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A Comparison of Four Processing Tomato Production Systems Differing in Cover Crop and Chemical Inputs

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Abstract. **Four tomato production systems were compared at Columbus and Fremont, Ohio: 1) a conventional system; 2) an integrated system [a fall-planted cover-crop mixture of hairy vetch (*Vicia villosa* Roth.), rye (*Secale cereale* L.), crimson clover (*Trifolium incarnatum* L.), and barley (*Hordeum vulgare* L.) killed before tomato planting and left as mulch, and reduced chemical inputs]; 3) an organic system (with cover-crop mixture and no synthetic chemical inputs); and (4) a no-input system (with cover-crop mixture and no additional management or inputs). Nitrogen in the cover-crop mixture above-ground biomass was 220 kg·ha^{-1} in Columbus and 360 kg·ha^{-1} in Fremont. Mulch systems (with cover-crop mixture on the bed surface) had higher soil moisture levels and reduced soil maximum temperatures relative to the conventional system. Overall, the cover-crop mulch suppressed weeds as well as herbicide plots, and no additional weed control was needed during the season. There were no differences in the frequency of scouted insect pests or diseases among the treatments. The number of tomato fruit and flower clusters for the conventional system was higher early in the season. In Fremont, the plants in the conventional system had accumulated more dry matter 5 weeks after transplanting. Yield of red fruit was similar for all systems at Columbus, but the conventional system yielded higher than the other three systems in Fremont. In Columbus, there were no differences in economic return above variable costs among systems. In Fremont, the conventional systems had the highest return above variable costs.**

Ecological problems associated with conventional agricultural practices include soil erosion, contamination of water and soil resources with pesticides and nitrates, and an overdependence on fossil fuel (National Research Council, 1989). Thus, there is interest in developing agricultural systems that rely less on fossil-fuel based inputs and more on biological processes to achieve similar productivity. Winter annual cover crops can enhance biological processes and potentially reduce fossil-fuel based inputs. They are seeded in late summer or early fall, overwinter, and then resume rapid growth in the spring. Winter annual cover crops can be an important source of biologically fixed nitrogen (Hoyt and Hargrove, 1986), help control soil erosion (Flach, 1990), improve soil physical properties (McVay et al., 1989), reduce nitrate leaching losses (Stivers and Shennan, 1989), add organic matter to the soil (Blevins et al., 1977), influence pest life cycles (Phatak et al., 1990), and suppress weeds (Teasdale, 1993).

One method of managing winter cover crops in the spring is to kill them and leave their residue as a surface mulch. The subsequent crop is then no-till (NT) planted into the residue. Some general benefits of conservation tillage in killed cover-crop mulches are less time to prepare fields for planting, higher water infiltration and retention, increases in organic matter, and improved soil physical and chemical properties (Hoyt et al., 1994).

Cover-crop residues remaining on the soil surface can suppress weeds by modifying light, soil temperatures, and soil moisture (Teasdale and Mohler, 1993), and by allelopathy, a direct or indirect harmful effect produced in one plant through toxic chemicals released into the environment by another (Rice, 1974). This definition includes chemicals produced by actinomycetes, algae, fungi, and other microbes that may associate with the plants in the rhizosphere (Putnam, 1988).

Diseases can be reduced, enhanced, or unaffected in cover-crop conservation tillage systems depending on the type of inoculum. If the disease inoculum survives best on surface residue, there can be increased disease. In fact, burying crop residue has been a suggested cultural control technique for many diseases (Merriman et al., 1979). By leaving plant debris on the surface, pathogens may survive until the next crop is planted (Fawcett, 1987). Many diseases are associated with surface residue including root diseases, as well as fungal and bacterial blights (Boosalis and Cook, 1973). On the other hand, conditions for biological control of plant pathogens may be enhanced by surface residue (Phillips, 1984). Organic matter is often beneficial in increasing populations of saprophytic fungi and bacteria that antagonize and parasitize root pathogens (Sumner et al., 1986).

Cover crops unrelated to the previous crop may help break disease cycles, whereas residue of a related previous crop could enhance disease cycles. The type of cover crop may also influence diseases. For example, tomatoes following legumes resulted in increased root disease (Sumner et al., 1986). The cover-crop residue will also modify soil moistures and temperatures that can stress crops and affect their susceptibility to disease.

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A limited amount of research has examined the effect of cover crops on insect incidence in vegetable crops. Cover crops can attract both beneficial insects and harmful pests to cropping systems (Altieri and Letourneau, 1982; Andow, 1988). The effect on insect populations will depend on the cover crop, the cash crop, and other environmental factors. A rye cover with tomatoes decreased tomato fruitworm damage, but increased stink bug damage (Roberts and Cartwright, 1991). In general, there were fewer insects and related damage in plots covered with rye in cabbage, sweet corn, and tomatoes. Cover crops can attract predators into a field to feed on other insects, nectar, or pollen. As the cover crops die, the predators can help to control pests in subsequent or adjacent crops. Particularly high densities of the generalistic predator bigeyed bugs (*Georcoris punctipes*) were found in late spring on several different types of clovers (Bugg et al., 1990). Another study suggests that predation of fall armyworm in cantaloupes increased when bigeyed bugs moved from dying cover crops onto adjoining cantaloupe plants (Bugg et al., 1991). Cover crops can also attract pests, which can cause damage to subsequent or nearby crops. In California, movement of *Lygus* spp. (Hemiptera: Miridae) from mown alfalfa to cotton causes economic damage (Stern et al., 1967).

The few studies on NT tomato production systems have reported contradictory results. Yield of seeded processing tomatoes grown in a NT system were equal to those grown with conventional tillage (Beste, 1973), but yields of marketable staked tomatoes tended to decrease as tillage intensity decreased (Doss et al., 1981). Staked tomato yields of conventionally produced tomatoes were either higher than or comparable to yields in NT systems (Shelby et al., 1988). Staked tomatoes NT planted into a killed mulch of hairy vetch yielded higher than conventionally grown tomatoes (Abdul-Baki and Teasdale, 1993).

Mixtures of cover-crop species rather than monocultures can be used to optimize some of the benefits associated with cover-crop use. By establishing a mixture, it is possible to increase the amount of above-ground biomass and N (Ofori and Stern, 1987), increase the amount of N fixed by legumes (Agboola and Fayemi, 1972), aid in the overwintering of some cover crops (Exner and Cruse, 1993), facilitate decomposition more timed with crop needs by moderating C : N ratios, and increase weed suppression.

