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Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms

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Abstract

Field experiments were conducted to examine the effects of organic and synthetic soil fertility amendments on soil microbial communities and soil physical and chemical properties at three organic and three conventional vegetable farms in Virginia and Maryland in 1996 and 1997. Two treatments, including either an alternative organic soil amendment (composted cotton-gin trash, composted yard waste, or cattle manure) or synthetic soil amendment (fertilizer) were applied to three replicated plots at each grower field location. Production history and time affected propagule densities of *Trichoderma* species which remained higher in soils from organic farms. Propagule densities of *Trichoderma* species, thermophilic microorganisms, and enteric bacteria were also detected in greater numbers in soils amended with alternative than synthetic amendments, whereas propagule densities of *Phytophthora* and *Pythium* species were lower in soils amended with alternative than synthetic fertility amendments. Concentrations of Ca, K, Mg, and Mn were higher in soils amended with alternative than synthetic fertility amendments. Canonical correlations and principle component analyses indicated significant correlation between these soil chemical factors and the biological communities. First-order canonical correlations were more negative in fields with a conventional history, and use of synthetic fertilizers, whereas canonical correlations were more positive in fields with a history of organic production and alternative soil amendments. In the first year, yields of corn or melon were not different in soil amended with either synthetic or organic amendments at four of six farms. In the second year, when all growers planted tomatoes, yields were higher on farms with a history of organic production, regardless of soil amendment type. Alternative fertility amendments, enhanced beneficial soil microorganisms reduced pathogen populations, increased soil organic matter, total carbon, and cation exchange capacity (CEC), and lowered bulk density thus improving soil quality.

Keywords: Soil chemical and physical factors; Organic agriculture; Sustainable agriculture; Soil microbial communities

1. Introduction

Demand for organically produced food has increased 24% yearly in the US in the 1990s, as many consumers have expressed concern over pesticide residues on foods (Govindasamy and Italia, 1998; Thompson, 1998). Food and environmental safety are often-cited

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reasons for the use of alternative soil amendments, but increasingly, economic considerations are becoming important with a rise in popularity of organically produced foods (Govindasamy and Italia, 1998; Klonsky and Tourte, 1998; Thompson, 1998). A premium of 12–60% is often obtained from organic produce (Lohr, 1998). Since this premium exists, organic agriculture has become more attractive to farmers (Langley et al., 1983; Klonsky and Tourte, 1998; Thompson, 1998).

The use of organic soil amendments has been associated with desirable soil properties including higher plant available water holding capacity and CEC and lower bulk density, and can foster beneficial microorganisms (Doran, 1995; Drinkwater et al., 1995). Benefits of compost amendments to soil also include pH stabilization and faster water infiltration rate due to enhanced soil aggregation (Stamatiadis et al., 1999). Soil chemical characteristics are affected by soil amendment and production system. For example, at the Rodale Institute, long-term legume-based and organic production systems have resulted in an increase in soil organic matter and reduced nitrate runoff (Drinkwater et al., 1998). Soils in organic production systems lost less nitrogen into nearby water systems than did conventional production systems (Liebhardt et al., 1989). The amount of soil nitrogen in fields under conventional production systems has been negatively correlated with soil microbial components, whereas soil nitrogen in fields under organic production was positively correlated with soil microbial components (Gunapala and Scow, 1998).

Yields of crops grown in organic and conventional production systems can be equivalent. Vegetable fields under organic production in California produced yields equal to those under conventional production (Drinkwater et al., 1995; Stamatiadis et al., 1999). Long-term research in Pennsylvania has also demonstrated little difference in yields between conventional and organic production systems (Drinkwater et al., 1998).

Limited field studies have been conducted to determine the impact of soil amendments on microbial communities in actual organic and conventional production systems in the fields (Drinkwater et al., 1995; Gunapala and Scow, 1998). However, it has been shown that microbial activity and biomass is higher in fields with organic amendments than fields with conventional fertilizers (Drinkwater et al., 1995). Many studies on soil microbial communities, as affected by organic amendments, have examined functional groups, or classes of organisms, while few studies have examined the impact on community composition and genera within these groups. One such study in organic tomato fields in California found that suppression of corky root disease was associated with increased actinomycete activity (Workneh et al., 1993; Workneh and van Bruggen, 1994).

Organic production systems have increased in recent years in the southeastern United States, but we know little about the soil microbial communities in these fields or the impact of these production practices on yield. We examined microorganisms in soil that were either beneficial (compost organisms that decompose organic matter, organisms that parasitize plant pathogens, or beneficial rhizosphere microorganisms), or potential pathogens that have a significant impact on soil ecology, plant and human health. The objective of our research was to examine the effects of either synthetic fertilizers or alternative soil amendments, including composted animal manures and plant materials on specific soil microbial communities, soil physical and chemical properties and yield on farms with a history of either conventional or organic production.

2. Materials and methods

2.1. Experimental design

Field experiments were conducted in 1996 and 1997 at three farms with a history of either conventional or organic production. Five of the six experimental sites were located in Virginia, and one was located in Maryland. The three conventionally-managed sites had a history of at least 5 years of vegetable or field crop monoculture, synthetic fertilizers, and pesticide use. The three organically-managed sites had a history of at least 3 consecutive years of organic soil fertility amendment, winter cover crops, mulch for weed control, and biologically-based pest control. Pesticides were not used during this study at any of the experimental sites. Grower field soil types, amendments used, and crops grown each year are shown in Table 1.

