EFFECTS OF SOIL MANAGEMENT HISTORY ON THE RATE OF ORGANIC MATTER DECOMPOSITION

N. GUNAPALA,[1,4] R. C. VENETTE,[2,3] H. FERRIS[3]* and K. M. SCOW[4]

[1]Department of Plant Pathology, University of Arizona, Tucson, AZ 85721, U.S.A., [2]Ecology Graduate Group, University of California, Davis, CA 95616, U.S.A., [3]Department of Nematology, University of California, Davis, CA 95616, U.S.A. and [4]Department of Land, Air and Water Resources, University of California, Davis, CA 95616, U.S.A.

Summary—In a sustainable agriculture farming systems experiment, soils managed under organic farming practices had greater microbial abundance and activity, and higher numbers of bacterial-feeding nematodes during crop growth, than those managed under conventional farming practices. We tested rates of organic matter decomposition in the two soils and monitored the abundance and activity of soil biota during the decomposition process. Differences in soil biology between soils from organic and conventional farming systems did not persist when soils were amended with organic matter and maintained under similar conditions. Microbial communities in soil from the conventional system were sufficient and active enough to respond to organic inputs. There were minimal differences in the ability of the microbial communities of the two soils to decompose organic residues. However, when soils were removed from the field at different times, cover crop decomposition rates were more consistent in the organic soils, suggesting a greater abundance and diversity of the microbial community in those soils. Microbial activity was most suppressed when field soils were dry but responded to organic matter amendment very rapidly when favorable moisture contents were restored. The pattern of microbial activity in both organic and conventional soils following organic matter incorporation consisted of a 100 h activity phase and then a gradual decline to a relatively constant stasis phase. © 1998 Elsevier Science Ltd. All rights reserved

INTRODUCTION

The maintenance of adequate soil fertility at key crop growth periods is a major management challenge in organic and low-input farming systems. Nitrogen is supplied in organic form, via cover crops and manures, rather than as inorganic fertilizers as in conventional farming systems. Large amounts of C are included in the mass of organic material required to achieve adequate amounts of N in organic and low-input systems. Consequently, in the long-term, organic matter-amended soils become carbon-rich, while those in conventional farming systems may become carbon-deficient. The positive effects of organic matter incorporation on soil biology has been documented for a diversity of agricultural systems (Martyniuk and Wagner, 1978; Schnürer *et al.*, 1985; Powlson *et al.*, 1987).

The requirements of California certified organic farmers (Anon., 1990) are a 3 y transition between conventional and "certified" organic production practices. The transition period is believed to be important, not only to reduce pesticide residues, but also to allow soil communities to adapt to mineralizing larger amounts of organic matter. The potential for reduced soil fertility and reduced profitability, during the transition of the soil biological communities, is a major concern in the decision to shift from one management system to another. The use of microbial inoculants and other products is among the strategies considered for enhancing decomposition rates in soils during transition.

The sustainable agriculture farming systems (SAFS) project in Davis, CA, is a long-term experiment comparing agronomic, economic and ecological differences among conventional, low-input and organic farming systems (Scow *et al.*, 1994; Temple *et al.*, 1994a,b). By the fourth year of the experiment, there were significantly more microbial biomass and activity in the organic and low-input than in the conventional systems. Also, the abundance of nematodes involved in decomposition in the organic system was greater than that in the conventional system, and their community structure was less diverse (Ferris *et al.*, 1996). We conjecture that these differences affect the rates of decomposition of organic material in the soil and, in organic systems, the rate of availability of N to the crop. Nitrogen may be mineralized at every link in the soil food web, so a diverse and dynamic soil biota is considered integral to a healthy, productive and

---

*Author for correspondence. E-mail: hferris@ucdavis.edu.

fertile soil (Anderson *et al.*, 1981). We have addressed two questions related to system fertility. (1) Are microbial communities in conventionally-managed soils capable of decomposing organic fertilizer sources as rapidly as communities in soil that has been amended with organic residues for 5 y and managed under organic farming practices? (2) Are there differences in the pattern of release of N from incorporated cover crops in the different soils or at different times of the year?

Conceivably, the microbial community of soils managed under conventional practices in the SAFS project is depleted by lower availability of C (Smith and Paul, 1990) and the application of pesticides (Sims, 1990) so that an extended recovery period will be necessary before decomposition and microbial activity rates are comparable with those in soil managed under organic farming systems. The activity and resilience of the soil food web can be tested by using organic material as a probe and measuring the functional response. Thus, the rate of decomposition of organic material may be used as a measure of biological activity in the soil and of the potential for the soil to provide adequate inorganic N to a crop. Since microbial communities vary throughout the year, the rate of organic matter decomposition in organic and conventional soils may vary seasonally. Changes in soil moisture and temperature can have substantial effects on soil microbial biomass and activity (Campbell and Beiderbeck, 1976). These fluctuations can be minimized by collecting field soil at prescribed times and testing decomposition rates in the laboratory under standardized conditions. In this study, we also monitored the abundance and community composition of microbial-feeding nematodes as indicators of the potential importance of food web activity on decomposition rates in soils. One of the postulated benefits of nematodes to soil fertility is that their grazing on soil microbes selects for an active community with high rates of N mineralization (Ingham *et al.*, 1985).

Our objectives were to test the hypotheses that (i) decomposition of organic material from incorporated cover crops is accomplished more rapidly by the assumed diverse and more active biological communities in soils under organic farming systems than in soils under conventional farming systems, (ii) the rate of organic matter decomposition differs in soils collected at different times of the year and (iii) that the microbial communities of conventionally-managed soils do not respond to the input of organic material to the same extent as those in organically-managed soils.

MATERIALS AND METHODS

The source of the soils used in these studies were plots managed under 4 y rotations in conventional and organic farming systems in the SAFS project in California's Sacramento Valley. The SAFS project, established in 1988, is located on an 11.3 ha site of class I Yolo silty loam soil.

Experimental designs

Experiment 1: biological activity and decomposition rates in organic and conventional soils At the end of the growing season (September, 1993), 225 kg of soil was collected from the top 15 cm of soil in the plant rows of selected tomato (*Lycopersicon esculentum* L.) plots in both the organic and conventional cropping systems of the SAFS project. The soil was collected from the two cropping systems on the same date, which was a few days prior to harvest of tomatoes in the organic system but a week following harvest and incorporation of plant residues in the conventional system. Larger aggregates were mechanically disintegrated, and the soil was sieved (4 mm), then mixed and amended with distilled water to bring the soil moisture to 15%. Soil was conditioned in $29 \times 33 \times 18$ cm plastic dishpans for 7 d to allow completion of an expected period of accelerated mineralization of organic matter following the disturbance associated with soil preparation. The containers were covered with paper to reduce moisture loss while permitting air exchange. After conditioning, two parallel studies were initiated. In one, the soil was uniformly amended with vetch (*Vicia villosa* Roth.) and used for periodic assessment of microbial activity and nematode numbers. In the other study, the vetch was placed in mesh bags that were buried in the soil and removed periodically to determine the rate of vetch decomposition.