This research examines the use of winter annual cover crops as a means of producing processing tomatoes more efficiently with regard to capital and resources. The objectives of this study were to compare four processing tomato production systems that varied in their level of chemical inputs, and presence of cover crops. Cover-crop growth and yield; tomato plant growth, development, yield, and quality; soil nitrate, moisture and temperatures; weed, insect, and disease levels; and the economics of the four systems were evaluated.

Materials and Methods

In 1991–92, 13 cover-crop mixtures were screened at two Ohio locations to find a species mix that established quickly, gave adequate erosion control, was winter hardy, contributed sufficient N for subsequent crops, had minimal N immobilization after cover-crop kill, could be killed by mechanical methods, and had high weed control potential. Based on species performance in the field screening the mixture used in this experiment was a hairy vetch, rye, crimson clover, and barley combination seeded at 22.5, 27, 11.2, and 27 kg·ha^{-1}, respectively.

Experiments were conducted in 1992–93 at the Ohio State Univ. (OSU) Horticulture Farm, Columbus, on a Miami silt loam with a pH of 6.8, and at the OSU/OARDC Vegetable Crops Branch, Fremont, Ohio, on a Colwood fine sandy loam with a pH of 6.1. The Fremont soil is more typical of those used for processing tomato production in Ohio. The four processing tomato production systems were as follows.

Conventional production (no cover crop). Preplant herbicides were trifluralin [2,6 dinitro-*N*,*N*-dipropyl-4-(trifluoromethyl) benzenamine] in Columbus and Fremont at 0.56 kg a.i./ha and metribuzin [4-amino-6-tert-butyl-3-(methylthio)-a5-triazin-5(4*H*)-one] in Fremont at 0.27 kg a.i./ha. A preplant fertilizer (78N–157P–157K kg·ha^{-1}) was applied immediately before planting. Insecticides were used as necessary, based on field scouting, and carbaryl [1-naphthyl *N*-methylcarbamate] was applied at 2.24 kg a.i./ha once in Fremont. Fungicides were applied based on the TOMCAST disease forecasting system that takes into account daily moisture and temperature readings (Pitblado, 1988). Seven fungicide applications were necessary in Columbus and 5 in Fremont [copper hydroxide at 2.04 kg a.i./ha and chlorothalonil (etrachloroisophthalonitrile) at 2.52 kg a.i./ha].

Integrated production (with cover crop). Postemergence herbicides were to be applied if necessary, however it was not necessary. Preplant fertilizer was applied at half the conventional rate (39N–78P–78K kg·ha^{-1}). Insecticides were applied based on scouting (2.24 kg a.i./ha carbaryl was applied once in Fremont). Fungicides were applied based on TOMCAST as above, but at half the rates listed in the conventional treatment.

Organic production (with cover crop). Management was based on the Ohio Ecological Food and Farming Association's (OEFFA) organic production standards (OEFFA, 1992). Mechanical weed control was to be used if necessary, however, it was not necessary. Three foliar fertilizer applications of fish extract (0.07N–0.008P–0.03K kg·ha^{-1}) were applied once every 2 weeks for the first 6 weeks of production. Seaweed powder (0.007N–0P–0.02K kg·ha^{-1}) was combined with the fish extract for the last fertilizer application. Insect control was based on scouting, and *Bacillus thuringiensis* (0.7 l a.i./ha) was applied once in Fremont. No fungicides were applied.

No additional inputs (with cover crop). After transplanting the tomatoes, there were no additional inputs or management. For the three treatments with cover crops, the mixture of rye, barley, hairy vetch, and crimson clover was planted on raised beds (1.5 m wide × 15.25 m long) on 2 Sept. (Columbus), and on 25 Aug. 1992 (Fremont). Raised beds were used because nearly all processing tomato production in the midwestern United States and Ontario relies on this crop management system. Seed was broadcast by hand on the surface of the beds, and lightly raked in.

On 26 May (Columbus) and 1 June 1993 (Fremont), the cover was mechanically killed with an undercutter and left as a surface mulch. Two blades at 45-degree angles from the direction of travel with a 15 degree pitch, cut approximately 5 cm deep. A mounted rolling harrow was attached to the undercutter to lay the cover crop flat on the surface after being cut (Creamer et al., 1995). On the same day, processing tomatoes ('OH 8245') were mechanically transplanted into the mulch. A NT transplanter (RJ Equipment, Blenheim, Ontario) was used for transplanting, and was able to successfully cut slots in the 10- to 15-cm-thick mulch. Twin rows were planted 40 cm apart, with 38 cm within row spacing.

Cover-crop measurements. On 24 May (Columbus) and 1 June (Fremont), 1-m^2 biomass samples from each of four replications were cut at the soil surface, separated into component species, dried at 65C for a minimum of 48 h, and weighed to determine above-ground biomass. Samples of each cover-crop species were coarsely ground with a Wiley mill. Representative subsamples

Table 1. Species composition, above-ground biomass (AGB), C : N ratios, and total N in cover crop mix at Columbus and Fremont, Ohio, 1993.

	Columbus				Fremont			
	Percent in mix	AGB (kg·ha^{-1})	C:N	Total N (kg·ha^{-1})	Percent in mix	AGB (kg·ha^{-1})	C : N	Total N (kg·ha^{-1})
Hairy vetch	57	5500	15.9	160	54	7810	13.2	265
Rye	28	2650	37.2	35	28	3940	36.7	50
Barley	10	950	26.4	15	7	990	27.0	15
Crimson clover	5	470	17.5	10	11	1550	20.5	30
Total for mixture	100	9570	23.0[z]	220	100	14290	21.6[z]	360

[z] Based on percentage species composition in mixture.

were reground to a fine powder with a Brinkmann 2 MI centrifugal grinding mill (200-µm mesh screen). Carbon and nitrogen were determined based on the Dumas method (Nelson and Summers, 1982), with a NA 1500 Series 2 analyzer (Carlo Erba Instruments, Milano, Italy).

Tomato plant measurements. Tomato survival was evaluated 2 weeks after transplanting. Plant height and stem diameters were measured 2 and 5 weeks after transplanting. The number of flower and fruit clusters were counted 1 and 2 months after transplanting to evaluate earliness of fruit set. Plants were harvested at the soil line 1 month after transplanting, dried at 65C for at least 72 h and weighed to determine above-ground dry weights. The fourth or fifth leaflet from the growing tip of 20 plants per plot was sampled at early fruit set (Jones and Case, 1990) for nutrient analysis on 8 July (Columbus), and 13 July (Fremont). The leaves were dried, ground, and analyzed for percentage N, P, and K by Mid-West Labs (Omaha, Neb.) Tomatoes were hand-harvested on 26 Aug. (Columbus) and 8 Sept. (Fremont) on 3-m lengths of bed and separated into red, green, rotten, and cull fruit categories. Following harvest, random samples of tomatoes were blended under vacuum suction to evaluate tomato quality, including color (Agtron ME-5M colorimeter), pH, and soluble solids (American Optic Abbey Refractometer).