The experimental design consisted of a randomized complete block with three replicates per field. Two treatments, consisting of either a blended synthetic

Table 1
Summary of soil series, amendments, crops, and production history for field experimental sites for 1996 and 1997

Grower	Soil series[a]	Location	Productivity[a] (mean corn yield, t/ha)	Alternative amendment[b]	Crop		Production history[c]
					1996	1997	
1	Eunola loamy fine sand (fine-loamy, siliceous, semiactive, thermic Aquic Hapludults)	Suffolk VA	6.92	Cotton-gin trash	Melons	Tomato	Conventional
2	Eunola loamy fine sand (fine-loamy, siliceous, semiactive, thermic Aquic Hapludults)	Suffolk VA	6.92	Cotton-gin trash	Melons	Tomato	Conventional
3	Eunola loamy fine sand (fine-loamy, siliceous, semiactive, thermic Aquic Hapludults)	Suffolk VA	6.92	Cotton-gin trash	Melons	Tomato	Conventional
4	Westphalia fine sandy loam (coarse-loamy, siliceous, semiactive, mesic Inceptic Hapludults)	Upper Marlboro MD	4.09	Cattle manure	Corn	Tomato	Organic
5	Chester loam (fine-loamy, mixed, mesic Typic Hapludults)	Leesburg VA	9.43	Hay-manure compost	Corn	Tomato	Organic
6	Glenelg loam (fine-loamy, mixed, semiactive, mesic Typic Hapludults)	Blacksburg VA	6.92	Yard waste compost	Corn	Tomato	Organic

[a] Classified according to the Virginia Agronomic Land Use Evaluation System, VALUES (Simpson et al., 1993) and based primarily on plant available water-holding capacity.
[b] Soil amendments were added to plots at least 1 week prior to planting.
[c] Production histories were either conventional production systems with synthetic fertilizer and pesticide use, or organic production systems that had at least 3 years of organic amendments and no pesticide use.

fertilizer or an organic waste, were applied at each of the six locations (Table 2). Alternative amendments consisting of organic wastes that were used as fertility sources were either composted cotton-gin trash, mixed yard waste-poultry litter compost, uncomposted cattle manure, or mixed hay-cattle manure compost. Synthetic fertilizers consisted of mixtures of nitrogen as ammonium nitrate (35.5-0-0), phosphorus as triple superphosphate (0-46-0), and potassium as muriate of potash (0-0-60).

Nutrient requirements for each crop and field were based on Virginia Cooperative Extension recommendations (Donohue and Heckendorn, 1994) following routine soil testing laboratory analysis performed in the Department of Crop and Soil Environmental Sciences (CSES) at Virginia Tech, Blacksburg, Virginia (Donohue, 1992). Synthetic fertilizers were applied to all farms according to Soil Test Laboratory analyses and recommendations. Organic wastes were applied at rates designed to provide required plant available nitrogen (PAN) on the historically conventional farms. On the historically organic farms, organic amendments were applied according to the recommendations of the farmers based on their experiences with anticipated residual nitrogen from continuous annual applications of compost and the use of green manure cover crops. The rates of compost used by organic farmers were generally lower than the rates calculated to provide the required PAN for each crop and soil (Table 2).

PAN contents of the organic wastes were estimated from analyses of the inorganic and organic forms of nitrogen in the composts according to the following equation:

$$\text{PAN} = [\text{Org-N}] \times A + [\text{NH}_4\text{-N}] \times B + [\text{NO}_3\text{-N}]$$

where Org-N is the concentration of organic-bound N in the waste as calculated by [TKN]-[NH_4-N]; TKN the total Kjeldahl nitrogen concentration; NH_4-N the ammonium nitrogen concentration; NO_3-N the nitrate nitrogen concentration; A the fraction of Org-N expected to mineralize or become plant available in

Table 2
Estimated rates of plant available nutrients from plots amended with synthetic or alternative soil amendments at six locations in 1996 and 1997

Grower	Amendment type[a]	Amendment rate (Mg/ha)[b]	Cover crop N[c]	Available nutrients from amendment (kg/ha)			Total PAN[d]
				N	P	K	
1996							
1	Alternative	33.6	0	92	165	346	92
	Synthetic		0	101	28	73	101
2	Alternative	33.6	0	92	165	346	92
	Synthetic		0	101	56	171	101
3	Alternative	33.6	0	92	165	346	92
	Synthetic		0	101	112	78	101
4	Alternative	28.0	40	29	71	188	74
	Synthetic		40	157	91	99	165
5	Alternative	8.7	60	63	22	86	130
	Synthetic		0	157	45	99	157
6	Alternative	20.0	0	72	176	250	72
	Synthetic		0	157	45	39	157
1997							
1	Alternative	69.5	0	133	224	926	133
	Synthetic		0	101	24	187	101
2	Alternative	51.3	0	113	166	684	113
	Synthetic		0	101	49	187	101
3	Alternative	51.8	0	115	169	697	115
	Synthetic		0	101	37	187	101
4	Alternative	42.1	40	50	109	462	95
	Synthetic		40	101	37	94	146
5	Alternative	17.3	60	24	22	48	91
	Synthetic		0	101	24	94	101
6	Alternative	30.0	0	66	138	288	66
	Synthetic		0	101	0	0	101

[a] Alternative refers to alternative amendments given in Table 1 for each grower. Synthetic amendments are ammonium nitrate (35.5-0-0), triple superphosphate (0-46-0), and muriate of potash (0-0-60).
[b] Rate of dry compost applied in metric tons per hectare (Mg/ha). Synthetic amendment rates are given in each row under available nutrients.
[c] Estimated nitrogen supplied by winter cover crop green manure (kg/ha).
[d] Total estimated PAN (kg/ha).

the year of application, generally estimated to be approximately 0.10–0.15 for compost and 0.35 for beef cattle manure in the mid-Atlantic region of the US (Evanylo, 1994); *B* the fraction of NH_4-N expected to be plant available in the year of application, generally estimated to be 1.0 for compost and 0.85 for beef manure incorporated within 24 h of application.

