Dynamics of Soil Microbial Biomass and Activity in Conventional and Organic Farming Systems

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Title: Microbial dynamics in different farming systems

DYNAMICS OF SOIL MICROBIAL BIOMASS AND ACTIVITY IN CONVENTIONAL AND ORGANIC FARMING SYSTEMS

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Summary-- Dynamics of microbial populations during two growing seasons were compared in soils under tomatoes managed by conventional (2- and 4 yr rotations), low input, or organic practices. Fumigation extractable carbon (FEC) and nitrogen (FEN), potentially mineralizable nitrogen, arginine ammonification and substrate induced respiration were significantly higher in organic and low input than conventional systems on most sample dates. Microbial parameters were significantly negatively correlated with levels of soil mineral nitrogen in the conventional 4 yr system, whereas they were positively correlated with mineral nitrogen in the organic system. The carbon to nitrogen ratios of material released after fumigation extraction were significantly higher in the conventional than organic soils. In all farming systems, soil moisture was positively correlated with FEC or FEN, but negatively correlated with the C/N ratio of the microbial biomass and substrate induced respiration. Soil temperature was negatively correlated with FEC and FEN, but positively correlated with the C/N ratio of microbial biomass.

INTRODUCTION

Nutrient cycling and energy flow in terrestrial ecosystems are tied to the turnover of organic matter in soil. Although small in mass, the microbial biomass is among the most labile pools of organic matter and thus serves as an important reservoir of plant nutrients, such as N and P (Marumoto *et al*, 1982; Jenkinson and Ladd, 1981). The microbial biomass is a sensitive indicator of changes resulting from agronomic practices and other perturbations of the soil ecosystem (Smith and Paul, 1990; Doran, 1987). Its size and activity is directly related to the amount and quality of carbon and other nutrients available from plant residues, organic amendments and root exudates (Fraser *et al*., 1988; Adams and Laughlin, 1981; Martyniuk *et al*., 1978; Powlson *et al*., 1987). Other factors influencing microbial populations are soil moisture and temperature (Campbell and Biederbeck, 1976), physical disturbance of the soil (Doran, 1987), and interactions with soil fauna (Beare *et al*., 1992).

An understanding of microbial processes is important for the management of farming systems, particularly those that rely on organic inputs of nutrients (Smith and Paul, 1990). Many studies concerned with the impacts of farm management systems on microbial population dynamics compare different tillage practices (Doran, 1987; Angers *et al*., 1992; Carter, 1986). Studies comparing changes in microbial populations resulting from different amounts and types of organic inputs, but subjected to the same tillage practices, are fewer. A general conclusion of such studies is the development of a higher microbial biomass in soils receiving cover crops and manures than in the same soils receiving only mineral fertilizers (Kirchner *et al*., 1993; Bolton *et al*., 1985; Fraser *et al*., 1988; Nannipieri *et al*., 1990; Anderson and Domsch, 1989; Powlson *et al*., 1987; Doran, 1987).

The Sustainable Agriculture Farming Systems (SAFS) Project at University of California, Davis is a longterm, multidisciplinary study that compares the agronomy, soil fertility, soil biology, pests and weeds, and economics of four farm management systems (Temple *et al*., 1994; Scow *et al*., 1994). A major goal of the project is to improve management of soil fertility and structure through a greater understanding of soil microbial populations and their activities. The objectives of this study were to: i) compare the seasonal dynamics of soil microbial populations and their activity in four farming systems; ii) identify relationships between microbial and soil nitrogen parameters; and iii) determine relationships between soil microbial parameters and environmental variables. During the growing seasons in 1992 and 1993, measurements were made in tomato plots of the carbon and nitrogen associated with the microbial biomass, the potential activity of the microbial

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populations, as well as of environmental variables that might influence microbial populations.

MATERIALS AND METHODS

The study was conducted as part of the Sustainable Agriculture Farming Systems (SAFS) Project, initiated in 1989 (Temple *et al.*, 1994). It is located on 8.1 ha of land at the Department of Agronomy Field Facility, University of California, Davis. The soils are recent alluvial soils classified as Reiff and Yolo loams. The climate is Mediterranean with average summer temperature of 32 °C and winter 8 °C. The majority of rainfall occurs between December and March with a yearly total of 635 mm.

The farming systems under study are three 4 year rotational systems which include organic, low-input, and conventional 4 year (conv 4 yr), and a 2 year conventional rotation system (Temple *et al.*, 1994). The summer crop rotations for the 4 year systems are tomatoes, safflower, corn and beans. During winter, cover crops are grown in the low input and organic systems, whereas the soil is fallow in the conventional systems with the exception of the bean year which is preceeded by winter wheat. The conventional 2 yr rotation consists of tomato and wheat/bean (Temple *et al.*, 1994).

Production practices during 1993 are summarized in Table 1. The organic system derives its fertility from a winter cover crop, Lana woolypod vetch (*Vicia dasycarpa*), manure, seaweed and fish powder. No pesticides are used and the plots are managed according to California Certified Organic Farmers requirements (California Certified Organic Farmers, 1994). The low-input system relies on cover crops as a source of N but is supplemented, as needed, with inorganic fertilizer and pesticides. The conventional systems use inorganic fertilizers and pesticides.

The plots are arranged in a randomized complete block, split plot design with four replicates per system. Each farming system is divided into a number of plots (67 m x 18.3 m) equal to the number of crops in rotation within that system, and all crops in the rotation are grown each year.

Soil samples were collected 3 to 4 days following irrigation in order to eliminate some of the potential variability due to extremes in moisture content. Thirty randomly selected 2.5 cm diameter soil cores per plot from the 0 to 15 cm depth were collected. Samples from 15-30 cm were also collected on one date in 1992. Sampling was confined to the area between 10 cm from the row and 5 cm from the bed edge. The cores were pooled and well-mixed into a single composite sample per plot and transported to the laboratory in a cooler on ice. Later, samples were subdivided for the different assays. In the laboratory, replicated 10 to 15 g subsamples were used for gravimetric soil moisture determination (105 °C for 24 h). Field moist soil was sieved through a 4 mm sieve and immediately stored at 4 °C until assayed. For 40 to 48 hours prior to the activity measurements, sieved soil was incubated at 24 °C in plastic bags loosely tied for sufficient aeration and to prevent moisture loss. Soil temperature at the 0 to 15 cm depth of each sampled plot was recorded in the field. All measurements are presented as Julian days (JD) where, for example, JD 1 = January 1 and JD 32 = February 1.