Soil and mulch measurements. Soil nitrate levels were measured every 2 weeks following transplanting. Ten 15-cm-deep soil cores were bulked and sieved through 2-mm screens, extracted with 2 M KCl (shaken for 1 h), and filtered (Keeney and Nelson, 1982). The leachates were kept at 4C until analyzed (within 1 week of sampling) on a Lachate autoanalyzer. Soil moisture was determined gravimetrically (Gardner, 1986) every two weeks from 15-cm-deep soil cores (10 bulked per plot). Soil temperatures were taken with min/max soil thermometers placed 10 cm deep in the plots. Temperatures from three replications each in the mulched and nonmulched plots were measured about every 7 days through July.

Weed, insect, and disease measurements. Weed densities (broadleaves and grasses) were counted in three 0.5-m^2 areas per plot 2 and 4 weeks after planting. Above-ground weed biomass was collected from 0.5-m^2 areas (4 per plot) 6 and 12 weeks after planting. Weeds were separated by species, dried at 65C for at least 48 h, and weighed. A 2.4-m section of each conventional plot was not treated with herbicides, and functioned as check plots. Only annual weeds were measured in this study, and the few patchy spots of perennial weeds were periodically hand-weeded.

The common insect pests of tomatoes in Ohio were scouted on a weekly basis. These included aphids (primarily *Myzus persicae* and *Macrosiphyn euphorbiae*), flea beetles (primarily *Epitrix hirtipennis*), tomato fruitworm (*Helicoverpa zea*), tomato hornworm (*Manduca quinquemaculata*), and Colorado potato beetle (*Leptinotarsa decemlineata*). Five plants per plot were randomly selected for scouting, and thresholds calculated by the Ohio integrated pest management project were used to determine pest management decisions.

Visual scouting for early blight (*Alternaria solani*) and septoria leaf blight (*Septoria lycopersici*) was conducted in mid-July and early August. At harvest, diseased fruits were sorted to quantify the incidence of anthracnose (*Colletotrichum coccodes*), ground rot (*Pythium* spp.), bacterial speck (*Pseudomonas syringae* pv. *tomato*), and bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*).

Economic analysis. An economic analysis of variable costs to compare the four systems (inputs, yield, and price received per ton) was done. Analysis of fixed costs was beyond the scope of this project and therefore was not done. Costs for purchased inputs where available, were taken from the OSU Dept. of Agricultural Economics 1993 processing tomato production budget, or directly from suppliers. Custom application charges were from the OSU Dept. of Agricultural Engineering's custom rate guide for Ohio. The 15% differential in price between conventionally grown tomatoes and certified organically grown tomatoes is what is currently available to certified organic producers for processing tomatoes (John Hirzel, Hirzel Canning Co. and Farms, Toledo, Ohio, personal communication).

Table 2. Influence of four processing tomato production systems on percent leaf tissue N–P–K at early fruit set (8 July at Columbus and 13 July at Fremont, Ohio) for processing tomato 'OH8245'.

	Columbus			Fremont		
System	N	P	K	N	P	K
			Percentage			
Conventional	4.96 H[z]	0.50 S	2.41 D	5.11 H	0.38 S	2.73 L
Integrated	4.01 L	0.62 H	2.57 D	4.87 H	0.42 S	2.72 L
Organic	3.87 L	0.59 H	2.36 D	5.02 H	0.39 S	2.53 L
No input	3.66 L	0.59 H	2.41 D	5.01 H	0.39 S	2.49 L
LSD$_{(0.05)}$	0.39	0.03	NS	NS	NS	NS

[z] H = high, S = sufficient, L = low, D = deficient fertility levels (A & L Labs).

Table 3. Influence of four processing tomato production systems on tomato ('OH8245') red fruit yield and quality measurements (pH, soluble solids, and color), in Columbus and Fremont, Ohio, 1993.

	Columbus				Fremont			
System	Red fruit ($Mg \cdot ha^{-1}$)	pH	Soluble solids (%)	Agtron ME-5M	Red fruit ($Mg \cdot ha^{-1}$)	pH	Soluble solids (%)	Agtron ME-5M
Conventional	35.9	3.98	5.40	39.25	65.5	4.10	3.38	40.75
Integrated	29.2	3.93	5.60	49.50	44.1	4.00	3.90	41.75
Organic	26.1	3.95	5.45	43.25	34.8	4.08	3.85	46.00
No input	25.3	3.85	5.35	44.00	36.4	4.08	3.75	53.25
$LSD_{(0.05)}$	NS	NS	NS	NS	13.9	NS	0.35	NS

The experimental design was a randomized complete block with four replications and four production systems at two locations. Data were subjected to analysis of variance, and LSD tests were used to separate means (Wilkinson, 1990).

Results and Discussion

Cover-crop variables. Cover crops were killed when the hairy vetch was at midbloom. The rye, crimson clover, and barley were more mature than the hairy vetch, but had not yet produced viable seed. There was no regrowth of the crimson clover and barley, and very little of the hairy vetch and rye. Total above-ground biomass (AGB) was substantial at both sites, but was 49% greater at Fremont (Table 1). This was probably due to better growing conditions in Fremont, and an additional 1-week growing period in the spring. Wagger (1987) found that substantial dry matter and N content were forfeited when cover crops were killed early rather than late. The C : N ratio of the mixture (based on the percent composition of the mixture and the C : N ratio of each species) was within the optimal 20C:1N to 30C:1N ratio for limited immobilization (Kommedahl, 1984) and release of N (Allison, 1966). Total N in the AGB was 220 $kg \cdot ha^{-1}$ in Columbus, and 360 $kg \cdot ha^{-1}$ in Fremont (Table 1). As a general rule, approximately half of the nitrogen in above-ground cover-crop biomass is mineralized during the following growing season (Broadbent, 1984).