Nitrogen contents of the organic wastes were determined in the CSES Department at Virginia Tech through analysis for TKN (Bremner and Mulvaney, 1982) and NH_4-N and NO_3-N (Keeney and Nelson, 1982). Most fields were allowed to remain fallow over winter, but organic growers 4 and 5 planted a rye cover crop in the winters of 1995 and 1996 (Table 2). All soil fertility amendments were applied between April and June of each year and immediately incorporated into soil.

Plots were 7.6 m $\times$ 7.6 m and consisted of four rows that were 1.6 m wide. Planting occurred within 1 week of soil amendment. In the first season, conventional growers planted melons (*Cucumus melo* L. var. reticulatum), and organic growers planted sweet corn (*Zea mays* L. var. Silver Queen) (Table 1). In the second season, all growers planted tomatoes (*Lycopersicon escelentum* L. var. Celebrity or Mountain Spring) (Table 1).

2.1.1. Soil sampling

Soil samples were removed from each field approximately 2 weeks after planting and at harvest in both years and subjected to physical and chemical analyses and assays for selected microbiological populations. Twelve soil cores (30 cm in length and 1.9 cm in diameter) were removed in a serpentine pattern from each of two center rows of each plot resulting in 24 soil cores per plot. Subsequently, all cores taken from a single plot were pooled. Samples were removed from the root zone around plants in the rows. Soil cores were placed in a large (4 l) plastic bag and stored on ice in coolers. In the laboratory, samples were stored at 5 °C and analyses were accomplished within 3 weeks of sampling. All soils were handled similarly so relative comparisons between soils from different farming systems were possible.

2.2. Propagule densities of selected soil microorganisms

Numbers of culturable bacteria, fluorescent pseudomonad bacteria, enteric bacteria, total fungi, thermophilic microorganisms, *Trichoderma*, *Fusarium*, *Phytophthora* and *Pythium* species were quantified. Soil samples were analyzed for selected soil microorganisms using 10-fold serial dilutions of soil and eight different selective media. The 10 g of soil was diluted in 90 ml sterile water agar (w/v, 0.25%, Difco, Detroit). Serial 10-fold dilutions were made to 10^{-7} (Table 3). Triplicate plates for each medium were used for each sample, and several media required different soil dilutions for statistically accurate propagule estimation (Table 3). Colonies were counted from plates containing 30–300 colonies. Variance in count data was normalized using $\log_{10}(x + 1)$ transformation prior to analysis where x equals the average number of propagules of each type of microorganism per gram dry soil. Percent soil moisture content for each sample was determined gravimetrically. Data are expressed as number of colony forming units (CFUs)/g of dry soil.

2.3. Soil chemical and physical parameters

Soil samples for physical and chemical parameters were collected concurrently with microbial samples, and were quantified for Mehlich I-extractable P, K, Ca, Mg, Mn, Zn, Cu, and B; pH (Donohue, 1992); total Kjeldahl N (Bremner and Mulvaney, 1982); NH_4-N, and NO_3-N (Keeney and Nelson, 1982). Additional soil chemical and physical properties: bulk density by core method (Blake, 1965); organic

Table 3
Media, dilution factors, organisms, and incubation conditions for microorganisms isolated from soils in organic and conventional field soils

Medium	Dilution factor[a]	Organism(s) cultured	Culture conditions			Reference
			Temperature (°C)	Incubation (days)	Light conditions	
Masago's[b]	10^{-1}, 10^{-2}	*Pythium* and *Phytophthora* spp.	22	5–7	Dark	Masago et al. (1977)
Trichoderma medium E	10^{-2}, 10^{-3}	*Trichoderma* spp.	22	7	Light	Papavizas and Lumsden (1982)
YGA	10^{-2}, 10^{-3}	Thermophilic microorganisms	45	2–4	Dark	Stevens (1974)
GYRBA	10^{-3}	*Fusarium* spp.	22	5–7	Dark	Newhouse (1980)
King's medium B	10^{-4}, 10^{-5}	Fluorescent *Pseudomonas* spp.	20–25	5–7	Dark	Sands and Rovira (1970)
Endo	10^{-5}, 10^{-6}	Enteric bacteria	37	1–2	Dark	Difco manual
PDA[c]	10^{-4}, 10^{-5}	Total fungi	20–25	3–5	Dark	Stevens (1974)
TSA[d]	10^{-6}, 10^{-7}	Culturable bacteria	20–25	1–2	Dark	Difco manual

[a] Dilution factor number is the 1:10 serial dilution from each sample which was plated in triplicate.
[b] Media not amended with hymexazol to allow growth of *Pythium* and *Phytophthora* species.
[c] Potato dextrose agar with 100 mg/ml streptomycin sulfate (Fisher Scientific, Pittsburgh) to inhibit bacterial growth.
[d] Tryptic soy agar with 100 mg/ml nystatin (Sigma, St. Louis) to inhibit fungal growth.

matter by Walkley-Black; total organic carbon by dry combustion (Nelson and Sommers, 1982); CEC (Rhoades, 1982); exchangeable cations (Thomas, 1982) and plant available water holding capacity by pressure plate method (Klute, 1986) were conducted on samples collected at harvest in 1996 and 1997.

2.3.1. Yield

Yield of marketable vegetables were taken from the center, 4 m of two center rows, in each plot and weighed by growers on a weekly basis once fruit began to ripen. Weights from each plot from each week were tallied, analyzed, and presented as average total per plot in metric tons per hectare (Mg/ha).