For the uniformly-amended study, above-ground biomass of vetch from an organically-farmed field plot was air-dried for 2 d and then chopped into pieces from 20 to 40 mm long. One half of each soil to be used for microbial and nematode assay was amended with vetch at the rate of $2 \, \text{g kg}^{-1}$ soil (equivalent to the rate of organic amendments in the organic cropping system in the field, $3.6 \, \text{t ha}^{-1}$) and mixed well. Fifteen kg of soil (with or without vetch) was placed in each dishpan so that the soil surface was 2.5 cm below the top of the container. The containers were arranged in a completely randomized design, with four replicates per treatment, in a constant temperature room at 24°C. An additional eight containers, with all four farming system-amendment combinations in two replicates, were also incubated as "refill" soil to fill holes in the experimental units after soil sampling. All containers were covered with perforated aluminum foil, and soil moisture was maintained between 15 and 20% by adjustments based on weight.

For the mesh bag study, 12.5 kg of soil from each cropping system was amended with vetch at a rate of $2 \, \text{g kg}^{-1}$. Of this, 15% (3.75 g) was initially

mixed with the soil while 85% (21.25 g) was retained for placing in mesh bags. Nylon mesh bags (11 × 7 cm; mesh size 0.1 × 0.1 cm) were washed with detergent to reduce microbial contaminants, dried at room temperature overnight and then at 60°C for 0.5 h, and weighed. Each bag was filled with 2.66 g of vetch, stapled closed, returned to 60°C and allowed to dry overnight. The dried mesh bags were weighed and a tag was tied to each bag using a length of monofilament fishing line prior to burial. Eight bags were buried in three layers, 3 cm apart vertically, in each container. There were three replicate containers of the conventional 4 y soil and two of the organic. Containers were covered with perforated aluminum foil and were incubated in a constant temperature room at 24°C. Soil moisture was maintained at 15 to 20% by frequent adjustments following weighing.

Starting from d 6 of the incubation in experiment 1, one preselected bag from each container was removed weekly for 6 week, then every 15 to 20 d until 82 d of incubation had elapsed. The bags were cleaned of surface soil and washed gently in distilled water, replacing the water four times. Bags were then soaked in distilled water for 5 h, replacing the water three times. Finally, bags were oven dried at 60°C and weighed. The reduction in weight was used as a measure of decomposition.

Experiment 2: seasonal effects on decomposition rates in organic and conventional soils Soil was removed from organic and conventional tomato plots at the SAFS site in July 1994 (at the observed time of decreasing microbial biomass the previous year (Ferris *et al.*, 1996)), September (following tomato harvest), January 1995 (mid-winter) and April (following incorporation of the vetch cover crop in organic plots). Approximately 35 kg soil was collected from the top 15 cm of soil in one plant row of each of the four organic and conventional 4 y tomato plots in the field experiment. The soil was passed through a mechanical aggregate disintegrator and poured into plastic dishpans. Soil moisture was determined gravimetrically. The field samples in January 1995 were collected after several weeks of rain, and soil was at or near field capacity (about 20%). These soils were stored in uncovered dishpans at room temperature in a draft created by an electric fan to facilitate drying. After 2 week, when soil moisture was approximately 12%, aggregates were disintegrated as for other sample dates.

Alfalfa (*Medicago sativa* L.) hay was chopped and passed through a 1.2 cm mesh. The chopped alfalfa was sifted (0.83 mm); the larger pieces (3 to 12 mm), retained on the screen, were used for the decomposition study. Since 15 g were to be added to each container in five mesh bags, 11 g was added directly to the 13 kg soil in each container while mixing it in a cement mixer. Soil moisture was adjusted to 12% in the cement mixer using a spray bottle to distribute the water.

Nylon mesh bags prepared as in Experiment 1 were filled with 3 g of alfalfa. A 22 cm length of 23 mm i.d. PVC tubing was placed upright in the center of a plastic dishpan. The tube was then surrounded by 6.5 kg of freshly mixed soil. Five mesh bags were placed on top of the soil and the bags were buried with another 6.5 kg of soil. There were five replicate dishpans for each soil. Each dishpan was weighed and stored on the laboratory bench. The dishpans were covered with butcher paper to reduce the rate of water loss. To maintain 12% soil moisture, dishpans were weighed every 3 d to determine the amount of water loss. Water lost through evaporation was replaced by pouring the equivalent amount through the PVC pipe so that it dispersed through the soil from the bottom. One bag was removed from each container every week and the rate of decomposition measured as in the experiment 1.

Microbial and nematode community measurements

For microbial analysis in experiment 1, soil was removed to 13 cm depth using 20 × 1.5 cm sampling tubes on day 0, then daily for 5 d; every 2 to 3 d thereafter, up to 28 d; and every 7 to 10 d thereafter, up to 45 d. Except for samples taken every 7 d, 4 to 5 cores were taken for microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), arginine ammonification (AA), substrate-induced respiration (SIR) and potentially-mineralizable nitrogen (PMN) determinations. For samples taken every 7 d starting from d 0 to d 35, and also on d 45, an additional 2 to 3 cores were taken to determine numbers of bacterial and fungal-feeding nematodes. Immediately after removal of the soil cores from the container, the sampling holes were filled with soil cores from the "refill" containers.

Microbial activity measurements were carried immediately after sampling. SIR was determined by amending subsamples with either nutrient broth plus glucose or nutrient broth alone and using an infrared gas analyzer to determine the difference in headspace CO_2 between the subsamples after 2 h of incubation (Smith *et al.*, 1985). Colorimetric comparison of NH_4–N of soil amended or not amended with arginine was used for AA analysis (Fawcett and Scott, 1960; Alef and Kleiner, 1987). The remaining soil was stored at 4°C; MBC, MBN, PMN and nematode analyses were conducted within 5 d of sampling. MBC was determined by fumigation–extraction followed by combustion in the presence of a platinum catalyst and infrared gas analysis of evolved CO_2 (Vance *et al.*, 1987; Tate *et al.*, 1988). MBN was determined by the ninhydrin-reactive method (Amato and Ladd, 1988; Carter, 1991) and PMN by the anaerobic incubation method (Keeney, 1982). The sugar-centrifugation

method was used for nematode analyses (Barker, 1985).