Tomato measurements. Tomatoes growing in the mulch looked vigorous throughout the season. Transplant survival averaged >95% at both sites; however, additional care was neces-

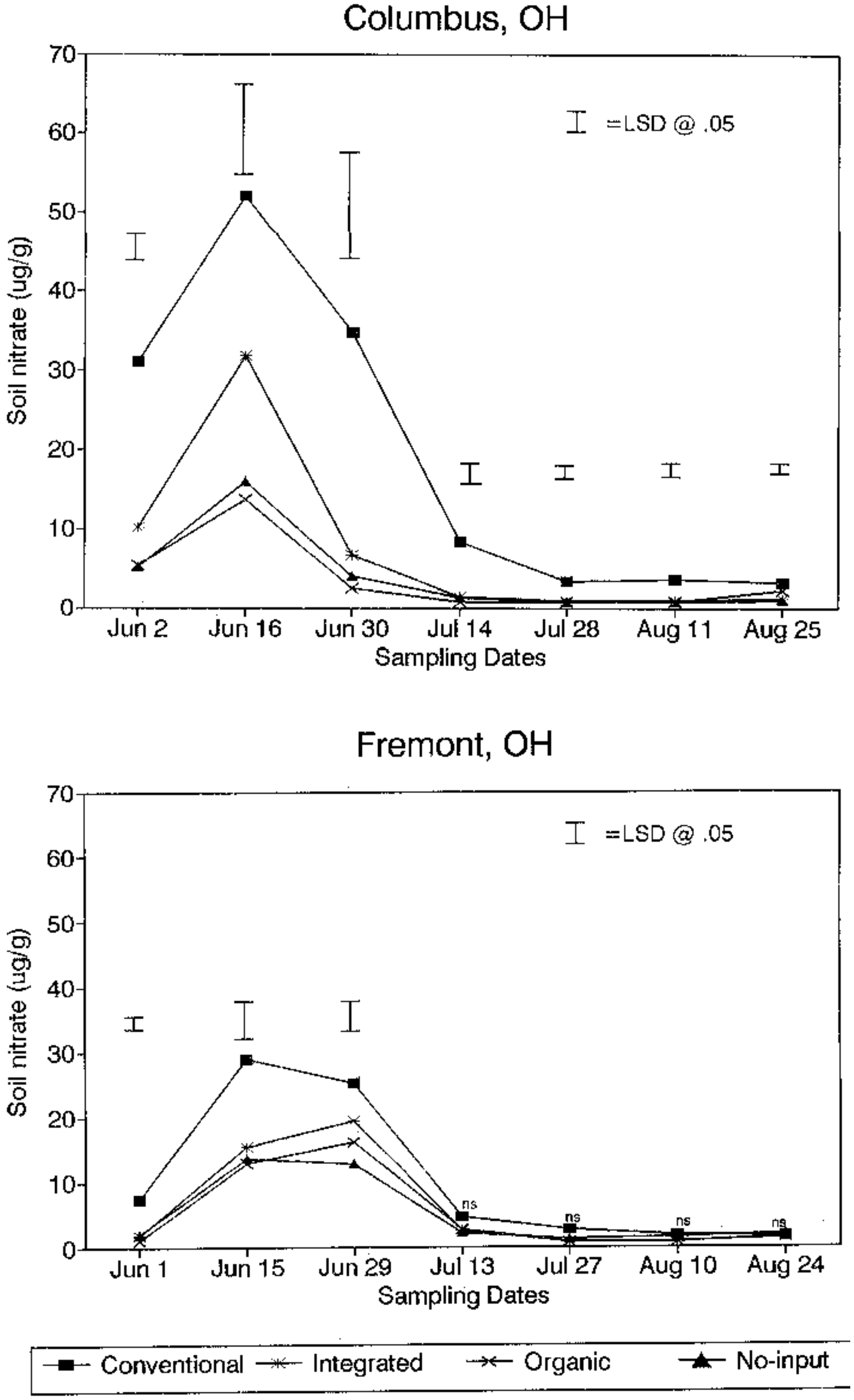

Fig. 1. Influence of four processing tomato production systems on soil nitrate levels in the top 15 cm, measured every 2 weeks in Columbus and Fremont, Ohio, 1993.

sary to insure that soil was well packed around the transplants in the cover-crop plots. With further adjustment to the transplanter, this problem could have been eliminated. There were no statistical differences in stem diameter (x = 10 mm at Columbus; x = 12 mm at Fremont) or plant height (x = 29 cm at Columbus; x = 42 cm at Fremont) 5 weeks after transplanting, though the plants at Fremont were taller. The number of fruit and flower clusters for the conventional system (x = 8.9 at Columbus; x = 11.5 at Fremont) were higher than the other systems (x = 6.8 at Columbus; x = 6.2 at Fremont) the first sampling date at both locations. By the second sampling date, clusters in the other systems were equivalent to those in the conventional system (x = 25.6 at Columbus; x = 25.0 at Fremont). Other studies have shown a delay in growth and development in NT cover-crop production systems. Price and Baughan (1987) showed that fresh market tomato plants began growth sooner after transplanting in conventional tilled plots, and also had a more rapid growth rate for an initial 40 days than in NT plots. Similar delays have been found in corn and squash (Fortin and Pierce, 1991; NeSmith et al., 1994).

There were no differences in tomato plant dry weights at Columbus 35 days after transplanting (data not shown). In Fremont, the plants in the conventional system were larger (16 g/ plant) than in the other systems, and the plants in the integrated system (10 g/plant) were larger than those in the organic and no-input systems (8 and 7.5 g/plant respectively).

In Columbus, there was more tissue N and less tissue P in the conventional system than the other systems (Table 2). The conventional system had high levels of N and sufficient levels of P, while the other systems had low N and high P levels. There were no differences in K levels. In Fremont, there were no differences in N, P, or K levels. Nitrogen levels were high, P levels were sufficient, and K levels were low.

Yields of red fruit were not different among systems in Columbus, but in Fremont, the conventional system had higher yields (Table 3). Overall, plots in Fremont had higher yields compared to Columbus, partially explained by soil type, and weather differences. State average yields of processing tomatoes in Ohio are about 53 Mg·ha^{-1}. There were no differences between systems in the amount of green or rotten fruit at either site (data not shown). Plants from the conventional system at Fremont were larger, but there were no differences in the number of flower clusters at 2 months after planting. Flower clusters were more concentrated on the smaller plants, but this did not compensate in yield for the reduced plant dry weight. Though fruit tended to be larger in the conventional system in Fremont, the difference was not significant (data not shown). There were few differences in tomato fruit quality measurements at either loca-

Table 4. Rainfall totals (cm) from 1 May–15 Sept. 1993, and long-term averages (>80 years) in Columbus and Fremont, Ohio.

