁻¹ (50 lb/acre) each of annual ryegrass and triticale in 1999; 2) 33.6 kg·ha⁻¹ (30 lb/acre) each of vetch, pea, and bell bean, and 28.0 kg·ha⁻¹ each of cereal rye and triticale in 2000. Cover crops were killed on 5 Apr. 2000 and 22 Mar. 2001 using a rolling

stalk chopper (Buffalo Manufacturing Company, Fleischer, Nebr.) and then incorporated on 7 Apr. 2000 and 27 Mar. 2001 only in the IP treatments. Other tillage operations completed at this time were the incorporation of the winter weeds in the F treatment and a single strip-tilling in the ST treatment using an Unverferth Ripper-Stripper Subsoiler (Unverferth Manufacturing Company, Kalida, Ohio). Delayed incorporation of the cover crop occurred 17 d after planting in 2000 and 19 d after planting in 2001.

Processing tomato (variety 'BOS 3155' in 2000 and 'CDX 179' in 2001, both from Timothy, Stewart, and Lekos, Woodland, Calif.) seedlings were transplanted on 12 Apr. 2000 and 13 Apr. 2001. A Sub Surface Tillage Transplanter (B&B No-Till, Laurel Fork, Va.) developed by Morse (1993) was used to transplant a single row per bed at 0.3 m (1 ft) distance between plants. Fish emulsion containing 3% N was applied at a rate of 374.1 L·ha⁻¹ (40 gal/acre) was applied during transplanting in 2001. All weed control in the NT and ST was done by hand hoeing. The first two cultivations in the IP, DI, and F treatment plots were done using a customized Lilliston cultivator (Park Farming, Meridian, Calif.), followed by hand hoeing in the months of June and July. In 2000, tomato plants were sprinkler-irrigated with 63.5 mm (2.5 inches) of water once after transplanting and then again 18 d later. The crop was then furrow-irrigated six times applying 127.0 mm (5 inches) of water each time. In 2001, tomato plants were sprinkler-irrigated throughout the season until the last two irrigations which were done by furrow. Fruits were machine harvested on 18 Aug. 2000 and 19 Aug. 2001.

In 2000 and 2001, above-ground cover crop biomass was sampled just prior to cover crop termination. One 1-m² (10.8-ft²) sample was taken per plot. Each sample was dried to a constant weight at 60.0 °C (140 °F), weighed, and then sent to the University of California (UC) Division of Agriculture and Natural Resources (DANR) Analytical Lab at Davis for total N and carbon (C) determinations using a Carlo Erba NA 1500 CHN analyzer (Carlo Erba Instruments, Milan, Italy).

Soil cores 2.5 cm (1 inch) in diameter were taken five times in 2000 and 2001 at two depths, 0 to 30.5 cm (12 inches) and 30.5 to 61.0 cm (24

inches), to measure soil N concentrations. Samples were taken before cover crop termination, after incorporation of the cover crop at planting, after delayed incorporation of the cover crop, and during both crop petiole and whole leaf samplings. Six samples were taken from each plot, mixed, and kept at 4 °C (39.2 °F) before extracting with KCl. About 100 g (3.5 oz) of each sample was used in the lab for gravimetric water content. The remainder of each sample and the potassium chloride (KCl) extracts were sent to the UC Davis DANR lab for KCl extractable soil nitrate (NO₃-N) and ammonium (NH₄-N) determinations as described by Carlson et al. (1990).

Tomato leaf N concentration was determined by sampling twenty young, fully-expanded leaves from each plot when the tomato plants were in late bloom (8 weeks after transplanting) and then again when roughly 10% of the fruits were red. The samples were separated into leaflets and petioles and dried for 24 h at 60.0 °C. Dried samples were ground and analyzed separately for total N concentration in the leaflets (Sweeny, 1989) and NO₃-N concentration in the petioles (Carlson et al., 1990) at the UC Davis DANR lab using a N gas analyzer (FP 428; LECO Corp., St. Joseph, Mich.).

Weed cover, surface residue, and tomato crop cover were visually estimated as percent cover of the total surface of the bed. Five estimates were made in 2000 and six in 2001, each corresponding to a day before any tillage activity. Weed estimates were subdivided into major weed species with a separate category for cover crop regrowth. Major weed species included johnsongrass (*Sorghum halapense*), barnyard grass (*Echinochloa crus-galli*), common lambsquarter (*Chenopodium album*), redroot pigweed (*Amaranthus retroflexus*), and common sowthistle (*Sonchus oleraceus*).