2.4. Statistical analyses of data

Statistical analyses were performed on all the data using the GLM procedure from PC SAS 6.2 and 7.0 (SAS Institute, Cary, NC). Analyses of microbial data were conducted using the transformed and arithmetic means and are presented in figures. Analyses of variance for both microbial and chemical parameters were performed. Principle components (PRINCOMP) partial correlations analyses and canonical correlations (CANCORR) were calculated between selected chemical and biological parameters. Variation occurred between experimental sites, climatic features, soil types, and weather conditions between years, so only interactions that were statistically significant ($P \leq 0.05$) for each year, and overall (combined data from 1996 and 1997) are presented in this paper.

3. Results

3.1. Soil microbial populations

Production history and time affected propagule densities of beneficial soil fungi in the genus *Trichoderma* in soil in both years ($P = 0.02$, Fig. 1A). Numbers of *Trichoderma* species were higher initially in 1996, in soils from fields with a history of organic than conventional production. Propagule densities increased over time in fields with a conventional history, but remained higher over time in soils from organic compared to conventional fields. Soil amendment also affected propagule densities of *Trichoderma* species in both years ($P = 0.01$, Fig. 1B). Soils with alternative amendments had higher propagule densities of *Trichoderma* species than soils amended with synthetic fertilizers in both years regardless of production system history (Fig. 1B).

Propagule densities of thermophilic microorganisms were significantly higher in soils amended with alternative amendments than in soils amended with synthetic fertilizers in both years. In 1996, propagules densities of thermophilic organisms were 2.1×10^4

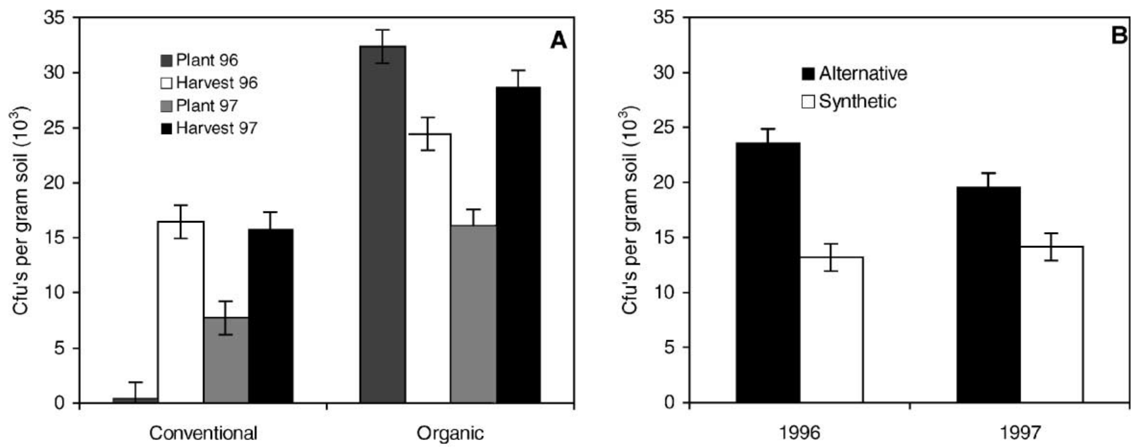

Fig. 1. (A) Impact of grower production history and time on propagule densities of *Trichoderma* species in grower field soils from three organic and three conventional field locations in 1996 and 1997 (Lsd = 1499 CFUs/g soil). (B) Effects of alternative and synthetic soil amendments on propagule densities of *Trichoderma* species in field soils from 1996 and 1997 (Lsd = 1223 CFUs/g soil).

CFUs/g dry soil in soils with alternative amendments and 1.47×10^4 CFUs/g dry soil in soils with synthetic fertilizers ($P < 0.01$). In 1997, propagules densities of thermophilic microorganisms were 5.07×10^4 and 1.94×10^4 CFUs/g dry soil in soils with alternative or synthetic amendments, respectively ($P = 0.01$).

Enteric bacteria were also affected by soil fertility amendments in both years. Soils with alternative fertility amendments had nearly twice as many propagules of enteric bacteria than soils with synthetic fertilizers in each year. In 1996, propagules densities of enteric bacteria were 1.85×10^7 CFUs/g dry soil in soils amended with alternative amendments and 1.08×10^7 CFUs/g dry soil in soils with synthetic fertilizers in 1996 ($P = 0.05$). In 1997, propagules densities of enteric bacteria were 3.88×10^7 CFUs/g dry soil in soils amended with alternative fertility amendments and 1.94×10^7 CFUs/g dry soil in soils amended with synthetic fertilizers ($P = 0.03$).

Propagule densities of *Phytophthora* plant pathogenic and *Pythium* species were affected by soil amendment and time in both years. Propagule densities of *Phytophthora* and *Pythium* species were lower in soils with alternative fertility amendments than in soils amended with synthetic fertilizers in both years ($P = 0.03$, Fig. 2A). In addition, propagule densities of these pathogens increased over time and were higher at harvest than at planting in both years ($P = 0.02$, Fig. 2B). Orthogonal contrast comparisons reveal that treatment effects on propagule densities of *Phytophthora* and *Pythium* species were not different between years ($P = 0.07$).

Production systems and soil fertility amendments did not affect propagule densities of *Fusarium* species at any location in either year. Initially, fluorescent pseudomonads were more abundant in 1996 in soils from fields under organic production than those in conventional production ($P = 0.05$), but these differences were not maintained over time. Total fungi and culturable bacteria were more abundant in soils with alternative than synthetic fertility amendments fertilizers in 1997 but not in 1996.