	1993		Long-term avg	
Date	Columbus	Fremont	Columbus	Fremont
1–15 May	3.10	0.43	4.90	3.91
16–31 May	2.49	2.03	5.63	5.23
1–15 June	5.92	6.50	5.28	5.54
16–30 June	9.37	4.65	5.56	4.60
1–15 July	10.41	3.23	5.79	5.38
16–31 July	2.57	0.25	5.33	4.55
1–15 Aug.	1.65	1.22	4.70	4.24
16–31 Aug.	0.58	0.69	4.49	4.57
1–15 Sept.	3.58	2.64	3.78	3.90

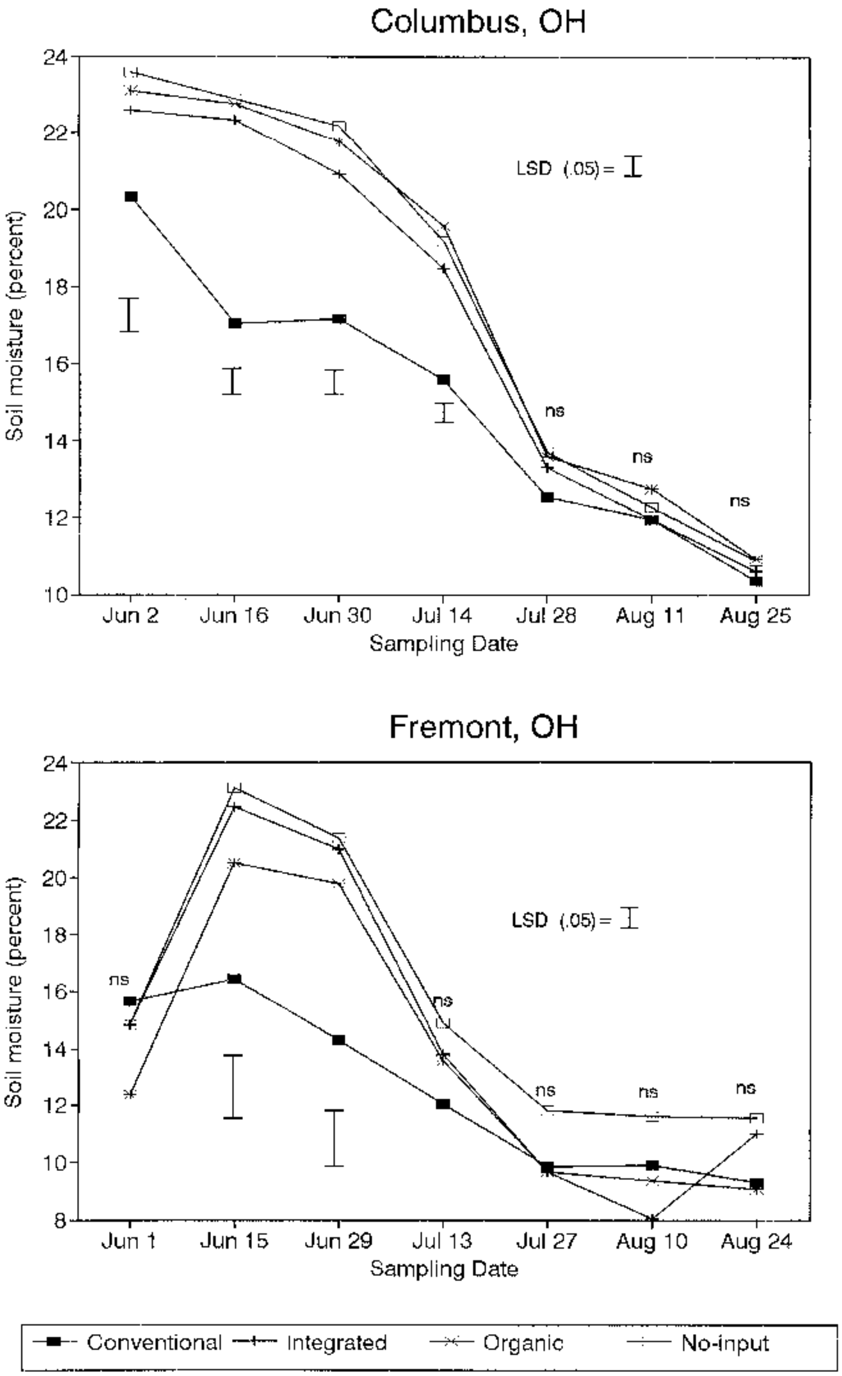

Fig. 2. Influence of four processing tomato production systems on percentage soil moisture in the top 15 cm, measured every 2 weeks in Columbus and Fremont, Ohio, 1993.