Soil water content was monitored in 2000 and 2001 using a neutron hydroprobe (Campbell Pacific Nuclear Co., Pacheco, Calif.). One PVC access tube was placed in the center of each plot and hydroprobe counts were taken at 15, 30, 60, 90, and 120 cm depths (5.9, 11.8, 23.6, 35.4, and 47.2 inches). Readings were taken during the growing season at 1-week intervals for July and August 2000 and from April to August 2001.

Two sets of data analyses were

run for the yield, N, weed, and water data using a mixed model analysis of variance (ANOVA) with a RANDOM statement (SAS, 1998). The first analysis (ANAL I) involved all 8 treatments and the second (ANAL II) involved only the six treatments that fit the factorial structure (GL, L $\times$ IP, DI, NT). The second analysis was used to get past the unbalanced design of the original 8 treatments and look deeper into the effects of cover crops and tillage on tomato yields. Treatment means for both analyses were separated according to the Fishers protected least significant difference (LSD) test ($P \leq 0.05$).

In 2000, tomato fruit yields were significantly influenced by treatments (ANAL I) (Fig. 1). A factorial analysis (ANAL II, no significant interaction) showed yields were greater in IP [67.03 t·ha⁻¹ (29.9 ton/acre)] and DI [54.70 t·ha⁻¹ (24.4 ton/acre)] compared to NT [28.47 t·ha⁻¹ (12.7 ton/acre)] and greater in plots with L [75.32 t·ha⁻¹ (33.6 ton/acre)] cover crops as opposed to GL [24.88 t·ha⁻¹ (11.1 ton/acre)]. Tillage impacted yields by reducing weed pressure/cover crop regrowth in IP and DI. The relationship between total percent weed cover (weeds + cover crop regrowth) and total percent tomato cover was described by a

linear model ($r^2 = 0.53$, $P \leq 0.05$) (Fig. 2). Consequently, in 2001, because of better weed control and less cover crop regrowth, there were no treatment effects on total percent tomato cover nor yields (ANAL I) (Fig. 1).

The GL cover crop produced more biomass than L in 2000 and 2001 (Table 1). However, L had the highest N accumulation, which resulted in lower C:N ratios. Weeds in F had the lowest biomass yield and N accumulation for both years but had similar C:N ratios to GL. Though GL and fallow weeds had higher C:N ratios than L, neither C:N ratio was above the breaking point between net N mineralization and net immobilization, which was calculated by Vigil and Kissel (1991) to be 40:1 based on a regression analysis of results from eight different cover crop N mineralization experiments. However, for a timely decomposition of organic matter and subsequent N release, a C:N ratio between 20:1 to 30:1 is desired (Allison, 1966; Kommedahl, 1984). Cover crop N accumulation differed between years. The earlier cover crop planting date and 64 more growing degree days (GDD) [351 vs. 287 GDD, base temperature = 10.0 °C (50 °F)] in 2001 allowed for more N uptake/fixation and biomass production before the March kill date.

Also, the increase in the legume seeding rate and decrease in the grass seeding rate may have contributed to more cover crop N accumulation.

Soil NH₄-N represented a very low proportion of the total inorganic N and did not differ among treatments in either year (ANAL I) (data not shown). However, results in 2000 showed strong differences in total soil NO₃-N concentrations (0 to 61.0 cm) between treatments over the growing season (ANAL I) (Fig. 3). A factorial analysis (ANAL II, no significant interaction) revealed that these differences were influenced by cover crops and tillage. Throughout most of the season, L [3.9 mg·kg⁻¹ (ppm)] maintained higher levels of soil NO₃-N than GL (0.9 mg·kg⁻¹). About 4 to 7 weeks after cover crop termination, the NO₃-N levels with all L treatments began to peak in late April/mid-May and then decreased in June and July to concentrations about equal to the highest concentrations of GL treatments. GL gradually increased in NO₃-N as the season progressed, but always remained low.

Wagger (1989) found that N release was greater from residues with C:N ratios approaching 1. However, lower levels of NO₃-N with GL treatments were more a function of higher weed

Fig. 1. Tomato yields for 2000 and 2001 from experimental plots near Meridian, Calif. IP = incorporate at planting; DI = delayed incorporation, NT = no-till, ST = strip-till, F = fallow, GL = grass/legume cover crop, L = legume cover crop. Means with the same letter in 2000 are not significantly different as determined by the Fisher's least significant difference test, $P \leq 0.05$; 1 t·ha⁻¹ = 0.45 ton/acre.