Analyses of KCl-extractable ammonium-N and nitrate-N were conducted by the Division of Agriculture and Environmental Resources Analytical Laboratory using a Carlson autoanalyzer (Carlson, 1978). Fumigation extractable carbon (FEC) and nitrogen (FEN) released after fumigation and extraction of soil were measured using a method adapted from Vance *et al.* (1987) and Sparling and West (1988). The fumigation time was 24 hours and a soil:extractant ratio of 1:2.4 was used. All extracts were stored at -20 °C until analysis. Before analysis, samples were thawed and incubated at room temperature for 30 minutes. Extractable carbon following fumigation was determined by a Dohrman Model DC-80 TOC analyzer in 1992 and by a Shimadzu Model 5050 TOC analyzer in 1993. For the analyses with the Shimadzu TOC analyzer, samples and standards were diluted to 3 and 6 fold prior to injection to prevent precipitation of K_2SO_4 from the extraction medium onto the catalyst pellets. The catalyst was removed and replaced every 72 samples and new standards were run every 24 samples to ensure there was no degeneration of the catalyst. Extractable nitrogen following fumigation-extraction was determined as ninhydrin reactive N, which includes NH_4-N, amines, amino acids, peptides and proteins (Amato and Ladd, 1988; Carter, 1991). The values reported are differences in extractable carbon and nitrogen between the fumigated and unfumigated samples and are not converted to "total" microbial biomass C and N because of the uncertainty associated with using existing correction factors (Horwath and Paul, 1994).

Substrate induced respiration (SIR) was measured according to Smith *et al.* (1985) in which both the control and glucose-amended soils are provided with nutrients. Five g of soil were amended with nutrient broth (Becton Dickinson Microbiology Systems, Cockeysville, MD) containing beef extract and gelatin digest and then either amended or not amended ("uninduced") with 200 μg glucose g^{-1} soil. This glucose concentration was determined in preliminary tests to be the level at which the short term respiration rate was at its maximum. The soil was incubated for 2 h at room temperature and the head space CO_2 concentration was determined using a CO_2 Analyzer with an infrared detector (Applied Electrochemistry, Inc., Sunnyvale, CA).

Arginine ammonification (AA) was measured according to Alef and Kleiner (1987). Following pre-incubation at 30 °C for 1 h, 5 g soil was amended or not amended with an arginine solution to give a final concentration of 196 μg N g^{-1}. After stopping the reaction at 45 minutes by immersion in liquid nitrogen, the soil was thawed, extracted with 2 M KCl, and NH_4-N in the extract was analyzed by colorimetry.

Potentially mineralizable nitrogen (PMN) was measured in 1992 by the autoclave method adapted from Stanford and Smith (1976) and Doran (1987), and in both 1992 and 1993 by the anaerobic incubation method adapted from Keeney (1982).

Analysis of variance, Fisher's Protected Least Significant Difference (PLSD) test, and the *t* test of significance were performed where appropriate (Geng and Hills, 1989; Little and Hills, 1978). Linear regression and correlation analyses were carried out using a Macintosh StatView 4.0 application program (Abacus Concepts, Inc., Berkeley, CA).

RESULTS

Comparison of 4 farming systems in 1992 and 1993.

All four farming systems were sampled on at least four dates during the growing season in 1992 and 1993. The year 1992 was the last year of the first 4-year rotation sequence and 1993 was the first year of the second rotation. Fumigation-extractable carbon (FEC) was significantly higher in the organic and low input systems than in conventional systems on most dates (Fig. 1A and 1B). These differences were present even at the beginning of the growing season, before the incorporation of organic residues, and incorporation was followed by little change or a decline in FEC in the organic and low-input systems. Differences among systems were observed in soil samples from deeper in the profile as well. In September, 1992, FEC was significantly higher in the 0 to 15 cm than the 15 to 30 cm layer in all systems (Table 2). At this depth, FEC was significantly higher in low input than other systems, whereas the organic did not differ from the conventional systems. In 1993, FEN also was higher in organic and low input than conventional (Fig. 2A). Potentially mineralizable nitrogen (PMN), on the other hand, was significantly different before incorporation of cover crop only in the low input system (Fig. 2B). After that, conventional 4 yr was significantly lower than all other systems in mid June, and later in the season there were no differences among systems. On the last sampling date there had been 3 weeks since the conventional tomatoes were harvested and its residues incorporated, whereas it was still 10 days prior to harvest in the organic and low input systems.

Comparison of organic and conv 4 yr systems during 1993.

Estimates were made of the total carbon (C) and nitrogen (N) contained in inputs (including external inputs and above-ground residues from the preceding crop) to the four farming systems in 1992 and 1993 (Table 3). In 1993, the inputs to the organic system had a considerably higher C/N ratio than in previous years because a large fraction of the cover crop consisted of volunteer oats, which contain lower N levels than vetch, and because the manure contained larger than usual quantities of straw. In contrast, in 1992 the C/N ratios for inputs to the conv 4 yr and organic systems were 8.2 and 19.9, respectively. As would be expected under the immobilization conditions associated with the high C/N ratios in 1993, soil nitrate and ammonium concentrations in the organic system were low over the entire season (Fig. 3A and 3B). In the conv 4 yr system, however, mineral N levels increased dramatically following application of sidedress fertilizer and remained relatively high for three weeks.

Intensive sampling of six microbial parameters describing biomass or potential activity was conducted in the organic and conv 4 yr systems on a total of 13 dates in 1993. On most dates, all six parameters were significantly higher in the organic than conv 4 yr system (Figs. 4-6). Fluctuations in FEC were minor in the conv 4 yr (± 7% of a mean of 76 μg/g) in comparison to the organic plots (± 18% of a mean of 110). In contrast, fluctuations in FEN were high in both conv 4 yr (± 26% of a mean of 5 μg/g) and organic (± 19% of a mean of 27 μg/g) plots (Fig. 4A and 4B).

Levels of SIR and AA were significantly higher over most of the growing season in the organic than conv 4 yr plots (Fig 5). Arginine ammonification (Fig 5C) substantially increased in the organic plots following input of organic residues, whereas SIR did not show any obvious response (Fig. 5A). SIR showed a substantial drop in the conv 4 yr and a small drop in organic plots immediately following the time of sidedressing (between JD 110 and 155) in the conv 4 yr plots. Uninduced respiration, was significantly higher in organic than conv 4 yr plots early to mid-season and, by the end of the season, declined to about 19% of its original level in both systems (Fig. 5B). Potentially mineralizable nitrogen showed the same differences between organic and conv 4 yr plots (Fig. 6) as seen for other parameters and its behavior was most similar to, of all the parameters measured, that of FEN. In the conv 4 yr system, PMN was not detectable on the two dates immediately following sidedress application. The decline may have been due to an inability of the method to detect mineralizable N above the high background level resulting from side-dressing or toxicity; however, this period also corresponded with a time when the SIR showed a temporary decline in the conv 4 yr plots.

The parameter SIR has been proposed as an estimate of microbial biomass (Anderson and Domsch, 1978) based on the assumption that short-term metabolic rates reflect the size of the microbial population at the time of measurement. Therefore, it could be concluded that differences in SIR, and perhaps AA, may simply reflect differences in the magnitude of microbial biomass. To test whether there were differences between the two farming systems with respect to the intrinsic activity of the microbial community, AA and SIR were converted to a per unit biomass basis by dividing by FEC determined on the same date. The ratio SIR/FEC was significantly higher in the organic than conventional system during more than 60% of the observations (Fig. 7), and continuously during the time between JD 128 and 172. For 20 days following cover crop incorporation, AA/FEC was significantly higher in the organic than conv 4 yr system (Fig. 7) and then there was little difference between systems. In striking contrast to the other measures, the ratios of uninduced respiration/FEC were virtually identical for the two systems except on one date shortly after cover crop incorporation (Fig. 7).