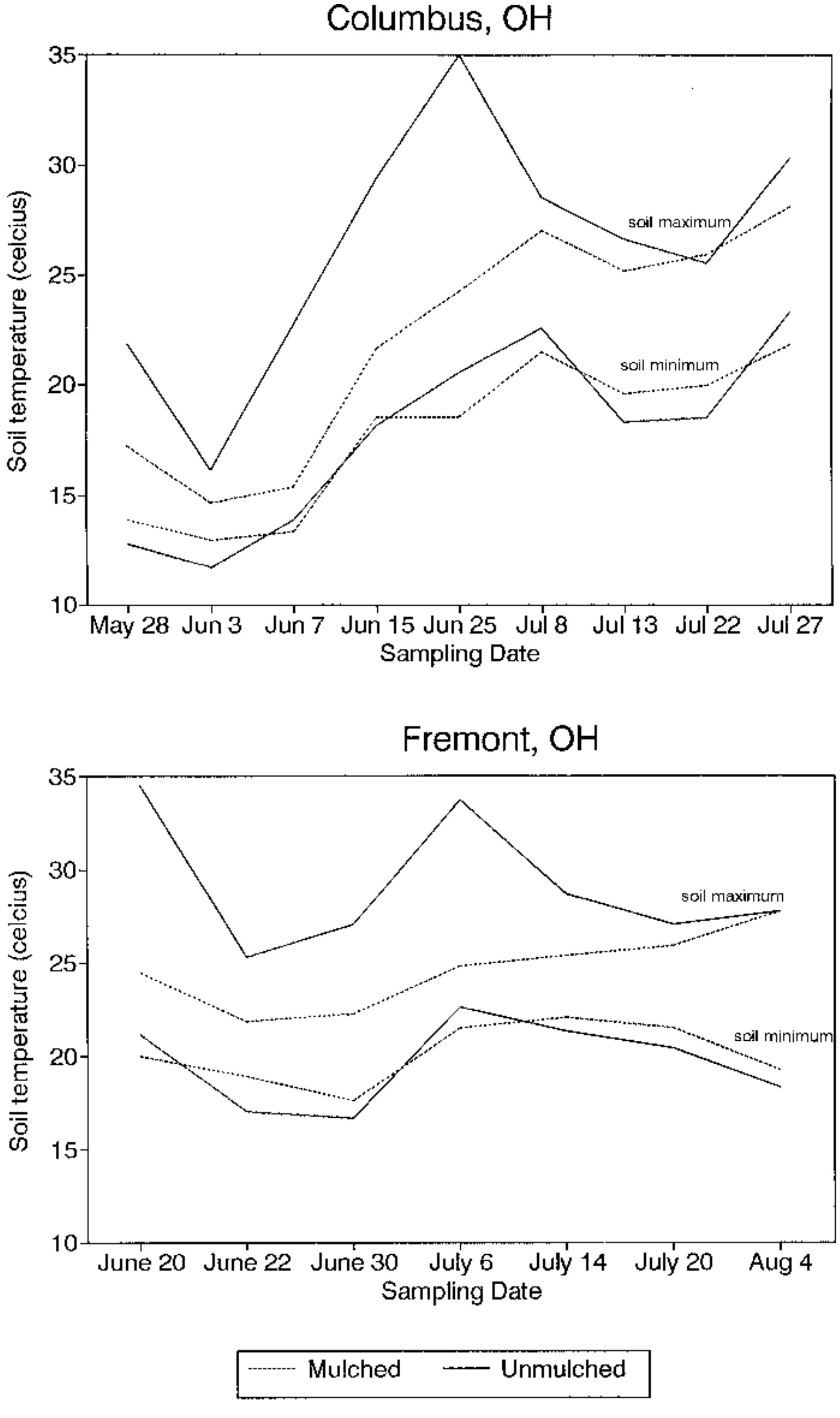

Fig. 3. Soil temperatures at 10 cm of the cover-crop mulch plots (integrated, organic, and no-input systems) and the conventional unmulched plots in Columbus and Fremont, Ohio, 1993.

tion (Table 3). At Fremont fruit soluble solids were lower in conventional systems than in the other systems, while soluble solids at Fremont were less than in Columbus. Relationships between soluble solids have been found to be negatively correlated with yield (Berry et al, 1988; Stevens and Rudich, 1978), which is consistent with high tonnage but lower soluble solids in Fremont than in Columbus.

Soil and mulch variables. Soils from the conventional system in Columbus generally had higher soil nitrate levels throughout the growing season compared with the other systems (Fig. 1). In Fremont, the conventional system had higher nitrate levels early in the season but after mid-July no differences were seen. The limited rainfall in July and August (Table 4) contributed to the limited amount of N release from the cover crops. Though the peak soil nitrate levels were higher in Columbus than in Fremont (in the conventional and integrated system), they remained above 5 to 10 $\mu g \cdot g^{-1}$ longer in Fremont. In general, tomato N uptake increases steadily from transplanting through flowering and fruit set, at which time there is a steady decline until there is no additional vegetative growth. Tomato plants are not very efficient users of applied fertilizer N and were found to absorb only 25% of total plant nitrogen from applied fertilizer, obtaining the rest from soil residual N (Hills et al., 1983). Low efficiency of fertilizer use by tomatoes occurs even with small initial residual N concentrations in the soil (Miller et al., 1981). An inefficient, poorly developed upper root system in tomato was offered as an explanation for a low recovery rate of applied fertilizer N (Jackson and Bloom, 1990). Tomato growth and development could therefore benefit from the N released from the deep decomposing cover-crop roots and possible increased root development in upper soil profiles with cover-crop residue mulch.

Mulch systems (integrated, organic, and no-input) had higher soil moisture levels than the conventional system for between 2 and 4 weeks after adequate rainfall ceased in early July (Fig. 2). Thus, moisture conservation is an important aspect of cover-crop mulch systems when dry conditions occur, as most of the processing tomato production in Ohio occurs on nonirrigated land. Cover-crop mulches help to maintain higher soil moisture levels by enhancing infiltration (Griffith et al., 1986), and reducing evaporation (Phillips, 1981). A mulch may have little effect in an extended drought (Bond and Willis, 1969).

The presence of the cover-crop mulch did not reduce daily minimum soil temperatures, but did reduce the daily maximum soil temperatures (Fig. 3). Other studies have found the same reduction in diurnal temperature fluctuations from mulches (Ghuman and Lal, 1983; Teasdale and Mohler, 1993). Soil temperature reductions were most dramatic for mulched plots during the periods when air temperatures were highest (data not shown). An important outcome of this temperature depression is the reduction of weed seed germination for species that require diurnal temperature fluctuations to break dormancy. Taylorson (1987) reported that fluctuations up to 10C were generally required to break dormancy for such weed seeds, and the cover-crop mulch in this study reduced diurnal fluctuations to <10C.

Weed, insect, and disease variables. Overall, the cover-crop mulch suppressed annual broadleaf weeds and no additional weed control was necessary during the season. The cover-crop mulch reduced the number of annual broadleaves at both locations 2 and 4 weeks after planting (data not shown).

Broadleaf weed dry weights from the different systems were greatly reduced compared with the weedy check 6 and 12 weeks after transplanting (Fig. 4), and there were no differences between the conventional herbicide-treated plots and the mulch plots. Grass pressure was low in Columbus, and there were no differences in grass dry weights between systems in Fremont or Columbus. In the conventional system in Columbus, smallflower galinsoga (*Galinsoga parviflora*) was not controlled by the herbicides used in this study and accounted for the higher dry weights of broadleaves. In the Fremont area, eastern black nightshade (*Solanum ptycanthum*) is a problem for most growers, as it is not controlled by herbicides registered for use on tomatoes. The cover-crop mulch suppressed the smallflower galinsoga and eastern black nightshade (data not shown). The cover-crop mulch kept the plots nearly weed free during the first 6 weeks after transplanting (Fig. 4). Friesen (1979) has shown that tomato fields kept weed free for 36 days yield similar amounts of tomatoes as fields kept weed free season long.

There were no differences in the frequency of scouted insect pests among the treatments (data not shown). Though some growers spray insecticides on a schedule, it is generally not necessary to spray for processing tomato pests in Ohio. In Columbus, insects were below threshold levels throughout the season. Tomato fruitworm exceeded the threshold once in Fremont so carbaryl was applied in the conventional and integrated plots, and *Bacillus thuringiensis* was applied in the organic plots. Beneficial insects [lady bugs (adults and larva) and parasitic wasps (larva)], and spiders, were not specifically monitored, but many were observed in the plots. In other studies (Bugg et al., 1990, 1991) winter annual cover crops have encouraged beneficial insects that can attack pests of succeeding crops.