In experiment 2, two samples for nematode analysis (500 cm^3 each) were collected from each soil directly from the cement mixer. Samples were stored at 4°C prior to processing. An additional 1 l of each soil was collected directly from the cement mixer for soil respiration analysis. Respiration analyses were conducted immediately by mixing 10 mg alfalfa into 10 g soil samples which were placed in 120 ml narrow-mouth glass vials. Vials were sealed and incubated at 24°C. Soil moisture was adjusted by weight when necessary. Gas samples (1 ml) of the headspace were taken for CO_2 determination at approximately 2.5 h intervals for the first 10 h, then at 8 h intervals for 24 h, and less frequently over 3–5 week. After sample removal, seals were removed for 2 min to prevent O_2 limitation. CO_2 was measured by injecting the headspace gas into an infrared gas analyzer. The rate of respiration was calculated as CO_2 evolved g soil^{-1} h^{-1}.

RESULTS

Microbial activity, C and N mineralization and nematode communities

In experiment 1 (biological activity and decomposition rates), microbial activity and abundance measurements fluctuated somewhat over the incu-bation period (Fig. 1). Measures of microbial abundance (MBC and MBN) followed similar trends, so only MBC data are presented (Fig. 1(A and B)). MBC was not consistently different over the 45 d period in the two soils when amended with vetch (Fig. 1(A)). Microbial abundance was frequently greater in the conventional soil than in the organic soil when the two were not amended with vetch (Fig. 1(B)). Microbial activity, as indicated by SIR, was identical in both soils when amended with vetch (Fig. 1(C)). However, in the unamended treatments, microbial activity was greater on most dates in the conventional than in the organic soil (Fig. 1(D)). For both the conventional and organic soils, microbial abundance (Fig. 1(A and B)) and microbial activity (Fig. 1(C and D)) were significantly enhanced by the addition of vetch.

Measures of microbial activity with direct relationship to N-mineralization and availability (AA and PMN) followed similar trends and are represented by PMN (Fig. 2(A and B)). PMN values for the two soils in the absence of vetch amendment were virtually identical (Fig. 2(B)). Five days after the soils were amended with vetch, PMN concentrations became greater in the organic than in the conventional soil and maintained that difference for the duration of the 45 d incubation (Fig. 2(A)). In both soils, PMN values were increased at least 2-fold by addition of vetch (Fig. 2(A and B)).
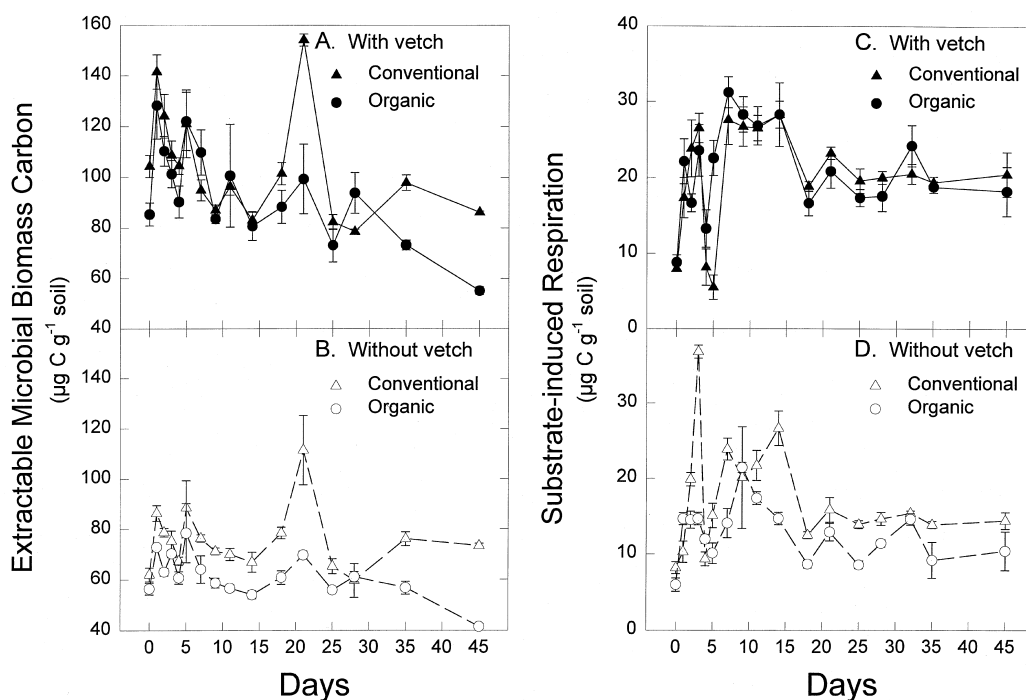

Fig. 1. Abundance and activity of the microbial biomass in conventional and organic soils incubated at 24°C with or without vetch organic amendment. Day 0 measurement was 5 h after vetch incorporation. Extractable microbial biomass C is used as an indicator of microbial abundance (panels A and B). Substrate-induced respiration is used as an indicator of microbial activity (panels C and D). Data points are means and standard errors of four replications.
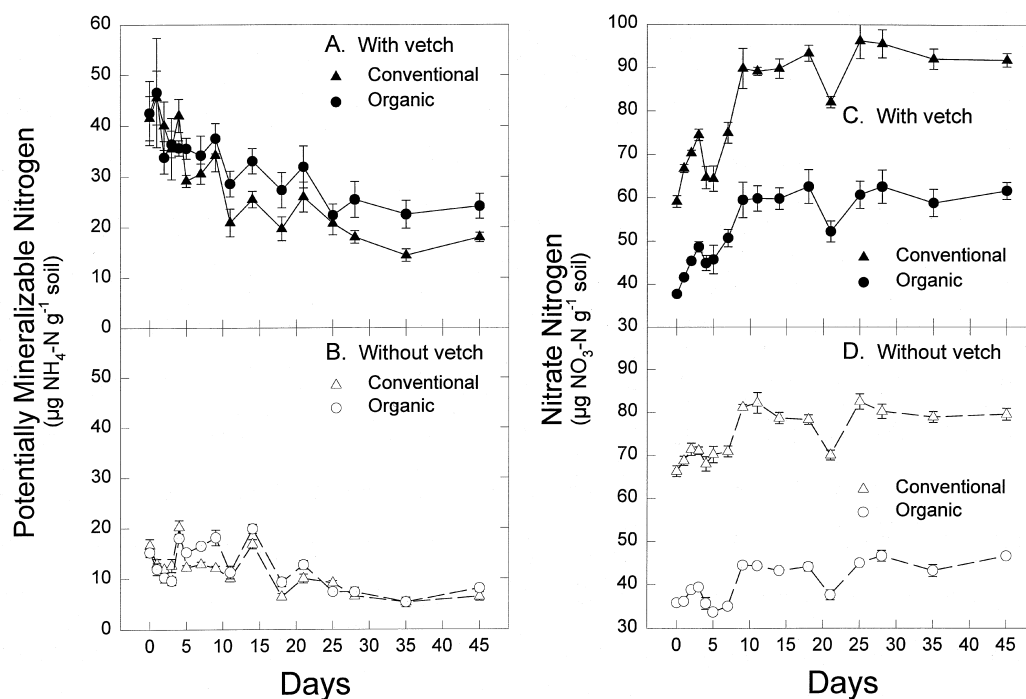
Fig. 2. Nitrogen availability and dynamics in conventional and organic soils incubated at 24°C. Day 0 measurement was 5 h after vetch incorporation. Potentially mineralizable N, determined by anaerobic incubation, is an indicator of N in the organic fraction and in the microbial biomass. (A) Potentially mineralizable N in the presence of vetch amendment; (B) Potentially mineralizable N in the absence of vetch amendment. Inorganic nitrate in the soil solution is an indicator of available inorganic N. (C) Inorganic nitrate in the presence of vetch amendment; (D) Inorganic nitrate in the presence of vetch amendment. Data points are means and standard errors of four replications.