3.2. Soil chemical components

Several soil chemical factors were affected by soil fertility amendments and time (Fig. 3). Calcium concentrations in soils with alternative fertility amendments were increased two-fold over the 2-year period. In contrast, no increase in calcium concentrations occurred in soils with the synthetic fertilizers ($P < 0.01$, Fig. 3A). Similarly, magnesium concentrations

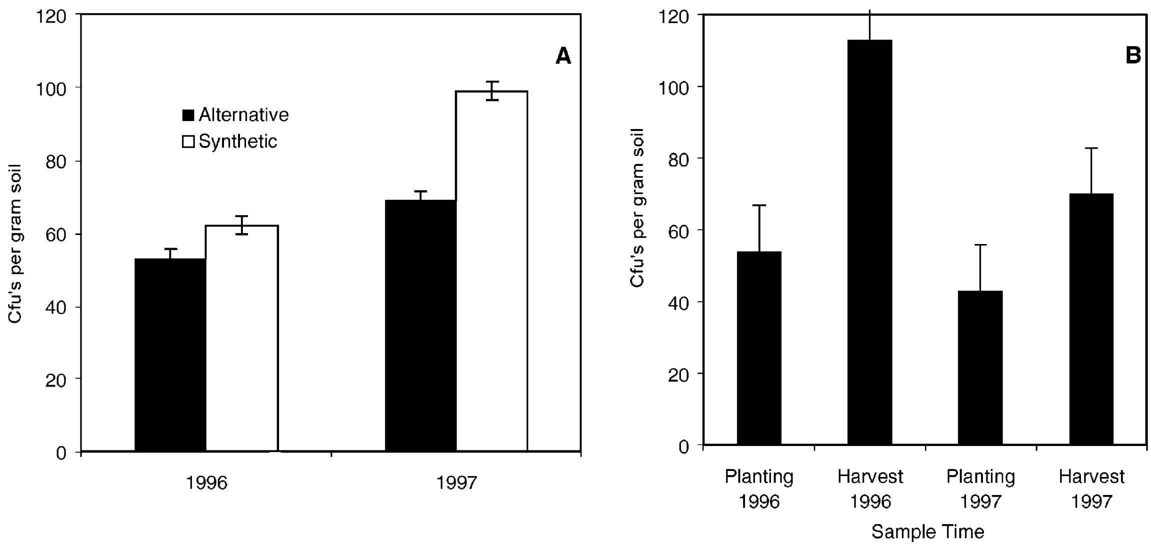

Fig. 2. (A) Impact of the alternative and synthetic soil amendments on propagule densities of *Phytophthora* and *Pythium* species in grower field soils from 1996 and 1997 (Lsd = 2.48 CFUs/g soil). (B) Effects of sampling time on propagule densities of *Phytophthora* and *Pythium* species in grower field samples from 1996 and 1997 (Lsd = 12.8 CFUs/g soil).

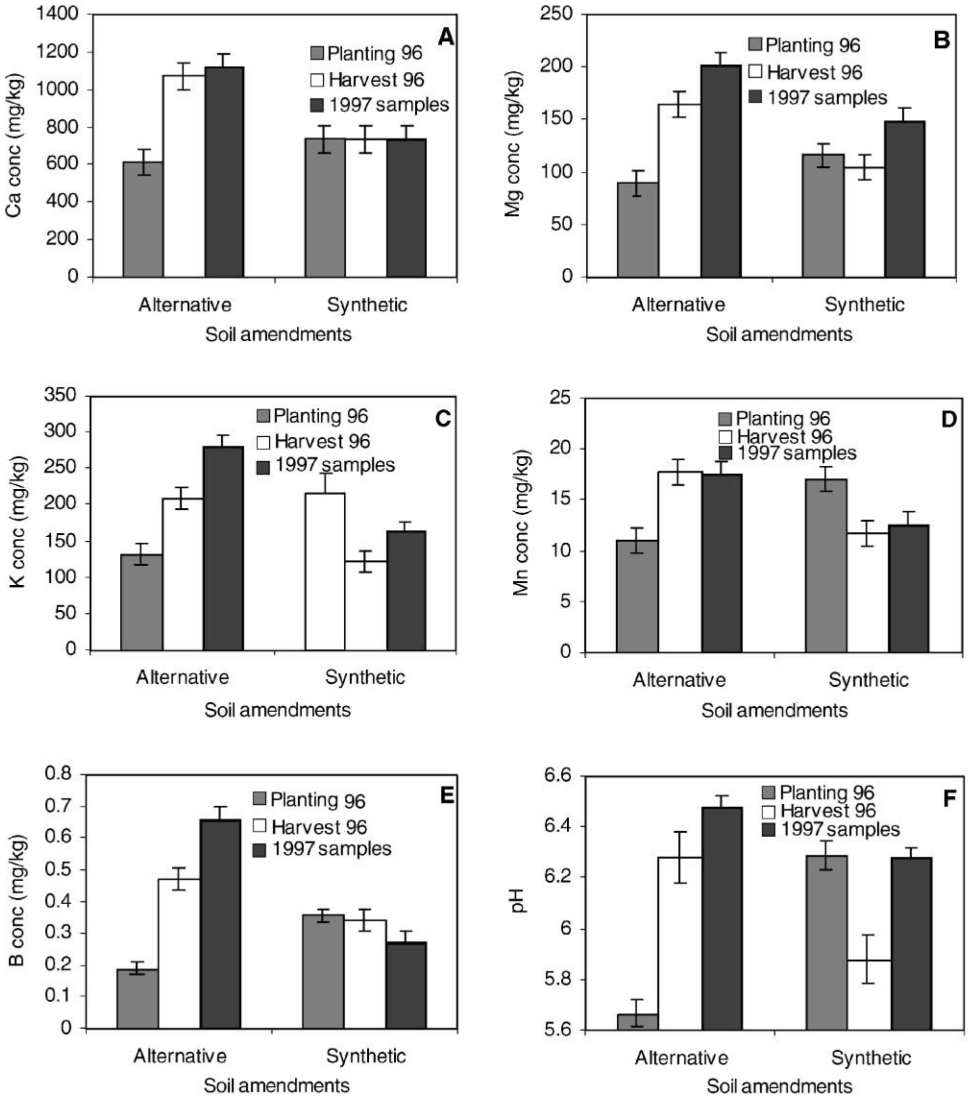

Fig. 3. Effects of alternative and synthetic soil fertility amendments and time on concentrations of (A) calcium (Lsd = 70 mg/kg soil); (B) magnesium (Lsd = 12 mg/kg soil); (C) potassium (Lsd = 14 mg/kg soil); (D) manganese (Lsd = 1.2 mg/kg soil); (E) Boron (Lsd = 0.06 mg/kg soil); and (F) pH (Lsd = 0.09 pH), respectively, from field soils in 1996 and 1997.