Most bacteria have lower C/N ratios than do fungi (Holland and Coleman, 1987) and therefore the C/N ratio of the microbial biomass may reflect the domination of the microbial community by fungi or bacteria. The C/N ratios of the microbial biomass were calculated for each date in 1993. Because biomass N is measured by ninhydrin-reactive nitrogen, rather than total N, and because neither C nor N have been corrected for total biomass, the ratios serve for purposes of comparison and not as absolute values. The C/N ratios were significantly higher in conventional than organic soils on most dates (Fig. 8). Microbial C/N ratios in the organic plots were remarkably stable over most of the growing season; whereas in the conv 4 yr system the ratios showed greater fluctuations and increased over the last third of the growing season.

Relationship between microbial and soil fertility parameters

Determining relationships among microbial parameters and soil nitrogen levels is complicated because of the short-term fluctuations in soil fertility and microbiological properties. Therefore, looking at relationships among data collected on the same date may not reflect important trends occurring prior to the sample date. Nevertheless, correlations among all microbial and soil fertility parameters showed that when data from the organic and conventional 4 yr systems (13 dates) (Table 4) or from all farming systems (4 dates) (data not shown) were combined, there were consistently significant ($p=0.05$) negative relationships among microbial parameters (FEC, FEN, SIR, AA and PMN) and soil nitrate or ammonium. Correlation analysis of data for the conv 4 yr system alone showed the same trends as for all farming systems combined. However, analysis of the organic system alone revealed no significant ($p=0.05$) negative relationships between microbial and soil fertility parameters; in fact, these analyses showed significant ($p=0.05$) positive relationships between FEC and soil nitrate or ammonium and between AA and ammonium (data not shown). In all systems, there was a strong positive correlation between most of the microbial parameters and PMN.

Relationship between microbial parameters and environmental factors

Frequent irrigation (shown as bars on Fig. 9) maintained soil moisture in organic and conv 4 yr plots at levels between 12 and 30% in the top 15 cm of soil (Fig. 9). Irrigation was more frequent and soil moisture was usually higher in the organic than conv 4 yr system. Values in the conv 4 yr system dropped considerably after irrigation was terminated after JD 200 (mid-July). Seasonal variations in soil moisture levels were not as great in organic as in conv 4 yr soils. As these samples were collected 3 to 4 days following irrigation and intervals between irrigations were often 8 to 10 days, soils became even drier than the measurements indicated and especially so in the top layer of soil. For example, Amezketa *et al.* (1996) found that moisture levels in the same soils during much of the 1994 growing season ranged from 4-9%, with a mean of 5.4%, in the top 5 cm of soil. Because the gravimetric moisture content for the SAFS soils at 0.33 bar is approximately 24% (Scow, unpublished data), it is likely that moisture levels were frequently suboptimal for microbial activity.

Correlation analyses for climatic and microbial data (organic and conv 4 yr systems combined) indicated significant positive relationships between soil moisture and either FEC or FEN, but negative relationships between moisture and the C/N ratio of the microbial biomass, SIR, and SIR/FEC (Table 5). Soil temperature had significant negative relationships with levels of FEC and FEN, but a positive relationship with the C/N ratio of microbial biomass.

DISCUSSION

Differences among farming systems

Estimates of microbial biomass and activity used in this study indicated that these parameters are almost always significantly higher in soils of the organic and low input than conventional farming system. Though management of the farming systems differs in many ways, we believe the most important factor differentiating the microbial populations in the different farming systems is the amount of carbon entering the systems. The fact that more pesticides are used in the conventional than organic systems is presumed to be unimportant for several reasons. First, pesticide use is minimal in the conventional systems because they are managed according to integrated pest management (IPM) practices. Also, although

different measurements. The organic system showed a higher AA/FEC immediately after incorporation whereas SIR/FEC was higher in the organic system in the middle of the growing season.

The large difference between patterns of uninduced respiration/FEC and SIR/FEC was unexpected. The ratio of uninduced respiration/FEC was virtually identical in the organic and conv 4 yr systems. Uninduced respiration reflects mineralization of soil carbon, as well as of the complex carbon contained in the nutrient broth amendment (pancreatic digest of gelatin and beef extract) in the method we employed, whereas SIR reflects the net mineralization of added glucose. The short term metabolism of soil carbon and nutrient broth was a direct function of the size of the biomass and thus, in our study, was a better estimate of biomass than glucose-induced respiration. Wardle and Parkinson (1990b) discuss the likelihood that not all of the soil biomass can respond rapidly to added glucose and thus SIR is not always proportional to microbial biomass estimates by fumigation methods.

Differences in microbial community composition.

Though the emphasis of our study was not on microbial community structure, there were indications of differences in the communities of the organic and conventional systems. Fungal-dominated communities are favored over bacterial-dominated communities in farming systems in which plant residues are not tilled, at least in part due to spatial stratification of the organic inputs (Beare *et al.*, 1992; Holland and Coleman, 1987). These studies have compared systems receiving the same amounts of organic matter but differing in whether or not the residues are incorporated. In contrast, our study considers systems differing in their organic inputs but not substantially in their tillage practices. The lower C/N ratios in microbial biomass in organic than conv 4 yr soils supported that bacteria may be more important and fungi not as dominant in organic compared to conventional soil. Other supporting evidence for the importance of bacterial populations in organic soils was the fact that in 1993 bacterial feeding nematodes were more prevalent in organic than conventional systems, with little difference between systems in fungal feeders (Ferris *et al.*, 1996). Also, Scow *et al.* (1994) found higher levels of fungal feeding nematodes in conventional than organic and low input soils of the SAFS project in 1992.

Two factors distinguishing the two farming systems that may have, in turn, contributed to differences in their soil communities were the types of organic inputs and the soil moisture levels. The conv 4 yr system receives no carbon inputs after harvest of beans in the previous October; therefore the major sources of C for soil organisms in the subsequent cropping season are soil humus and the exudates and sloughing of tomato roots. The organic system, on the other hand, receives large single inputs of manure and cover crops. Bremer and van Kessel (1992) found that microbial biomass growing on green manure crops had significantly lower C/N ratios than biomass growing on straw residues and Neely *et al.* (1991) found a direct correspondence between the C/N ratio of organic inputs and the C/N ratio of microbial biomass. With respect to soil moisture, fungi are known to be favored at low water potentials in soil (Paul and Clark, 1989) and thus the consistently lower moisture content in the conventional soils may also have selected for fungal-dominated populations. The significant negative relationship between soil moisture and microbial C/N ratios supported this hypothesis. Other researchers have also used changes in C/N ratios of microbial biomass to infer changes in the community (Garcia and Rice, 1994; Wheatley *et al.*, 1990; Collins *et al.*, 1992).