At each sampling date in experiment 2 there was a phase of intense microbial activity, as indicated by soil respiration rates, that persisted for less than 100 h following organic amendment (Fig. 3). That was followed by a rapid decline in activity of the microbial community during transition to a stasis phase. In July 1994, the soil respiration rate was slightly greater in the organic system than in the conventional system for the first 24 h after amendment with alfalfa (Fig. 3(A)). Thereafter, both systems settled to a low, steady respiration rate after about 3 d and remained in stasis for the duration of the 35 d of observation. At the September 1994 sampling, respiration in the organic soil during the activity phase was double that in the conventional soil (Fig. 3(B)). At the February 1995 mid-winter sampling, soil respiration was lower than on any other sampling date. Microbial activity during the activity phase was greater in the conventional soil and remained higher in the conventional soil during the stasis phase (Fig. 3(C)). At the April 1995 sampling, the soil respiration rate was slightly higher in the organic soil during the activity phase, but the rates in both soils converged during the stasis phase (Fig. 3(D)).

Soil NH_4–N contents in experiment 1 were low, similar in both soils, and changed little throughout

the incubation when soils were not incubated with vetch. Where soils were amended with vetch, NH_4–N contents increased to similar amounts in both soils for 5 d and then declined to values similar to those in the unamended soil (data not shown). Soil NO_3–N contents, however, varied greatly between soils and with the addition of vetch (Fig. 2(C and D)). Generally, soil NO_3 increased for the first 20 d after incubation and then stabilized. Soil NO_3–N in the conventional soil was at least 2-fold greater than in the organic soil when there was no vetch amendment. Vetch amendment increased soil NO_3–N contents in both soils. That increase was immediate in the organic soil but was manifested only after 5 d in the conventional soil. Even after vetch amendment, soil NO_3–N contents in the conventional soil remained twice as high as those in the organic soil (Fig. 2(C)).

At the start of experiment 1, numbers of bacterial-feeding nematodes did not differ significantly between the two soils (Fig. 4(A)). During the latter part of the experiment, however, in the conventional soil amended with vetch they were consistently more abundant than in the organic soil amended with vetch. Numbers of fungal-feeding nematodes (Fig. 4(B)) were initially not different between the
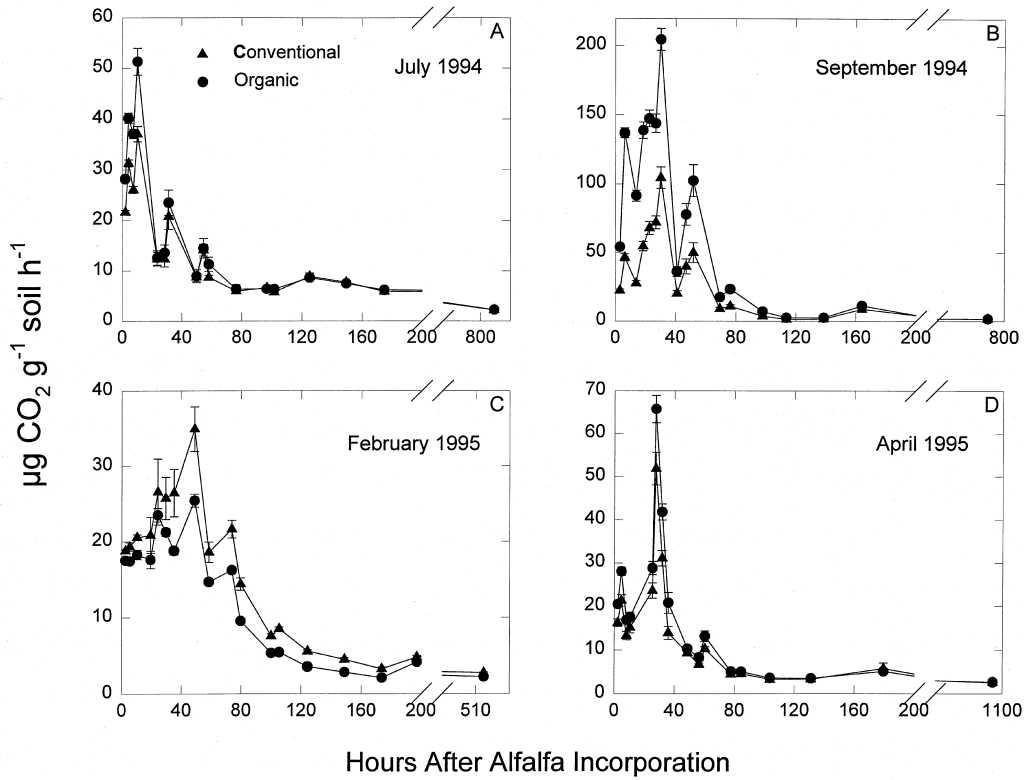
Fig. 3. Soil respiration rate in conventional and organic soils removed from a field site at different times of the year and incubated at 24°C with organic amendment. (A) Soil removed from the field near the mid-point of a summer tomato crop; (B) Soil removed from the field after completion of a summer tomato crop; (C) Soil removed from the field in mid-winter; (D) Soil removed from the field prior to planting of a summer tomato crop. Data points are means and standard errors of four replications.