Fig. 2. Linear relationship of total percent weed cover (weeds + cover crop regrowth) and total percent tomato cover. Data collected in 2000 near Meridian, Calif.

densities/cover crop regrowth than higher C:N ratios. A factorial analysis (ANAL II) of the total percent weed cover in 2000 showed that treatments with GL (27%) cover crops had more weeds than L (15%). This was due to the tremendous amount of regrowth of the ryegrass (Fig. 4A and B). The relationship of total soil $\text{NO}_3\text{-N}$ concentrations and total percent weed cover just before DI was described by a linear model ($r^2 = 0.68$, $P \leq 0.05$) (Fig. 5). At that time, the total percent weed cover in GL treatments consisted of 100% annual ryegrass regrowth. In 2001, there was also some regrowth from the cereal rye (Fig. 4C and D), but not enough to affect $\text{NO}_3\text{-N}$ levels, as there were no treatment differences in $\text{NO}_3\text{-N}$ (Fig. 3).

Creamer et al. (1997) also found annual ryegrass to be difficult to kill

mechanically. Ryegrass is a strong competitor for soil N and, as a weed, can be described as a luxuriant consumer of nutrients (Radosevich et al., 1997). Appleby et al. (1976) found that ryegrass interference was highly detrimental to wheat production. Ryegrass was better able to respond to increased N fertility than the wheat crop. Liebl and Worsham (1987) also found similar results with both N and P fertilization with wheat and ryegrass.

Within tillage treatments for 2000, a factorial analysis (ANAL II) showed IP ($3.2 \text{ mg}\cdot\text{kg}^{-1}$) resulted in the highest soil $\text{NO}_3\text{-N}$ concentrations and NT ($2.5 \text{ mg}\cdot\text{kg}^{-1}$) the lowest. DI ($2.8 \text{ mg}\cdot\text{kg}^{-1}$) was not significantly different from IP or NT in soil $\text{NO}_3\text{-N}$ concentrations. Greater amounts of available N are normally found in tilled soils due to faster decomposition and mineraliza-

tion rates of organic residues (Fox and Bandel, 1986; House et al., 1984; Varco et al., 1987). Varco et al. (1987) found that 15 d after vetch residues were applied, 47% of the incorporated vetch was mineralized while less than 10% of the surface-applied vetch N was made available. IP also resulted in the lowest weeds/cover crop regrowth which led to more available N for the crop. As mentioned before, many weeds are strong, luxuriant consumers of nutrients compared to crops. Qasem (1992) found that in the analysis of nutrient accumulation by weeds in comparison to tomato crops, percentages of N, phosphorus, potassium, and magnesium were 30%, 55%, 43%, and 19% higher, respectively, in weed shoots. This point can be further exemplified by the L-NT treatment which resulted in lower soil $\text{NO}_3\text{-N}$ concentrations compared to the

Table 1. Above-ground biomass, nitrogen (N) accumulation, and carbon to nitrogen (C:N) ratio of cover crops. Data collected in April 2000 and March 2001 near Meridian, Calif. Legume cover crops were common vetch (*Vicia sativa*), field pea (*Pisum sativum*), and bell bean (*Vicia faba*). Grass cover crops were annual ryegrass triticale (*Lolium multiflorum* × *Triticosecale*) in 2000 and cereal rye (*Secale cereale*) triticale in 2001.

Cover crop	Above-ground biomass ($\text{t}\cdot\text{ha}^{-1}$) ^z		N accumulation ($\text{kg}\cdot\text{ha}^{-1}$) ^y		C:N ratio	
	2000	2001	2000	2001	2000	2001
Grass and legume	6.26 a ^z	10.71 a	111 b	142 b	21.8 a	33.0 a
Legume	4.82 b	6.72 b	170 a	193 a	11.3 b	14.1 b

^z1 $\text{t}\cdot\text{ha}^{-1} = 0.45 \text{ ton/acre}$.

^y1 $\text{kg}\cdot\text{ha}^{-1} = 0.89 \text{ lb/acre}$.

^zMean separation within columns determined by Fisher's LSD (least significant difference) test, $P \leq 0.05$.

other legume treatments partly because of higher weed densities and greater cover crop regrowth. However, because legumes do not remove soil $\text{NO}_3\text{-N}$ as effectively as grass cover crops, fix some of their own N, and increase N availability to succeeding crops (Kuo et al., 1996; McCracken et al., 1994), the impact of legume regrowth on tomato yields was not as detrimental as that of the grasses.