Seasonal variations.

Seasonal fluctuations in FEC are minor at longterm sites such as Rothamsted (Jenkinson, 1990; Jenkinson and Rayner, 1977; Patra *et al.*, 1990), where carbon inputs in the form of animal manures have been occurring for over a century and presumably a steady-state has been achieved with respect to microbial biomass. However, seasonal fluctuations in FEC and/or FEN have been observed in numerous other systems, such as pesticides are used in the low input but not organic plots, the levels of microbial biomass are similar in the two systems. Finally a large body of literature supports the premise that most pesticides applied at recommended application rates, with the exception of fumigants, do not significantly impact microbial biomass and activity (Fraser *et al.*, 1988; Martyniuk and Wagner, 1978; Hicks *et al.*, 1989). Because carbon is so often a limiting factor for soil microbial populations, the higher carbon associated with the organic and low input than conventional systems presumably overrides small, if any, differences in microbial populations due to toxicity from pesticides.

Since the establishment of the SAFS project in 1989, C and N inputs have quantitatively and qualitatively differed among the farming systems (Scow *et al.*, 1994). In 1993, total C inputs to the organic system were 2.3 times the levels of C to the low input system, yet differences in microbial biomass estimates were not substantial. This lack of difference may be due to the recalcitrance of the carbon in the poultry manure; however, this hypothesis has not been tested. Levels of C to the organic system were, on the other hand, 6.2 times greater than inputs to the conv 4 yr system and the differences in microbial biomass estimates were always significant and as great as 2 fold. The impact of the organic inputs was seen beyond the growing season, as evidenced by the presence of differences in FEC and FEN between organic and conv 4 yr systems even before cover crop incorporation and even following tomato harvest. Activity measurements, on the other hand, were usually not significantly different among systems before and after the growing season.

Another factor contributing to differences among the farming systems is unique to Mediterranean and other seasonally warm climates. The mild winters of California make it possible to maintain plant cover over winter with only a 1 to 2 month period of bare fallow, as is done in the organic and low input farming systems. In the conventional systems, however, winter management in the Sacramento Valley involves keeping the soil fallow from September until March to conserve moisture and to permit field operations to be carried out for the next year's crop. The warm, wet winters of California can support relatively high microbial activity compared to levels in climates with colder winters, and this activity would be even more enhanced in rhizosphere, e.g. of the cover crop, than fallow soil. Microbial populations tend to be lower in systems with fallow periods than with continuous cropping (Collins *et al.*, 1992). The presence of a high microbial biomass in early spring in the organic and low input plots may be beneficial if the biomass could rapidly mineralize organic residues into plant-available nitrogen. On the other hand, a possible consequence of a high microbial biomass fostering high rates of mineralization and nitrification could be nitrate leaching during periods of heavy rainfall in spring. The possible benefits and disadvantages of maintaining large and active microbial populations over winter needs further investigation.

There was indirect evidence that side dressing of the conventional system may have had temporary negative impacts, possibly due to osmotic shock (Paul and Clark, 1989), on microbial populations. Between Julian days 125 and 140 (early to mid-May), declines in the conventional system occurred during a period when high concentrations of mineral N were present following sidedressing. Substrate induced respiration, uninduced respiration and SIR/FEC were the parameters that showed the greatest declines during this period. Less substantial declines in the same parameters within the same time period in the organic plots also occurred, suggesting that part of the decline may have been due to climatic conditions experienced by both systems (see below); however, declines were clearly more severe in the conventional system.

Measures of microbial biomass or activity, alone, do not reflect all important differences between systems because a large portion of the microbial community may be inactive (Gray and Williams, 1971). Thus, the ratio of an activity measurement--e.g., SIR, AA, or uninduced respiration to FEC gives an indication of the specific activity of the microbial biomass. Generally, when there were differences, microbial populations were more active in the organic than conv 4 yr system, although not at the same time for the

tall grass prairie (Garcia and Rice, 1994) and agricultural systems (Lynch and Panting, 1980; Campbell and Biederbeck, 1976; Wheatley *et al.*, 1990; McGill *et al.*, 1986). In both years of our study, most microbial parameters showed a sharp decline following JD 155 (early June) which corresponded to a period during which the temperature increased substantially. Similar declines in FEC during this same time period have been observed in previous years in all 4 farming systems (Scow *et al.*, 1994). In the organic system, early season fluctuations were most likely due to incorporation of organic material.

Even though the SAFS plots were irrigated, soil moisture sometimes dropped to levels low enough, particularly in the conventional system, to limit microbial populations. Numerous studies have reported decreases in microbial biomass due to drying of the soil (Van Gestel *et al.*, 1992; Ladd *et al.*, 1986; Wardle and Parkinson, 1990a). Soil moisture and microbial biomass levels were significantly positively correlated in our study. High temperatures were also associated with lower microbial biomass, and, as with low moisture conditions, were associated with high microbial C/N ratios. Because soil moisture is closely related to temperature, it is difficult to isolate the contribution of each of these variables in governing population levels. Also, the very high temperatures in the late growing season may have led to additional short-term moisture limitations between irrigation events that we were unable to detect with our sampling frequency. On the regional scale, temperature and moisture are positively correlated with decomposition rates and negatively correlated with biomass levels (Insam *et al.*, 1989); however, these relationships are rarely based on data collected in arid climates and do not consider irrigation as a variable.

Relationship between microbial and soil fertility parameters

An important and challenging objective of the SAFS project is to assess whether the striking differences in microbial parameters correspond to differences in soil fertility among the different farming systems. In previous years we have shown that seasonal patterns in soil nitrate levels differ among farming systems (Scow *et al.*, 1994). The pattern changed from previously higher (e.g. in 1989, 1990) to lower nitrate levels in organic than conventional tomatoes.

In 1993, the cover crop and manure inputs into the organic system had considerably higher C/N ratios than in previous years and mineral N levels in organic soils showed few fluctuations and remained well below levels in the conventional soil. Nevertheless, tomato yields were equivalent in the organic and conventional systems. Due to poor weather conditions, the mean yield of conventional tomatoes in Yolo County was low in 1993 relative to other years (SAFS, unpublished data); thus it was not a high yielding year for tomatoes in general. However, we believe the high mineralization activity of the large microbial biomass in the organic soil lead to release of sufficient N for that year. This N was then taken up by the tomatoes so rapidly that it never accumulated in the soil. The observed increases in microbial activity and increased nematode activity (Ferris *et al.*, 1996) after incorporation of inputs in the organic system support this hypothesis.

A side-benefit of organic inputs with high C/N ratios is their potential to reduce nitrate leaching. It is likely that C/N ratios as high as those observed in the organic system in 1993 would, in years when tomato yields are not so unusually low, lead to microbial immobilization and nutrient deficiency to crops. Thus, though such high C/N ratios might be beneficial in their ability to facilitate the capture of nitrate, these ratios would not be recommended from the perspective of soil fertility. It is possible, however, that C/N ratios intermediate between the high levels observed in 1993 and the relatively low ratios usually recommended (e.g., ratios of around 15) may provide fertility that is sufficient, while being less likely to negatively impact the environment. Studies are in progress at the SAFS plots to determine the effect of C/N ratio of organic fertilizers on tomato yields under organic management.