more than doubled in soils amended with alternative fertility amendments, whereas only slight increases in magnesium concentrations were observed in soils with synthetic fertilizers over the same time period ($P < 0.01$, Fig. 3B). Potassium concentrations in soils amended with alternative fertility amendments increased by a factor of 3, and were higher at the end of the second year in soils with alternative amendments than in soils with synthetic fertility amendments, whereas potassium concentrations decreased over time in soils with synthetic fertilizers ($P = 0.01$, Fig. 3C). Soil manganese concentrations increased over time in soils amended with alternative fertility amendments, but decreased in soils with synthetic fertilizers ($P = 0.02$, Fig. 3D). Boron increased in soils with alternative fertility amendments over time

Table 4
Chemical and physical parameters as affected by alternative or synthetic soil fertility amendments at six grower locations after 2 years

Chemical or physical factor	Soil amendment		
	Alternative[a]	Synthetic[b]	Lsd[c]
Organic matter (%)	2.83	2.00	0.25
Total C (%)	1.90	1.17	0.29
CEC (cmol/kg)	7.97	6.05	0.84
Bulk density (g/cm^3)	1.01	1.17	0.07

[a] Alternative soil amendments were either cotton-gin trash, hay manure compost or yardwaste.
[b] Synthetic soil amendments were commercial fertilizers.
[c] Lsd from ls-means procedure in SAS 7.0.

whereas no differences in boron concentration were observed in soils with synthetic fertilizers ($P = 0.003$, Fig. 3E). Soil fertility amendments also affected soil pH ($P = 0.05$, Fig. 3F). Soils with alternative fertility amendments initially had a lower soil pH than soils with synthetic fertilizers, but over time soil pH increased in soils with alternative amendments to higher levels than pH in soils with synthetic fertilizers. Levels of other soil nutrients (zinc, iron and aluminum) were not affected by soils amendment, sample time, production history or interactions of these components in 1996 and 1997. However, in 1997, copper and phosphorus levels were higher in soils with alternative than synthetic soil fertility amendments.

Mean soil organic matter, total C, and CEC were higher and bulk density was lower in plots with the alternative soil amendments compared to synthetic fertilizers after 2 years (Table 4). Continuous annual applications of compost are typically required to cause significant enhancements in these soil properties (Mays et al., 1973; Shiralipour et al., 1992), thus, it was not surprising that these changes were not observed at all locations after the first year.

3.3. Canonical correlations and principle components of soil chemical and microbial parameters

A positive correlation of principle components was detected between the levels of calcium, magnesium and manganese, and propagule densities of *Trichoderma* species in soils (Table 5). Significant positive correlation exists when the r^2 was above 0.32. Propagule densities of thermophilic microorganisms were also positively correlated with levels of calcium and magnesium in soils (Table 5). Other correlations were not significant.

Analyses of canonical correlations of soil chemical components and soil microbial propagule densities revealed that specific chemical components of the soil and some propagule densities of soil microorganisms were highly correlated (Fig. 4). For each sample time, a correlation coefficient of 0.89–0.98 was observed for the interaction of the first-order canonical correlations. Cumulative correlations of 88–97% were observed in the first four canonical correlations over time. Clustering of correlations existed with more negative correlations associated with conventional production systems and synthetic fertilizers, with 27 of 36 canonical correlations in the fourth quadrant ($-X$, $-Y$) (Fig. 4). More positive correlations were associated with organic production systems and organic amendments, with 20 of 36 canonical correlations in the first quadrant ($+X$, $+Y$) (Fig. 4). Organic production systems with synthetic fertilizers had 19 of 36 canonical correlations in the fourth quadrant, and 12 of 36 canonical correlations in the first quadrant

Table 5
Partial correlation matrix (r^2) from microbial data, and soil chemical data from principle components analysis in 1996 and 1997

	Partial correlation matrix (r^2)			
	Trichoderma species	Thermophilic microorganisms	*Phytophthora* and *Pythium* spp.	Enteric bacteria
Calcium	0.483[a]	0.328[a]	0.316	0.109
Magnesium	0.451[a]	0.418[a]	0.286	0.144
Potassium	0.317	0.256	0.110	0.123
Manganese	0.359[a]	0.245	0.279	0.028

[a] Significant correlations ($P < 0.05$) from principle components procedure in SAS 7.0.