two soils, but increased to higher numbers in the organic soils than in the conventional soils. Opportunistic species of bacterial-feeding nema-

todes increased in response to the incorporated vetch in both soils (Fig. 5). Other species responded more slowly.
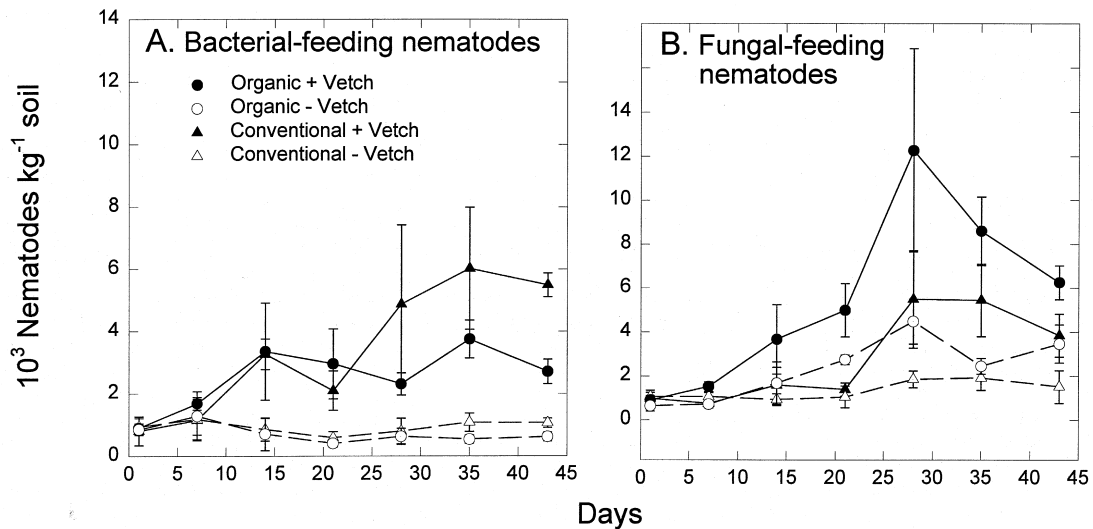

Fig. 4. Total abundance of 11 species of bacterial-feeding (panel A) and two species of fungal-feeding (panel B) nematodes in conventional and organic soils incubated at 24°C with or without vetch organic amendment. Data points are means and standard errors of four replications.
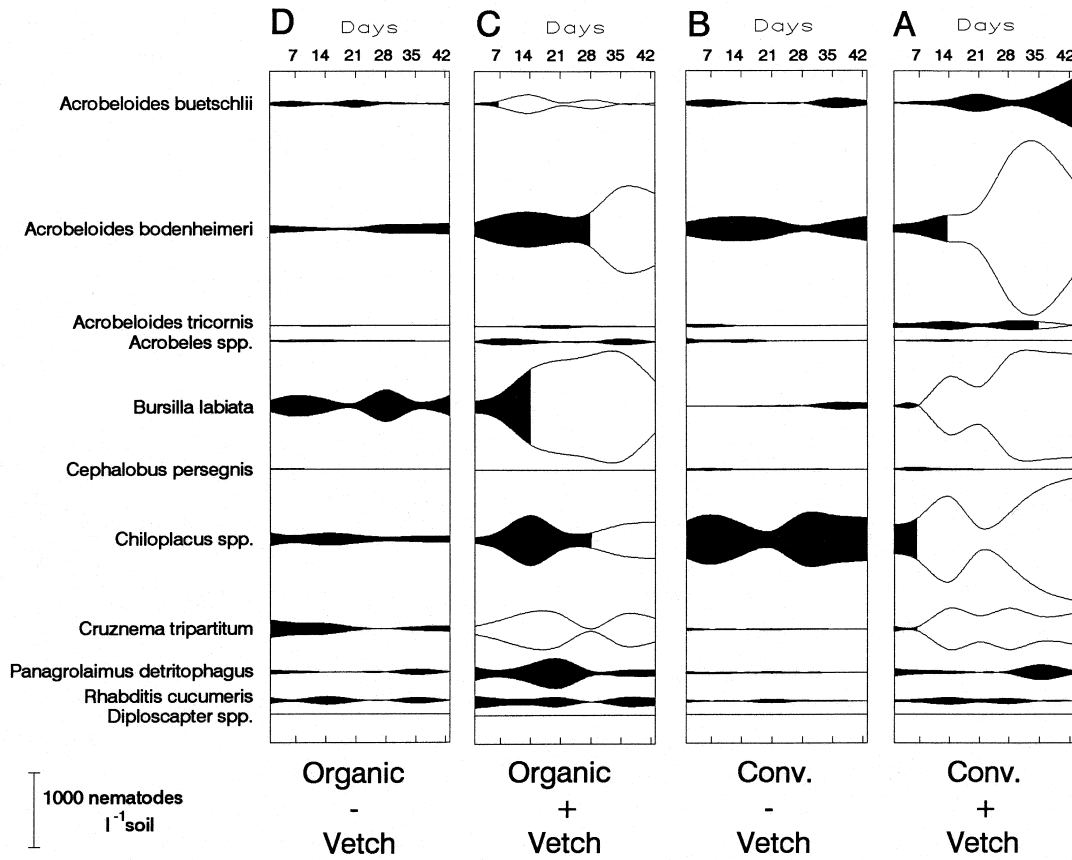
Fig. 5. Temporal abundance of 11 species of bacterial-feeding nematodes in conventional (panels A and B) and organic (panels C and D) soils incubated at 24°C with (panels A and C) or without (panels B and D) vetch organic amendment. Data are means of four replications. Change in shading within a population abundance graph indicates the time after the start of the incubation at which that population increased significantly from the starting condition.

Organic matter decomposition rates

In experiment 1, there was no difference between the organic and conventional soils in weight loss of vetch during the first 30 d (Fig. 6). Between 28 and
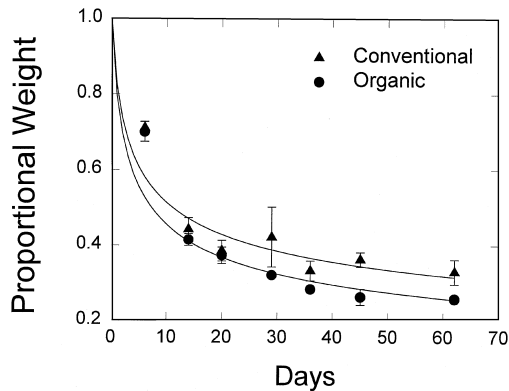

Fig. 6. Cumulative (proportional) weight loss of vetch contained in mesh bags buried in conventional and organic soils incubated at 24°C with vetch organic amendment. Data points are means and standard errors of four replications.