Substantial increases in mineral nitrogen concentrations have been shown to correspond to declines in soil microbial biomass (Haynes, 1986; Bonde *et al.*, 1988). The inverse relationship in the conventional 4 yr system between microbial biomass and mineral nitrogen supported this observation. In contrast, the relationship betw microbial biomass and mineral N was positive in the organic system. Presumably in organic system there was a continuous release of plant available N from the microl biomass, e.g. via wet-dry cycles (Marumoto *et al.*, 1977, 1982) and/or predat (Clarholm, 1985; Ferris *et al.*, 1996), as indicated by the fact that there was enough N sustain adequate tomato yields in this system. The absence of an obvious net decline FEC in the organic system during the period of maximum crop demand (in late May June) may imply that the high carbon inputs to this system could maintain microl populations at levels that matched their losses due to death.

There is considerable interest in conserving or increasing organic matter level agricultural soils (Paustian *et al.*, 1995). A commonly held, but largely untested, belie that it is not possible to increase organic matter contents in irrigated agricultural soil California due to their very high rates of carbon mineralization. After one four y rotation cycle, total organic matter content had increased in the organic system by 8-15% comparison to the conventional systems (Scow *et al.*, 1994) and, since then, organic ma levels have been consistently and significantly higher in low input and organic t conventional systems (SAFS, unpublished results). More significant was the increas amount of C associated with microbial biomass in the organic and low-input relative to conventional system, as has been observed by others (Powlson *et al.*, 1987). Microl biomass is one of the most labile of the pools comprising organic matter (Paul and Cl 1989) and, if soil fertility is the main interest, an increase in FEC is likely to be represent changes in the nutrient-supplying capacity of organic matter than is an increas total organic matter.

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LEGENDS

Figure 1. Fumigation extractable carbon in the four cropping systems during 1992 (A) and 1993 (B). Vertical bars = standard error (n=4).

Figure 2. Fumigation extractable nitrogen (A) and potentially mineralizable nitrogen (B) in the four cropping systems in 1993. Vertical bars = standard error (n=4).

Figure 3. Changes in soil NH_4 N (A) and soil NO_3 N (B) in conv 4 yr and organic systems in 1993. Vertical bars = standard error (n=4).

Figure 4. Changes in fumigation extractable carbon (A) and fumigation extractable nitrogen (B) in conv 4 yr and organic systems in 1993. Vertical bars = standard error (n=4).

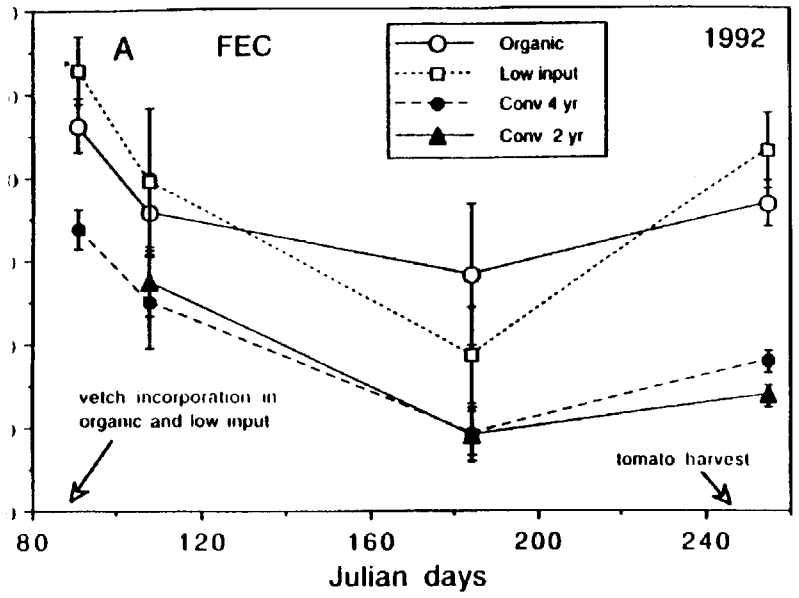
Figure 5. Changes in substrate induced respiration (A), uninduced respiration (B) and arginine ammonification (C) in conv 4 yr and organic systems in 1993. Vertical bars = standard error (n=4)

Figure 6. Changes in PMN in conv 4 yr and organic systems in 1993. Vertical bars = standard error (n=4).

Figure 7. Changes in substrate induced respiration / FEC (A), uninduced respiration / FEC (B) and arginine ammonification / FEC (C) in conv 4 yr and organic systems in 1993. Vertical bars = standard error (n=4).

Figure 8. Changes in fumigation extractable C/N ratios in conv 4 yr and organic systems in 1993. Vertical bars = standard error (n=4).

Figure 9. Changes in soil moisture and the amount of irrigation water applied over the season in conv 4 yr and organic systems in 1993.


A
FEC
1992
Organic
Low input
Conv 4 yr
Conv 2 yr
vetch incorporation in organic and low input
tomato harvest
80
120
160
200
240
Julian days