In 2000, consistently low soil $\text{NO}_3\text{-N}$ concentrations with GL-IP and GL-DI, even after cover crop regrowth was controlled, may have been caused by an overall increase in the cover crop's C:N ratio due to regrowth of only the ryegrass after cover crop termination.

Originally, the GL mixture had a C:N ratio of 21.8, however with the regrowth of the ryegrass, which has a C:N of about 32 (Vyn et al., 1999) or higher, the total C:N ratio increased to a point where net N immobilization by microbes might have become a factor. Waggener et al. (1985) showed that increasing the C:N ratio of crop residues from 28 to 37 increased the net N immobilization of the applied material from 12% to 33%.

Another possible reason for reduced levels of soil $\text{NO}_3\text{-N}$ concentrations with GL-IP may have been due to dry soil conditions at time of cover crop incorporation. In 2000, rainfall ended >1 month before cover crop incorporation. Dur-

ing early spring, the grass cover crops transpired large amounts of water from the soil profile, especially at the surface, where most of the N mineralization occurs (Cassman and Munns, 1980). Soil moisture levels may have been low enough to significantly diminish N mineralization rates.

Despite not having any cover crop, F resulted in similar levels of soil $\text{NO}_3\text{-N}$ as with the L-NT treatment from early May 2000 to the end of the growing season (Fig. 3). One possible explanation was the reduced number of weeds with F. Also, organic fields in dry climates have been known to build up soil nutrient reserves over time, and perhaps the increased tillage in F helped to access those reserves. After several seasons of organic farming, N cycling becomes more efficient, resulting in greater nutrient conservation than in conventional fields (Poudel et al., 2001; Scow et al., 1994).

Overall soil $\text{NO}_3\text{-N}$ concentrations were greater the second year. The highest average was $12.8 \text{ mg}\cdot\text{kg}^{-1} \text{ NO}_3\text{-N}$ in 2001 as opposed to $7.7 \text{ mg}\cdot\text{kg}^{-1} \text{ NO}_3\text{-N}$ in 2000. Possible reasons include the increased levels of N accumulation in the cover crops, the addition of compost [$201.7 \text{ kg}\cdot\text{ha}^{-1}$ (180 lb/acre) of N] and fish emulsion [$11.2 \text{ kg}\cdot\text{ha}^{-1}$ (10 lb/acre) of N] to the soil just prior to transplanting, and the reduction in weed pressures and cover crop regrowth. However, low levels of soil $\text{NO}_3\text{-N}$ are not uncommon in otherwise very productive organic fields. Organic forms of N are more complex than fertilizers and the rate of N release is subject to the quality of organic matter and the short-term variations in factors that affect the relationship between microbes and soil N (Scow, 1995). Experiments with pre-plant incorporation of a high-N green manure led to residual soil $\text{NO}_3\text{-N}$ peaks after 3 to 4 weeks, followed by a return to relatively low levels, $<10 \text{ mg}\cdot\text{kg}^{-1}$, for the rest of the season (Scow, 1996; Shennan, 1992).

In 2000, tissue N concentration (either unassimilated $\text{NO}_3\text{-N}$ in petioles or total N in the whole leaf) sampled 8 weeks after transplanting (late bloom) was greater with GL-IP/L-IP and GL-DI/L-DI than with GL-NT/L-NT or GL-ST (ANAL I) (Table 2). Incorporation of the cover crop and better control of regrowth with these treatments allowed for more soil N to be available for plant uptake. In 2001, there were no treatment effects for petiole $\text{NO}_3\text{-N}$ con-

Fig. 3. Soil nitrate ($\text{NO}_3\text{-N}$) concentration [0-61.0 cm (24-inch) depth] as affected by cover crop and tillage treatments. Data collected in 2000 and 2001 near Meridian, Calif. IP = incorporate at planting; DI = delayed incorporation, NT = no-till, ST = strip-till, F = fallow, GL = grass/legume cover crop, L = legume cover crop, ^ denotes incorporation dates for the cover crop. Mean separation within sampling dates determined by the Fisher's least significant difference test, $P \leq 0.05$.