40 d, the rate of vetch decomposition was greater in the organic than in the conventional soil. After 40 d the rate stabilized in both soils, with the result that cumulative decomposition after 40 d was marginally greater in the organic than in the conventional soil (Fig. 6).

In experiment 2 (seasonal effects on decomposition rates), rates of alfalfa decomposition in the soils from the two farming systems varied at different sampling dates (Fig. 7). The rate of decomposition (*b*) was derived from the model $y = e^{b(\ln(d + 1))}$, where *y* is the proportional in weight of the alfalfa in the mesh bags at each sampling day (*d*), *e* is the base of the natural logarithm (ln), and *b* is the slope of the log-linearized relationship between *y* and *d*. The model assumes no decomposition on *d* = 0 when bags are buried in the dishpans. In July 1994, decomposition rates of alfalfa did not differ between soils (Fig. 7(A), Table 1). However, after tomato harvest in September 1994, the alfalfa decomposition rate was more rapid in soil from the organic farming system than in soil from the conventional system (Fig. 7(B), Table 1). In February 1995, decomposition was
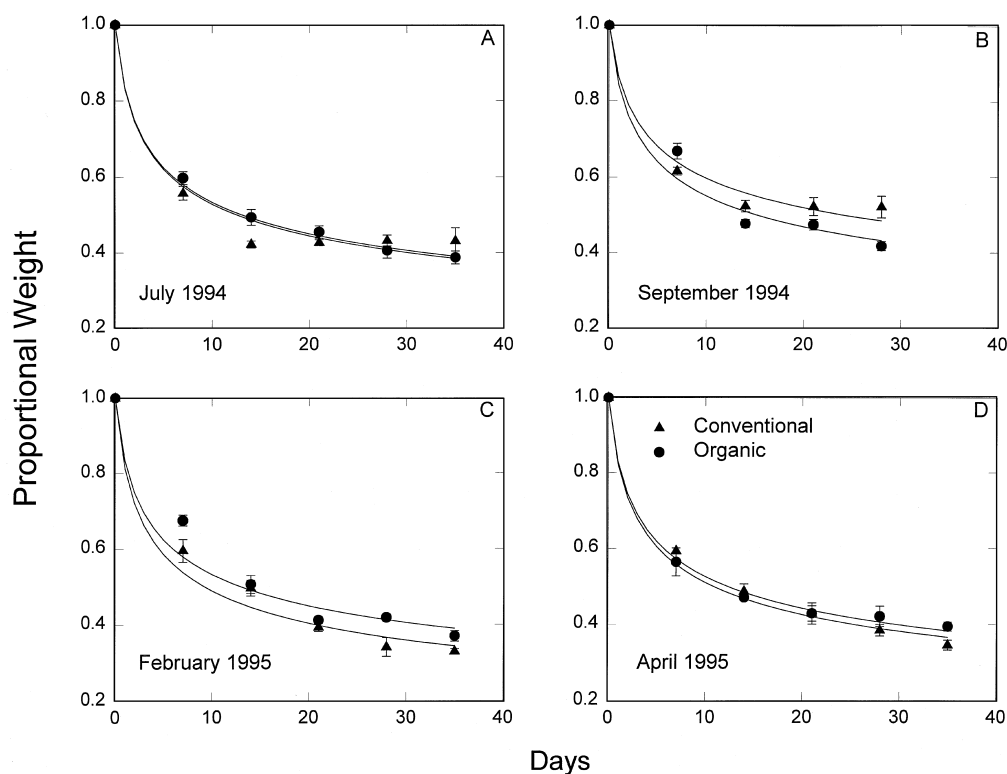
Fig. 7. Cumulative weight loss of alfalfa contained in mesh bags buried in conventional and organic soils removed from a field site at different times of the year and incubated at 24°C with organic amendment. (A) Soil removed from the field near the mid-point of a summer tomato crop; (B) soil removed from the field after completion of a summer tomato crop; (C) soil removed from the field in mid-winter; (D) soil removed from the field prior to planting of a summer tomato crop. Data points are means and standard errors of four replications.

more rapid in the conventional soil (Fig. 7(C), Table 1) and, in April 1995, there was no difference between the soils (Fig. 7(D), Table 1).

DISCUSSION

Distinct differences in soil biology between soils from organic and conventional farming systems did not persist when soils were amended with organic matter and maintained under similar conditions. There were minimal differences in the ability of the microbial communities of the two soils to decompose organic residues.

In the experiment 1 (biological activity and decomposition rates) microcosm study, MBC, MBN, microbial activity and nematode numbers were not consistently different between the two soils after amendment with vetch, suggesting that the microbial community and soil food web are not destroyed in the conventional soil and that they respond rapidly to carbon amendment. Interpretation of the study, however, was problematic since the soil was collected from the organic system a few days prior to tomato harvest but a week following harvest and incorporation of plant residues in the conventional system. The recent

Table 1. Rates of decomposition of vetch (experiment 1) or alfalfa (experiment 2) in organic and conventional soils collected at different times during the year. Rates (b) are derived from the relationship $y = e^{b(\ln(d + 1))}$, where y is remaining weight of organic substrate and d is days

Collection date	Substrate	Decomposition rates (b)		
		conventional (b_1)	organic (b_2)	$P(b_1 = b_2)$*
September 1993	vetch	−0.2787	−0.3288	0.004
July 1994	alfalfa	−0.2665	−0.2624	0.685
September 1994	alfalfa	−0.2153	−0.2490	0.003
February 1995	alfalfa	−0.2986	−0.2633	0.002
April 1995	alfalfa	−0.2812	−0.2685	0.182
C.V. (experiment 2)†		11.7%	2.8%	

*Probability that decomposition rates in the two soils are equal.
†Coefficient of Variation among decomposition rates for experiment 2.

input of organic matter in the conventional system may have reduced differences between the microbial and nematode communities in the two systems. For example, the higher microbial biomass in the unamended conventional than in the unamended organic soil (Fig. 1(B)) was unexpected and contrary to previous observations (Ferris et al., 1996). We further recognize the potential alteration of soil properties by the intensive processing of soils carried out before the experiment. That processing was necessary because the soils had been allowed to dry before tomato harvest. Field characteristics of the soils were likely to be profoundly altered by fracturing of aggregates and sieving. Such treatment can lead to depletion of oxidizable organic matter, mortality of native microorganisms and introduction of foreign organisms.