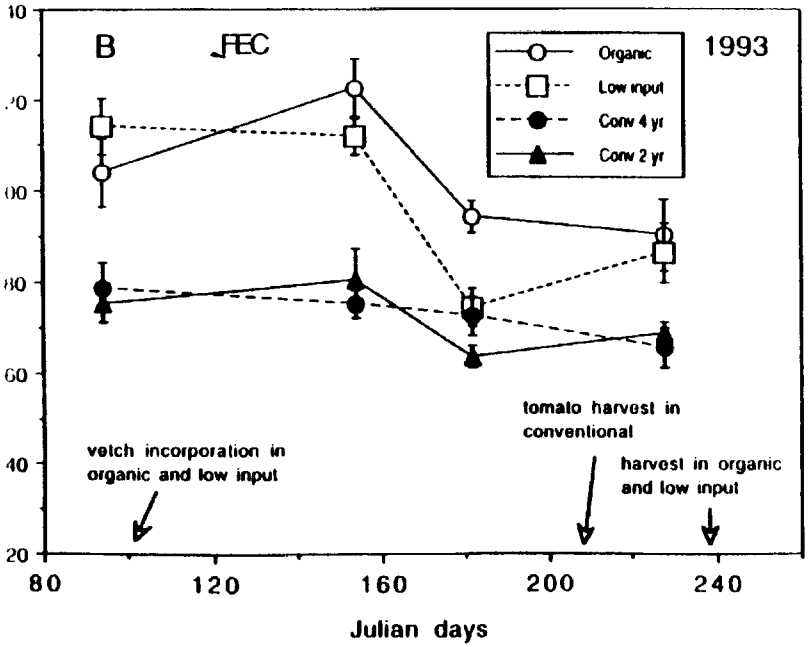
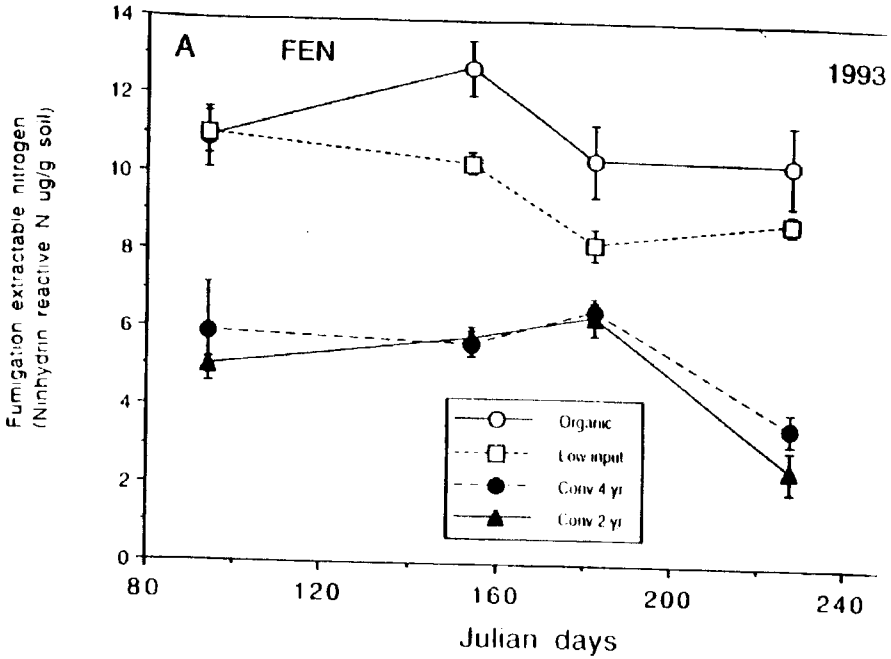

B
FEC
1993
Organic
Low input
Conv 4 yr
Conv 2 yr
tomato harvest in conventional
vetch incorporation in organic and low input
harvest in organic and low input
80
120
160
200
240
Julian days

Fig 1


A
FEN
1993
Fumigation extractable nitrogen (Ninhydrin reactive N ug/g soil)
Organic
Low input
Conv 4 yr
Conv 2 yr
0
2
4
6
8
10
12
14
80
120
160
200
240
Julian days

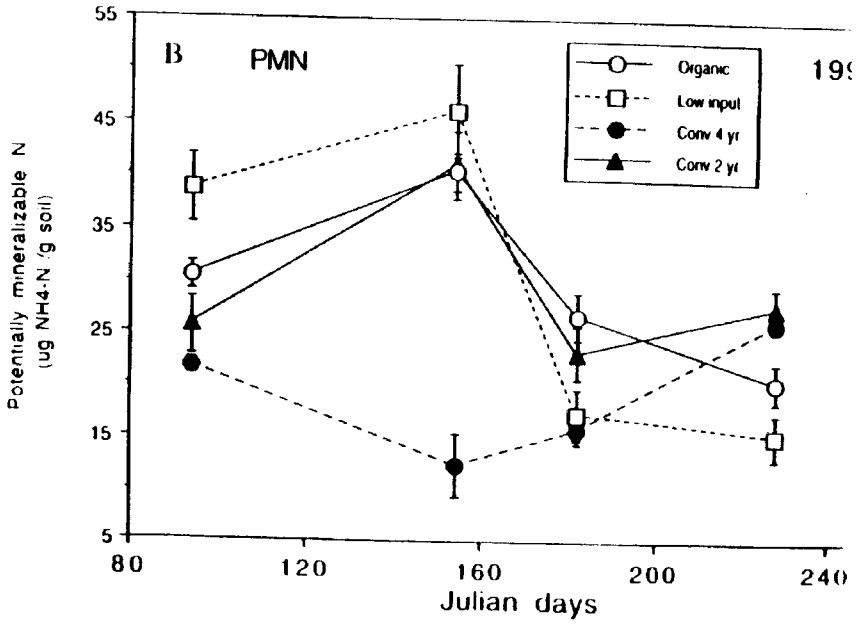
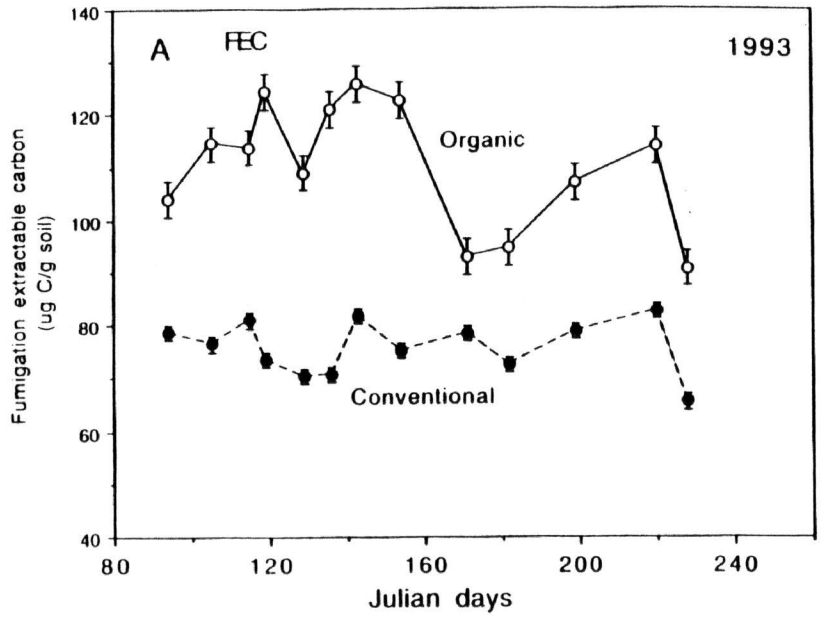

B
PMN
Potentially mineralizable N (ug NH4-N /g soil)
Organic
Low input
Conv 4 yr
Conv 2 yr
5
15
25
35
45
55
80
120
160
200
240
Julian days

Fig 2


A
FEC
1993
Organic
Conventional
Fumigation extractable carbon
(ug C/g soil)
Julian days