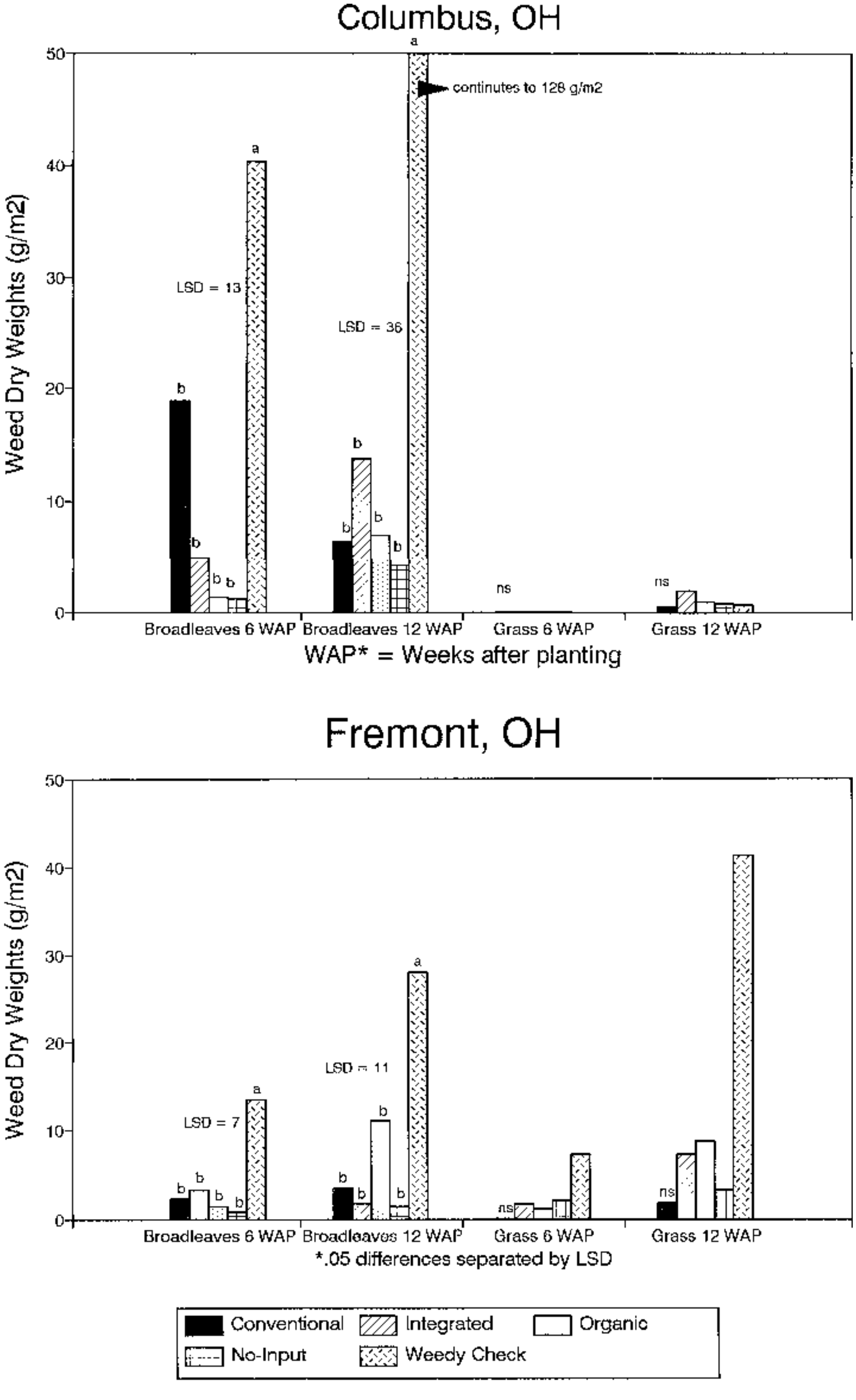

Fig. 4. Influence of four processing tomato production systems on weed dry weights ($g \cdot m^{-2}$) for broadleaves and grasses 6 and 12 weeks after planting in Columbus and Fremont, Ohio, 1993.

Five fungicide sprays in Fremont and seven in Columbus, based on the TOMCAST disease forecasting system, were applied during the season to the conventional and integrated plots. However, there were no differences in the incidence of early blight, *Septoria*, anthracnose, bacterial speck, or bacterial spot between the sprayed plots and the organic and no-input plots at either location. Blossom end rot was slightly higher in the conventional plots in Columbus (data not presented). After a rain, tomato plants in the conventional system were covered with rain-splashed soil whereas plants in the mulched plots were completely clean. For diseases transmitted

Table 5. Economic analysis of variable costs of the conventional, integrated, organic, and no-input production systems at Columbus, Ohio, 1993.

	Amount/ha					$/ha			
Item	Conventional	Integrated	Organic	No input	Price ($)/unit	Conventional	Integrated	Organic	No input
Fertilizer									
Starter	46.8 liters	46.8 liters	---	---	0.29/liter	13.57	13.57	---	---
Starter (organic)	---	---	2.7 kg	---	10.67/kg	---	---	28.81	---
Nitrogen	78.4 kg	39.2 kg	---	---	0.48/kg	37.63	18.81	---	---
Phosphorus	156.8 kg	39.2 kg	---	---	0.55/kg	86.24	43.12	---	---
Potassium	156.8 kg	78.4 kg	---	---	0.26/kg	40.77	20.38	---	---
Foliar fish	---	---	10.1 kg	---	5.27.kg	---	---	53.23	---
Seaweed extract	---	---	0.7 kg	---	16.10/kg	---	---	11.27	---
Cover-crop seed									
Hairy vetch	---	22.4 kg	22.4 kg	22.4 kg	1.32/kg	---	29.57	29.57	29.57
Rye	---	26.9 kg	26.9 kg	26.9 kg	0.31/kg	---	8.34	8.34	8.34
Barley	---	26.9 kg	26.9 kg	26.9 kg	0.31/kg	---	8.34	8.34	8.34
Crimson clover	---	11.2 kg	11.2 kg	11.2 kg	1.52/kg	---	17.02	17.02	17.02
Herbicide									
Trifluralin	2.30 liters	---	---	---	8.48/liter	19.50	---	---	---
Sencor	0.4 kg	---	---	---	55.12/kg	22.05	---	---	---
Fungicide									
Kocide	6.7 kg	3.36 kg	---	---	4.63/kg	31.02	15.55	---	---
Bravo	21 liters	10.37 liters	---	---	12.43/liter	261.02	128.89	---	---
Insecticide									
Sevin	---	---	---	---	---	---	---	---	---
Bt	---	---	---	---	---	---	---	---	---
Custom application									
Fertilizer	1 appl.	1 appl.	---	---	7.41/appl.	7.41	7.41	---	---
Foliar fertilizer	---	---	3 appl.	---	13.59/appl.	---	---	40.77	---
Herbicide incorporation	1 appl.	---	---	---	35.82/appl.	35.82	---	---	---
Fungicide	8 appl.	8 appl.	---	---	13.59/appl.	108.72	108.72	---	---
Insecticide	---	---	---	---	---	---	---	---	---
Seeding cover crop	---	1 appl.	1 appl.	1 appl.	29.64/appl.	---	29.64	29.64	29.64
Undercutting	---	1 appl.	1 appl.	1 appl.	29.64/appl.	---	29.64	29.64	29.64
Total variable costs						663.76	479.01	256.55	122.55
Receipts[z]						2731.82	2215.59	2285.29	2208.85
Return above variable costs[y]						2068.06	1736.58	2028.64	2086.30

[z] Based on $76.04/t for conventional and $87.44/t for organic tomatoes.