Fig. 4. Percent weed cover as influenced by cover crop and tillage treatments. Data collected in 2000 and 2001 near Meridian, Calif. A and C show total weed cover (weeds + cover crop regrowth). B and D show only weed species. IP = incorporate at planting, DI = delayed incorporation, NT = no-till, ST = strip-till, F = fallow, GL = grass/legume cover crop, L = legume cover crop, ^ denotes incorporation dates for the cover crop. Mean separation within sampling dates determined by the Fisher's least significant difference test, $P \leq 0.05$.

Fig. 5. Linear relationship for total soil nitrate ($\text{NO}_3\text{-N}$) concentrations and total percent weed cover just before delayed incorporation of the cover crop (DI). Data collected in 2000 near Meridian, Calif.

centrations and only slight effects for total N concentrations in the whole leaf.

Samples taken 12 weeks after transplanting (10% red fruit) showed petiole $\text{NO}_3\text{-N}$ concentrations to be highest with GL-NT in 2000 and highest with

L-NT in 2001 (ANALI). Similar results were also observed for total N concentrations in the whole leaf. Increases in tissue N concentrations with NT were not observed until later in 2000 because of the N tie-up from the higher weed

cover/cover crop regrowth. However, in 2001, when weed/cover crop competition was reduced and overall soil $\text{NO}_3\text{-N}$ concentrations were higher, N use efficiency increased with NT. Studies have shown that N use efficiency can be

Table 2. Effects of treatments on tomato petiole nitrate (NO₃-N) and total leaf nitrogen (N) at late bloom (8 weeks after transplant) and 10% red fruit (12 weeks after transplant). Samples were taken in 2000 and 22001 from experimental plots near Meridian, Calif. IP = incorporate at planting, ID = delayed incorporation, NT = no-till, ST = strip-till, F = fallow, GL = grass-legume cover crop, L = legume cover crop.

Treatment	Petiole NO ₃ -N (mg·kg ⁻¹) ^a				Total leaf N (g·kg ⁻¹)			
	Late bloom		10% Red fruit		Late bloom		10% Red fruit	
	2000	2001	2000	2001	2000	2001	2000	2001
GL-IP	1600 bc ^z	5320 a	62 b	42 b	42.8 ab	48.6 ab	31.0 c	31.1 de
L-IP	2220 ab	7570 a	34 b	274 b	44.4 ab	51.0 a	28.8 c	34.7 bc
GL-DI	3390 a	5900 a	284 b	442 b	46.9 a	48.9 ab	35.4 b	36.7 bc
L-DI	2190 ab	7520 a	198 b	522 b	44.8 ab	50.4 a	30.9 c	37.0 abc
GL-NT	500 c	5620 a	558 a	422 b	40.7 bc	47.9 ab	39.1 a	37.6 ab
L-NT	660 c	6190 a	100 b	1204 a	39.8 bc	49. ab	29.5 c	40.1 a
GL-ST	160 c	2830 a	242 b	190 b	36.7 c	41.8 c	35.9 ab	33.7 cd
F	1430 bc	4190 a	68 b	40 b	42.1 ab	45.3 bc	29.4 c	30.3 e

^a1 mg·kg⁻¹ = 1 ppm. Sufficiency concentration ranges for total NO₃-N in petioles: late bloom = 4000–6000 mg·kg⁻¹, 10% red fruit = 2000–3000 mg·kg⁻¹ (Lorenz and Tyler, 1983)

^zg·kg⁻¹/10%. Sufficiency concentration ranges for total N in whole leaf: late bloom = 25–40 g·kg⁻¹, 10% red fruit = 20–30 g·kg⁻¹ (Hochmuth et al., 1991).

enhanced by the use of hairy vetch in no-till tomatoes (Abdul-Baki et al., 1997). Sainju et al. (2000) found that no-till with hairy vetch helped promote tomato root development, thus increasing nutrient uptake. Root growth, however, was not related to tomato yields.

Volumetric water content measurements taken during the growing seasons of 2000 and 2001 showed no response to treatments (ANAL I) (data not shown). Generally, water conservation under no-till improves due to lower evaporation loss by having a surface cover and increased water infiltration from reduced surface crusting (Griffith et al., 1986). However, because of the field's proximity to a canal, the water level in the canal may have kept the soil water level in the field artificially high.

In conclusion, since regrowth of the cover crop was such an important factor in determining tomato yields for both years, appropriate selection of cover crop species is paramount for its success in organic CT. Only cover crops with low C:N ratios that can easily be killed mechanically should be considered. Once appropriate cover crops are identified, additional research is needed to develop strategies that use a cover crop mulch for early-season weed control and then lightly incorporate that mulch to provide some additional N for the tomato crop later in the season.

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