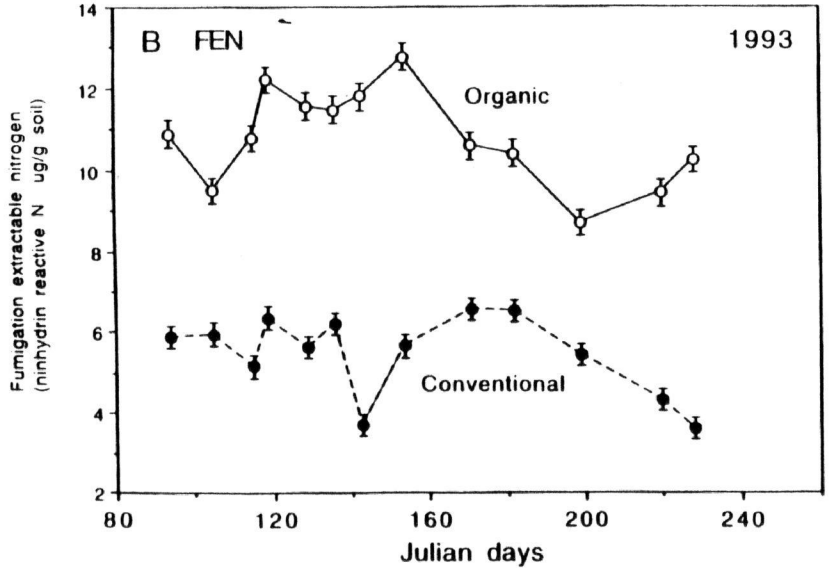
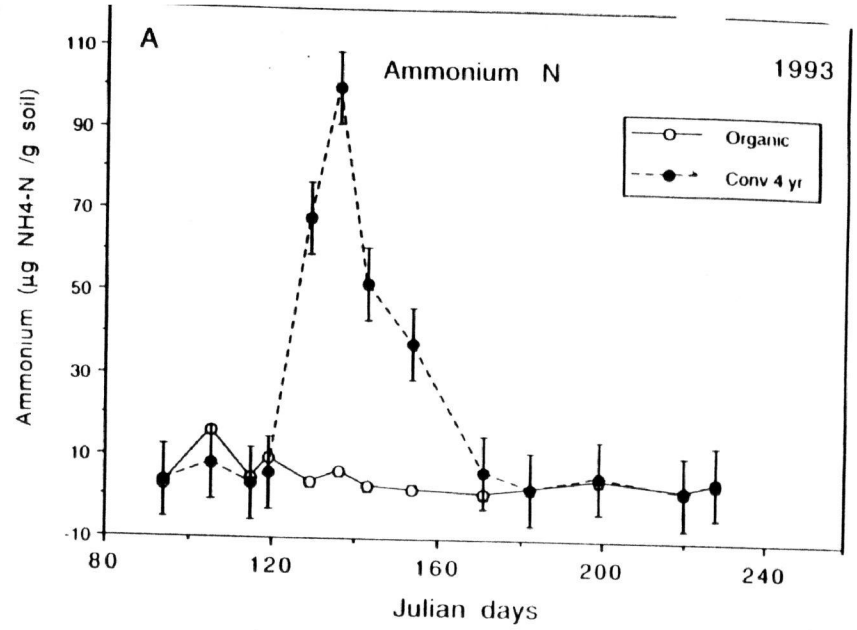

B
FEN
1993
Organic
Conventional
Fumigation extractable nitrogen
(ninhydrin reactive N ug/g soil)
Julian days

Fig 4


A
Ammonium N
1993
Organic
Conv 4 yr
Ammonium (µg NH4-N /g soil)
Julian days

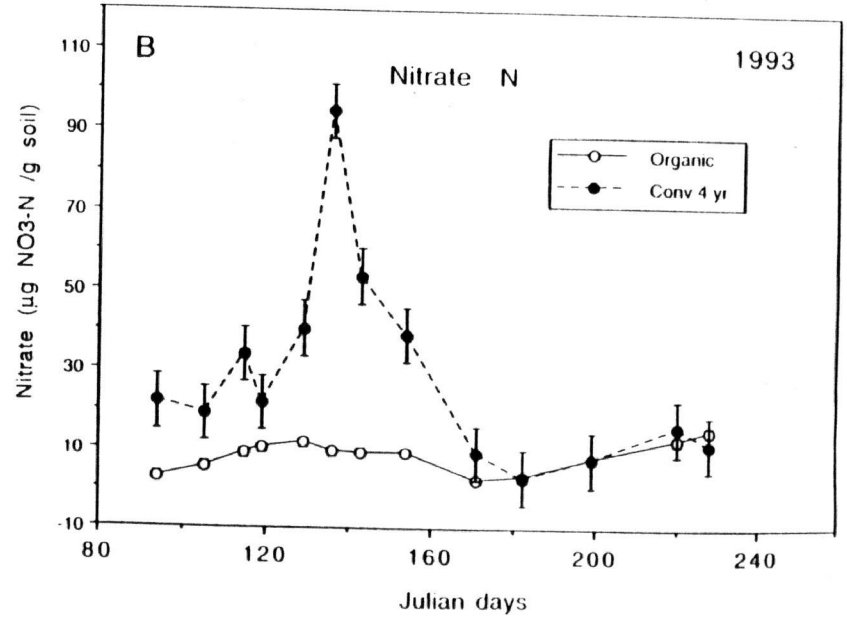
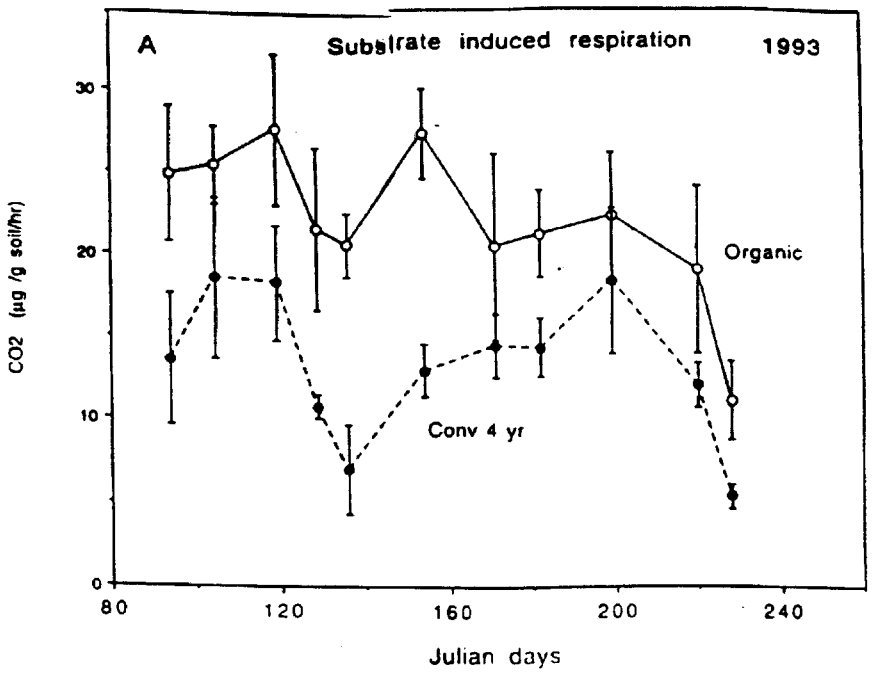
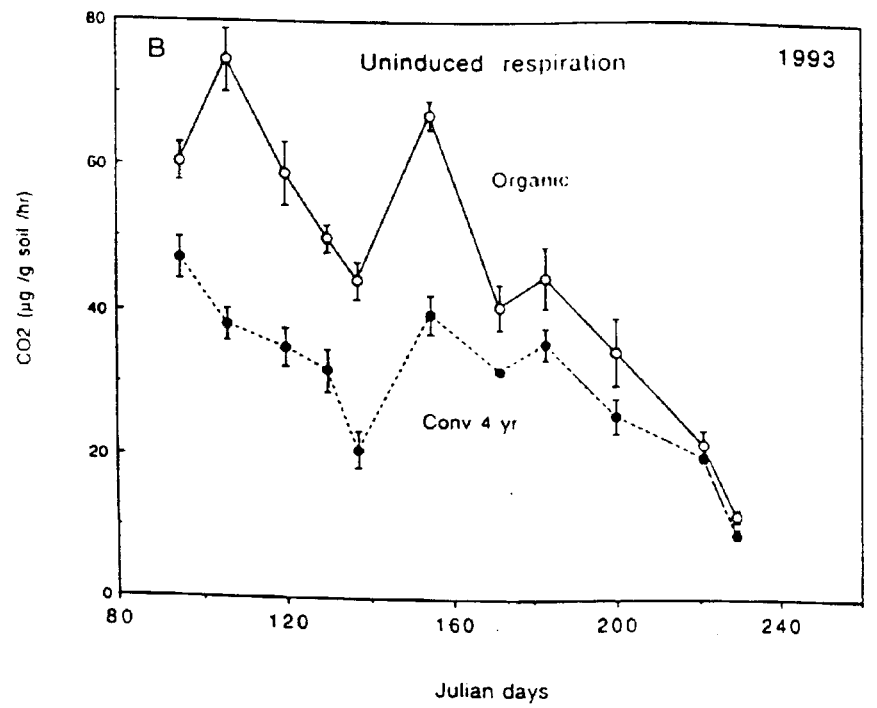