[y] No significant differences ($P = 0.05$).

partially by soil splashing onto the plants (e.g., *Alternaria* and anthracnose), the mulch may help to reduce their incidence.

Economic analysis. There were no significant differences in economic return above variable costs at Columbus (Table 5). In Fremont, the conventional system had a higher return/hectare ($4315) than the other systems (Table 6). Though the level of chemical inputs was reduced in the integrated system, the applications still had to be made, which substantially added to the cost of the integrated system. In addition, there was the additional cost of seeding and undercutting the cover crop compared to the conventional system. The key difference between the organic and no-input was the foliar fish–seaweed applications, and in this study the applications did not translate to higher returns.

Cover crops can be managed in various ways in vegetable crop production systems. This method of undercutting the cover-crop mixture and leaving the residue intact on the soil surface as a mulch has several potential benefits. Cover-crop residue suppressed annual broadleaf and grass weeds in these experiments as effectively as the herbicides used in conventional systems. Organic and other vegetable growers seeking to reduce purchased inputs generally view weed management as the biggest problem they face, and this cover-crop management system may be a partial answer to their problem. In general, the tomatoes planted into the mulch looked vigorous throughout the growing season. The fact that all cover-crop treatment plots had minimal foliar or fruit disease incidence is encouraging, and the ability of the mulch to reduce soil splashing onto the leaves most likely plays a role in this.

Although this was only a 1-year study, the two locations were separated by >100 miles and provided the opportunity to quantify differences in two distinct environments. Comparing rainfall averages for the year of the study to long term averages showed a much wetter than average 16 June–15 July in Columbus, and a significantly drier than average August at both sites (Table 4). However, the differences in precipitation between Columbus and Fremont for the study year were actually larger in four of the nine 2-week segments than differences in precipitation at Columbus between 1993 and 1994 (data not shown). This illustrates that though the test was conducted in only 1 year, the variability between the two environments (Columbus and Fremont) was almost as great as if the test had been conducted in 1993 and 1994 in Columbus. Future studies will determine if some of the benefits in this study, for example, reduced tomato disease incidence, will be a consistent benefit when producing tomatoes and other vegetables in a dead cover-crop mulch. More study is also needed to determine opti-

Table 6. Economic analysis of variable costs of the conventional, integrated, organic, and no-input production systems at Fremont, Ohio, 1993.

	Amount/ha					$/ha			
Item	Conventional	Integrated	Organic	No input	Price ($)/unit	Conventional	Integrated	Organic	No input
Fertilizer									
Starter	46.8 liters	46.8 liters	---	---	0.29/liter	13.57	13.57	---	---
Starter (organic)	---	---	2.7 kg	---	10.67/kg	---	---	28.81	---
Nitrogen	78.4 kg	39.2 kg	---	---	0.48/kg	37.63	18.82	---	---
Phosphorus	156.8 kg	78.4 kg	---	---	0.55/kg	86.24	43.12	---	---
Potassium	156.8 kg	78.4 kg	---	---	0.26/kg	40.77	20.38	---	---
Foliar fish	---	---	10.1 kg	---	5.27/kg	---	---	53.23	---
Seaweed extract	---	---	0.7 kg	---	16.10/kg	---	---	11.27	---
Cover-crop seed									
Hairy vetch	---	22.4 kg	22.4 kg	22.4 kg	1.32/kg	---	29.57	29.57	29.57
Rye	---	26.9 kg	26.9 kg	26.9 kg	0.31/kg	---	8.34	8.34	8.34
Barley	---	26.9 kg	26.9 kg	26.9 kg	0.31/kg	---	8.34	8.34	8.34
Crimson clover	---	11.2 kg	11.2 kg	11.2 kg	1.52/kg	---	17.02	17.02	17.02
Herbicide									
Trifluralin	2.30 liters	---	---	---	8.48/liter	19.50	---	---	---
Sencor	0.4 kg	---	---	---	55.12/kg	22.05	---	---	---
Fungicide									
Kocide	16.8 kg	8.4 kg	---	---	4.63/kg	77.78	38.89	---	---
Bravo	17.5 liters	8.7 liters	---	---	12.43/liter	217.52	108.14	---	---
Insecticide									
Sevin	4.67 liters	4.67 liters	---	---	6.89/liter	32.18	32.18	---	---
Bt	---	---	7.0 liters	---	6.89/liter	---	---	48.23	---
Custom application									
Fertilizer	1 appl.	1 appl.	---	---	7.41/appl.	7.41	7.41	---	---
Foliar fertilizer	---	---	3 appl.	---	13.59/appl.	---	---	40.77	---
Herbicide incorporation	1 appl.	---	---	---	35.82/appl.	35.82	---	---	---
Fungicide	5 appl.	5 appl.	---	---	13.59/appl.	67.95	67.95	---	---
Insecticide	1 appl.	1 appl.	1 appl.	---	13.59/appl.	13.59	13.59	13.59	---
Seeding cover crop	---	1 appl.	1 appl.	1 appl.	29.64/appl.	---	29.64	29.64	29.64
Undercutting	---	1 appl.	1 appl.	1 appl.	29.64/appl.	---	29.64	29.64	29.64
Total variable costs						671.87	486.60	301.25	122.55
Receipts[z]						4986.93	3357.47	3042.81	3184.92
Return above variable costs[y]						4315.06	2870.87	2742.56	3062.37

[z] Based on $76.04/t for conventional and $87.44/t for organic tomatoes.

[y] LSD (0.05) = $817.28.

mum N rates, optimum source of N, and the best method of application for all systems. As is common when transitioning from a conventional system to an organic system of production, improvements in soil physical, chemical, and biological properties may also lead to increased yields after 4 to 5 years.

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