All microbial activity and abundance measurements fluctuated over the incubation period (Figs 1 and 2), perhaps attributable to changes in soil moisture during the early part of the experiment. Although the soil moisture was maintained between 15 to 20%, and soil containers were covered, soils dried rapidly due to the presence of an exhaust fan in the constant temperature incubation room. Thus, the soils required frequent rewetting. Average amounts of MBC were higher in the conventional soil than in the organic soil, both in the presence or absence of vetch amendment (Fig. 1(A and B)). This observation may reflect the additional organic material incorporated into the conventional plots prior to removal of the soil for this experiment. Only PMN contents in soil from the organic system were consistently higher than the conventional soil after amendment with vetch (Fig. 2(A)). This result might suggest a larger mineralizable N pool in the organic soil built up from continued organic amendments over the past 5 y. However, PMN concentrations in the two soils not amended with vetch were statistically indistinguishable. The higher PMN contents in the vetch-amended organic soil might also indicate a greater abundance of anaerobic organisms in that soil since the PMN measurement involves anaerobic incubation. The conventional soil had significantly higher NO_3–N contents than the organic soil throughout this experiment, whereas the NH_4–N content did not differ significantly between the two soils. The additional NO_3–N in the conventional soil may have resulted from the decomposition and mineralization of the recently-incorporated tomato residues or more probably from fertilizer N in excess of crop uptake. The net nitrification rate, represented by the increase in NO_3–N from the d 0 reading, was approximately 50% in both soils when amended with vetch and 30% in both soils when not amended with vetch.

In experiment 2 (seasonal effects on decomposition rates), we attempted to resolve some of the problems in the first microcosm study, and to test some of the unexpected and counterintuitive results, by using soil sampled at different key periods during the year. There was no difference in the rate of alfalfa decomposition between soils when they were removed from the two-farming systems in mid-summer, at the time of microbial exhaustion in the organic soil, and primed with an organic amendment (Fig. 7(A)). Although microbial activity immediately after amendment was greater in the organic soil, the community in the conventional soil exhibited equivalent activity within 24 h (Fig. 3(A)). In September 1994, immediately after harvest, the pattern was distinctly different. The conventional soil was dry and compacted at sampling, while the organic soil was moist and friable. The microbial community in the organic soil responded vigorously to the organic amendment, as exhibited by much higher activity during the activity phase (Fig. 3(B)) and a greater rate of decomposition of the buried alfalfa (Fig. 7(B)). In mid-winter, when moisture and temperature conditions in the field were normalized across treatments by winter rain, the microbial community in the conventional soil was more responsive (Fig. 3(C)), resulting in a correspondingly higher decomposition rate (Fig. 7(C)). However, rates of soil respiration and decomposition were lower in the mid-winter soil than in soil sampled at any other time during the year. By the spring sampling, there were no differences in microbial activity and decomposition rates between the soils (Fig. 7(D), Fig. 3(D)). Interestingly, and perhaps a reflection of the abundance and diversity of the microbial community in the organic soils, decomposition rates were more consistent over time, as indicated by a lower coefficient of variation among the rates, in the organic than in the conventional soils (Table 1).

In experiment 1, individual species of bacterial-feeding nematodes responded to vetch amendment and consequent increase in microbial biomass, as seen in our field studies (Ferris et al., 1996). During the incubation period, the communications of bacterial-feeding nematodes increased 6-fold in the conventional soil but only 4-fold in the organic (Fig. 6(A) and Fig. 5). Communications of fungal-feeding nematodes increased about 12-fold in the organic soil but only about 6-fold in the conventional (Fig. 4(B)). This may indicate that decomposition processes were dominated by fungal pathways in the organic soil and by bacterial pathways in the conventional. That suggestion is inconsistent with our previous observations on the abundance of bacterial- and fungal-feeding nematodes during the tomato-growing season. However, it may have resulted from the incorporation of the N-rich crop residue into the conventional soil prior to the experiment. In experiment 2, where there was no confounding effect of differences in cultural practices at

the time of soil sampling, fungal-feeding nematodes were generally higher in the conventional than in the organic soil before and after the incubation, which is consistent with our field observations (Ferris *et al.*, 1996).

In the absence of added organic material, the abundance of individuals of any species did not change in either soil. Not all species of bacterial-feeding nematodes responded equally to the incorporation of organic material (Fig. 5). Some species in the family Rhabditidae (e.g. *Bursilla labiata* and *Cruznema tripartitum*) responded to the food resource while others did not (e.g. *Rhabditis cucumeris*). Similarly, some species in the family Cephalobidae (e.g. *Acrobeloides buetschlii*, *A. bodenheimeri*, *Chiloplacus* sp.) increased, while others did not (e.g. *A. tricornis*, *Cephalobus persegnis*). Generally, nematodes in the family Rhabditidae are considered to be enrichment opportunists and are expected to respond rapidly to increases in a food source, while those in the Cephalobidae are expected to respond more slowly (Bongers, 1990). As we have reported in other studies, the dynamics of individual species are determined by food availability, lifetable properties, and environmental conditions. The temperature conditions of these experiments may not have been conducive to a population increase of the some species (e.g. *R. cucumeris*) (Venette and Ferris, 1997).

Some of the cephalobid nematodes that increased in numbers during the course of the incubation (*Chiloplacus* sp. and *A. bodenheimeri*) in experiment 1 were most abundant in the conventional soil, suggesting a more persistent community of bacterial-feeding nematodes than represented in the organic soil. In experiment 2, where soils were removed from the field at different times of the year, total bacterial-feeding nematode counts were similar in both soils before and after incubation, although the abundance of individual species differed between farming systems and times of the year (data not shown). For example, in September 1994, *Chiloplacus* sp. was more abundant in the conventional soil as in experiment 1 (Fig. 5). *Acrobeloides buetschlii* was essentially absent from the conventional soil but, along with *Panagrolaimus detritophagus*, it was more abundant in the organic soil.

In these investigations, only the nematodes that graze on soil bacteria and fungi were monitored. However, many studies have shown the importance of other soil predators on N-cycling in soil. Protozoa reduce bacterial biomass and increase available N in soil (Clarholm, 1985; Kuikman *et al.*, 1991). Nematodes and protozoa are by far the most numerous predators of bacteria in soil, but other organisms may also play a role in the N-cycling process. Microarthropods and enchytraeids also regulate bacterial prey populations and release

the N sequestered in these organisms (Hansson *et al.*, 1990). The increase in inorganic N in the vetch incubation study (Fig. 2(C and D)) may be, at least in part, a result of the grazing pressure. However, the studies were not designed with grazer-free controls.