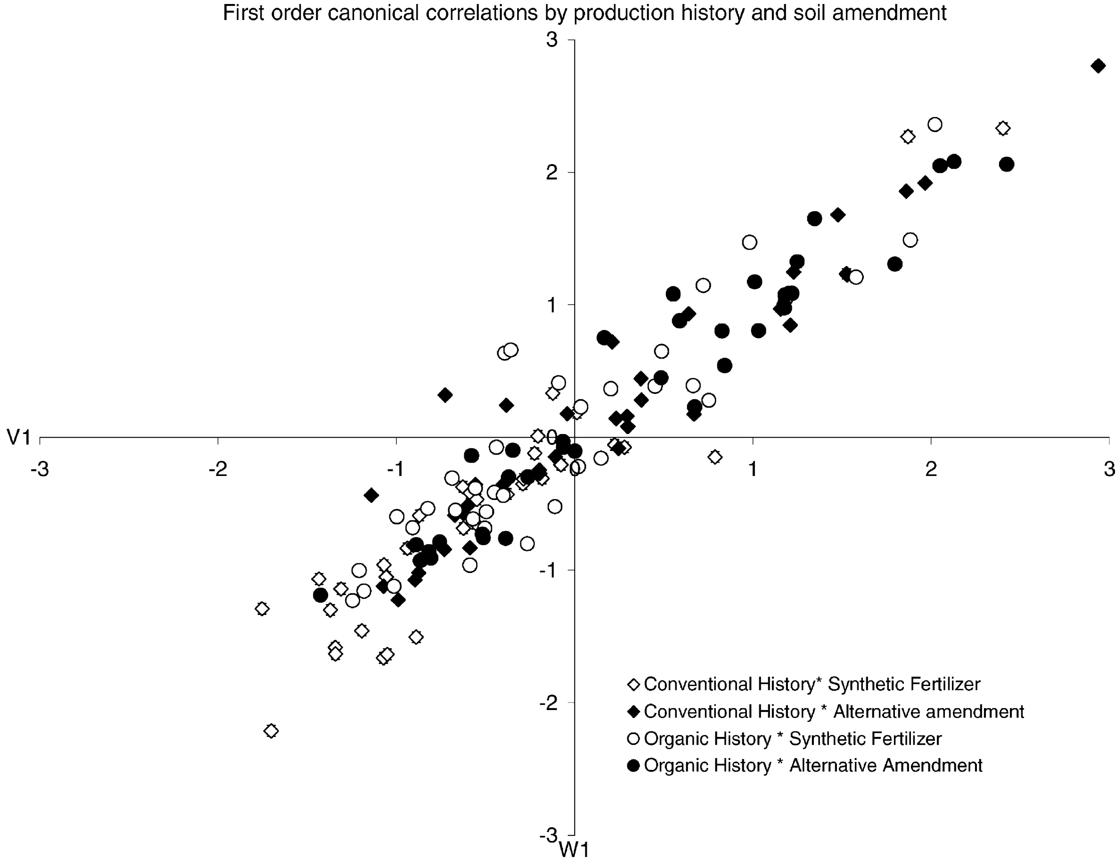

Fig. 4. First-order canonical of all chemical parameters (W1) with all microbial propagule densities (V1) over time (first-order canonical correlations coefficient of correlation = 0.98). Canonical correlations are identified by production history and soil amendment.

Table 6
Impact of alternative and synthetic fertility amendments on yield of vegetables from grower fields with a history of organic or conventional production in 1996 and 1997

Grower	Production history[a]	Crops 1996/1997[b]	Yield 1996 (Mg/ha)			Yield 1997 (Mg/ha)		
			Alternative[c]	Synthetic[d]	Lsd[e]	Alternative	Synthetic	Lsd[d]
1	Conventional	Melon/tomatoes	14.88	23.09	5.63	28.07	26.30	13.22
2	Conventional	Melon/tomatoes	16.25	15.42	3.29	6.32	3.72	4.65
3	Conventional	Melon/tomatoes	3.97	4.82	1.90	14.35	17.28	5.41
4	Organic	Sweet corn/tomatoes	6.66	10.96	2.16	40.93	28.54	6.49
5	Organic	Sweet corn/tomatoes	6.90	8.81	4.01	39.50	47.86	11.40
6	Organic	Sweet corn/tomatoes	2.53	2.78	1.17	32.82	37.84	9.54

[a] Fields under conventional production included monoculture of vegetable or field crops for several years and a history of synthetic fertilizers and pesticide use, while fields under organic production included 3 years of organic amendments and no chemical pesticide use.

[b] Melon (*Cucumis melo* var. *reticulatus* or *Citrullus lanatus*) or sweet corn (*Zea mays* var. "Silver Queen") were planted in 1996 and tomatoes (*L. esculentum* var. Celebrity or Mountain Spring was planted in 1997.

[c] Alternative amendments were either composted cotton-gin trash, composted yard waste, composted hay-manure, or composted cattle manure.

[d] Conventional amendments were synthetic fertilizers.

[e] Least significant difference from 95% confidence intervals from SAS 7.0.

(Fig. 4). Conventional production systems with organic amendments had 17 of 36 canonical correlations in both the first and fourth quadrants (Fig. 4).

3.4. Yield

Differences in yield of melon, corn or tomatoes were not detected on four of six farms in plots amended with alternative or synthetic fertilizer in 1996 and five of six farms in 1997 (Table 6). Yields from different growers could not be compared statistically because growers grew different crops and used different production practices. Nevertheless, in 1997 when all growers grew tomatoes, growers with a history of organic production had higher yields than growers with a history of conventional production, regardless of soil amendments.

4. Discussion

Specific components of the soil microbial community were changed by the addition of synthetic or alternative fertility amendments to soil in this experiment. The addition of alternative soil amendments led to increased propagule densities of *Trichoderma* species, thermophilic microorganisms, enteric bacteria, and decreased numbers of plant-pathogenic microorganisms, such as *Phytophthora* and *Pythium* species in soil. These changes were observed regardless of previous production history on a particular farm. Therefore, soil quality on conventional farms was significantly improved over a 2-year period by the addition of organic fertility amendments. Furthermore, little yield difference was observed in on-farm comparisons.