Microbial communities in conventional soils were obviously sufficient and active enough to respond to organic inputs. Consequently, the rates of decomposition were not limited in conventional soils, suggesting that microbial inoculation may not be necessary during the transition from conventional to organic farming systems. Similar conclusions emerge from studies in Austria in conventionally farmed and ecofarmed fields (Foissner, 1992). Even though decomposition rates in our studies were similar in conventional and organic soils, it is possible that there are differences in N-cycling pathways. For example, the initially higher microbial biomass in organic soils may provide a larger, labile pool of N to crops than is available in the conventional soil. The greatest seasonal suppression in microbial activity occurred in soils in which the soil moisture was very low (e.g. September 1994 in the conventional system). The soil in the organic system was not moisture stressed at that time. Even in the conventional system, however, the activity of the microbial community in the soil responded to amendment with alfalfa, although microbial activity and the decomposition rate during the important 100 h activity phase were significantly lower than those in the organic soil.

REFERENCES

Alef K. and Kleiner D. (1987) Applicability of arginine ammonification as indicator of microbial activity in different soils. *Biology and Fertility of Soils* **5**, 148–151.

Amato M. and Ladd J. N. (1988) Assay for microbial biomass based on ninhydrin-reactive nitrogen in extracts of fumigated soils. *Soil Biology & Biochemistry* **20**, 107–114.

Anderson R. V., Coleman D. C. and Cole C. V. (1981) Effects of saprotrophic grazing on net mineralization. In *Terrestrial Nitrogen Cycles*, ed. F. E. Clark and T. Rosswall, pp. 201–216. Ecological Bulletin, Stockholm.

Anon. (1990) *California Organic Foods Act of 1990*. California Department of Food and Agriculture, Sacramento.

Barker K. R. (1985) Nematode extraction and bioassays. In *An Advanced Treatise on Meloidogyne. Volume II, Methodology*, ed. K. R. Barker, C. C. Carter and J. N. Sasser, pp. 19–35. North Carolina State University Press, Raleigh.

Bongers T. (1990) The maturity index: an ecological measure of environmental disturbance based on nematode species composition. *Oecologia* **83**, 14–19.

Campbell C. A. and Beiderbeck V. O. (1976) Soil bacterial changes as affected by growing season weather conditions: a field and laboratory study. *Canadian Journal of Soil Science* **56**, 293–310.

Carter M. R. (1991) Ninhydrin-reactive N released by the fumigation–extraction method as a measure of microbial biomass under field conditions. *Soil Biology & Biochemistry* **23**, 139–143.

Clarholm M. (1985) Interactions of bacteria, protozoa and plants leading to mineralization of soil nitrogen. *Soil Biology & Biochemistry* **17**, 181–187.

Fawcett J. K. and Scott J. E. (1960) A rapid and precise method for the determination of urea. *Journal of Clinical Pathology* **13**, 156–159.

Ferris H., Lau S. and Venette R. (1996) Dynamics of nematode communities in tomatoes grown in conventional and organic farming systems and their impact on soil fertility. *Applied Soil Ecology* **3**, 161–175.

Foissner W. (1992) Comparative studies on the soil life in ecofarmed and conventionally farmed fields and grasslands of Austria. *Agriculture, Ecosystems and Environment* **40**, 207–218.

Hansson A. C., Andrén O., Boström S., Boström U., Clarholm M., Lagerlöf J., Lindberg T., Paustian K., Petterson R., Sohlenius B. (1990) Structure of the agroecosystem. In *Ecology of Arable Land- Organisms, Carbon and Nitrogen Cycling*, ed. O. Andrén, pp. 41–83. Ecological Bulletin, Copenhagen.

Ingham R. E., Trofymow J. A., Ingham E. R. and Coleman D. C. (1985) Interactions of bacteria, fungi and their nematode grazers: effects on nutrient cycling and plant growth. *Ecological Monographs* **55**, 119–140.

Keeney D. R. (1982) Nitrogen availability indices. In *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*, ed. A. L. Page, R. H. Miller and D. R. Keeney, pp. 711–733. Soil Science Society of America, Madison.

Kuikman P. J., Jansen A. G. and Van Veen J. A. (1991) ^{15}N-Nitrogen mineralization from bacteria by protozoan grazing at different soil moisture regimes. *Soil Biology & Biochemistry* **23**, 193–200.

Martyniuk S. and Wagner G. H. (1978) Quantitative and qualitative examination of soil microflora associated with different management systems. *Soil Science* **125**, 343–350.

Powlson D. S., Brookes P. C. and Christensen B. T. (1987) Measurement of soil microbial biomass provides an early indication of changes in total soil organic matter due to straw incorporation. *Soil Biology & Biochemistry* **19**, 159–164.

Schnürer J., Clarholm M. and Rosswall T. (1985) Microbial biomass and activity in an agricultural soil with different organic matter contents. *Soil Biology & Biochemistry* **17**, 611–618.

Scow K. M., Somasco O., Gunapala N., Lau S., Venette R., Ferris H., Miller R. and Shennan C. (1994) Transition from conventional to low-input agriculture changes soil fertility and biology. *California Agriculture* **48**, 20–26.

Sims G. K. (1990) Biological degradation of soil. In *Soil Degradation*, ed. R. Lal and B. A. Stewart, pp. 290–330. Springer-Verlag, New York.

Smith J. L. and Paul E. A. (1990) The significance of soil microbial biomass estimates. In *Soil Biochemistry, Vol. 6*, ed. J. M. Bollag and G. Stotzky, pp. 357–396. Marcel Dekker, New York.

Smith J. L., McNeal B. L. and Cheng H. H. (1985) Estimation of soil microbial biomass: an analysis of the respiratory response of soils. *Soil Biology & Biochemistry* **17**, 11–16.

Tate K. R., Ross D. J. and Feltham C. W. (1988) A direct extraction method to estimate soil microbial C: effects of experimental variables and some different calibration procedures. *Soil Biology & Biochemistry* **20**, 329–335.

Temple S. R., Friedman D. B., Somasco O., Ferris H., Scow K. and Klonsky K. (1994a) An interdisciplinary, experiment station-based participatory comparison of alternative crop management systems for California's Sacramento Valley. *American Journal of Alternative Agriculture* **9**, 64–71.

Temple S. R., Friedman D. B., Somasco O., Ferris H., Scow K. and Klonsky K. (1994b) Conventional, low-input and organic farming systems compared. *California Agriculture* **48**, 14–19.

Vance E. D., Brookes P. C. and Jenkinson D. S. (1987) An extraction method for measuring soil microbial biomass C. *Soil Biology & Biochemistry* **19**, 703–707.

Venette R. and Ferris H. (1997) Thermal constraints to population growth of bacterial-feeding nematodes. *Soil Biology & Biochemistry* **29**, 63–74.