Production history influenced initial propagule densities of *Trichoderma* species. Soils with a history of organic production had higher initial populations of these fungi than soils with a conventional history. Conventional field soils amended with alternative fertility amendments had significantly higher propagule densities of *Trichoderma* at the end of the second year, but these levels remained lower than in soils with a history of organic production.

Trichoderma species are known biological control agents of many different plant-pathogenic fungi (Punja et al., 1982; Papavizas and Lewis, 1989; Abada, 1994; Benhamou and Chet, 1996). Because propagule densities of *Trichoderma* species were higher in soils amended with organic than synthetic soil amendments, lower propagule densities of soilborne plant pathogens might be expected in the organically-amended soils. Soils may have indigenous populations of *Trichoderma* species, but these fungi also can be added to soils through the application of composted organic materials, as they are able to quickly colonize compost during curing (Hoitink, 1986). We found similar results in soils amended with composted plant materials in experiment station plots (Bulluck and Ristaino, 2002).

Numbers of thermophilic microorganisms were also higher in soils amended with organic amendments than soils amended with synthetic fertilizers. Actinomycetes were a major constituent of the thermophilic microorganisms detected in our study. Greater propagule densities of actinomycetes in tomato field soils under organic production compared with conventional production systems in California have also been reported (Drinkwater et al., 1995). Actinomycetes present in alternative fertility amendments used in avocado plantations were suppressive to *Phytophthora* species (You and Sivasithamparam, 1995; You et al., 1996). Since thermophilic microorganisms were more abundant in soils with organic amendments, this may explain lower propagule densities of *Phytophthora* and *Pythium* species in soils in our study with alternative fertility amendments.

In this study, we observed higher numbers of enteric bacteria in soils with organic amendments than in soils with synthetic fertilizers. However, enteric bacteria were also present in soils with synthetic fertilizers at densities greater than 1.0×10^7 CFU/g soil. Research has shown that *E. coli* that was released in water was killed in 10 days, and those released to soil were reduced by 8 orders of magnitude in 60 days (Bogosian et al., 1996). Because *E. coli*, *Salmonella* spp., and other enteric bacteria are adapted to an environment with a constant nutrient supply and temperature, their survival rates in soils are minimal. Most cases of food-related illness in the US are caused by enteric bacterial pathogens in undercooked meat, eggs, poultry, or contaminated deli meats and are not linked to contaminated produce (Mead et al., 1999; Food Safety and Inspection Service, 1998).

Much of the research that compares different types of production systems is conducted in fields at experimental stations, because of the inherent difficulty associated with using grower fields for comparisons. Tomato agroecosystems were studied under conventional or organic production systems in grower fields in a California study (Workneh et al., 1993; Workneh and van Bruggen, 1994; Drinkwater et al., 1995). Microbial activity and nitrogen mineralization rates were higher under organic production than under conventional production practices in experimental plots (Workneh et al., 1993; Workneh and van Bruggen, 1994).

In our study, differences in chemical properties of the soil were more related to amendment type than to production history. Calcium, potassium, magnesium and manganese increased in the soils in our study that received organic amendments, but not in those soils receiving synthetic fertilizers. Clark et al. (1998) found that concentrations of carbon, phosphorus, potassium, calcium, and magnesium were greater in soils with incorporated manures and cover crops, and soil carbon, phosphorus, and potassium declined after manure applications ceased. Soils with alternative fertility amendments initially had a lower soil pH than soils with synthetic fertilizers, but over time pH increased in soils with alternative amendments to higher levels than pH in soils with synthetic fertilizers. Despite the soil pH-lowering mineralization that occurs upon addition of composted N-containing organic wastes to soil (Bevacqua and Mellano, 1994; Sikora and Yakovchenko, 1996), compost additions typically raise the pH of acid soils by complexing Al and increasing base saturation (Shiralipour et al., 1992; Van den Berghe and Hue, 1999).

Organic amendments provide advantages beyond the benefits of increased organic matter content on soil physical and chemical properties since nutrients that are seldom applied by farmers (e.g. manganese, zinc, and sulfur) are added as insurance against potential yield limitations. Furthermore, nutrients that are normally applied in commercial fertilizers (e.g. potassium) and liming sources (i.e. calcium, magnesium) are supplemented in organic amendments and permitted to accrue in the soil.

Yield increases in fields transitioning from conventional to organic production systems usually require 3–5 years to detect (Parr et al., 1992; Altieri, 1995). The sustainability of organic production systems has been questioned recently (Trewavas, 2001). However, in a recent study, yield of apples under organic, integrated, and conventional production systems were equal (Reganold et al., 2001). In addition, lower negative environmental impact, higher profitability, and higher apple fruit quality were demonstrated in the organic farming systems (Reganold et al., 2001). No differences in the yields of tomato were observed between organic and conventional production in California (Drinkwater et al., 1995). Similarly, soybean yields were as high in fields undergoing transition from conventional to low-input production as in fields under conventional production practices (Liebhardt et al., 1989). In our study, yields were higher in fields under organic production than conventional production in the second year, and these differences were not related to soil amendment type used in a given year at a given location. Field soils on organic farms were more productive than conventional fields probably due to the beneficial effects on soil properties of long-term organic amendments. Few statistically significant differences in yields were observed between soils amended with alternative amendments and soils amended with synthetic fertilizers regardless of production system. Therefore, the argument that organic farming is equivalent to low yield farming is not supported by our data (Avery, 1995).

The use of recycled organic wastes as alternative soil fertility amendments can result in increased organic matter and biological activity in soils. Our results demonstrate that alternative soil amendments can enhance soil biological, chemical, and physical attributes of soil compared with synthetic fertilizers and improve plant yield. The use of alternative soil amendments can result in a higher quality soil and greater plant disease suppressiveness (Bulluck and Ristaino, 2002).

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