B
Nitrate N
1993
Organic
Conv 4 yr
Nitrate (µg NO3-N /g soil)
Julian days

Fig 3


A
Substrate induced respiration
1993
CO2 (µg /g soil/hr)
Organic
Conv 4 yr
0
10
20
30
80
120
160
200
240
Julian days


B
Uninduced respiration
1993
CO2 (µg /g soil /hr)
Organic
Conv 4 yr
0
20
40
60
80
80
120
160
200
240
Julian days

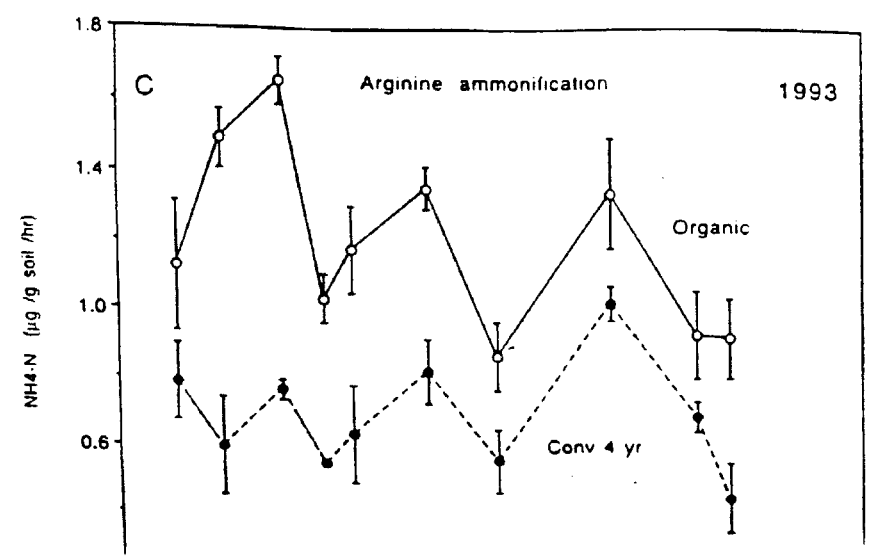

C
Arginine ammonification
1993
NH4-N (µg /g soil /hr)
Organic
Conv 4 yr
0.6
1.0
1.4
1.8

Fig 5

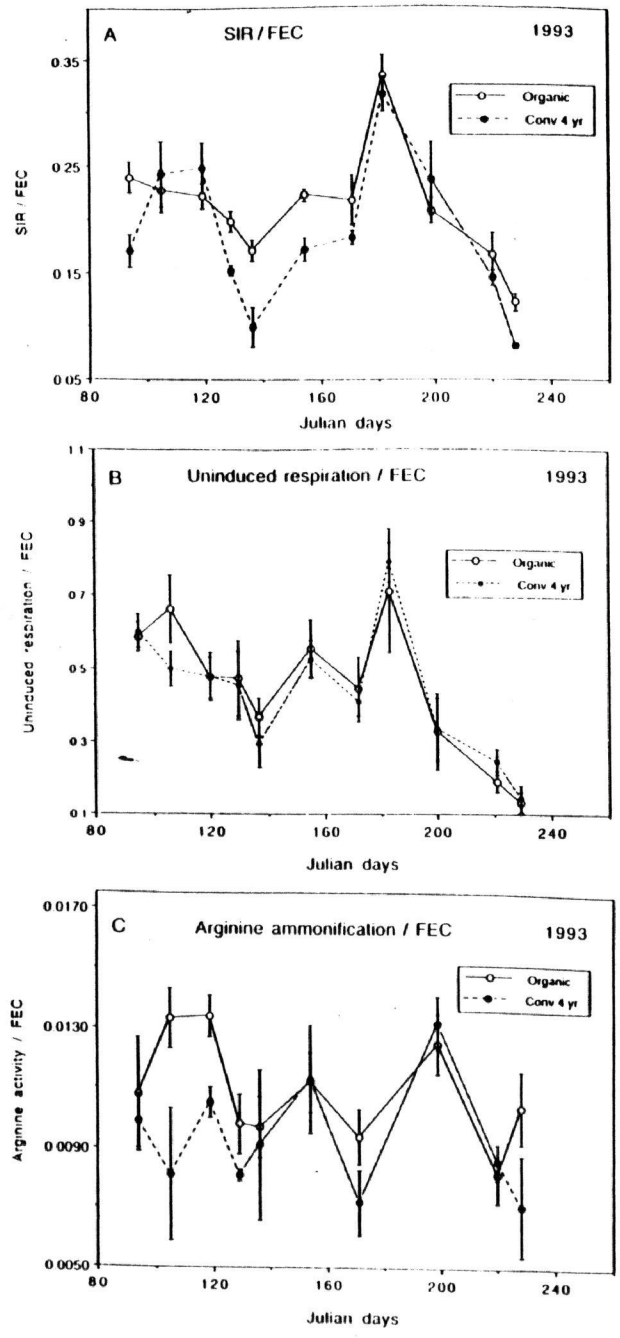

A
SIR / FEC
1993
Organic
Conv 4 yr
SIR / FEC
0.35
0.25
0.15
0.05
80
120
160
200
240
Julian days
B
Uninduced respiration / FEC
1993
Organic
Conv 4 yr
Uninduced respiration / FEC
0.9
0.7
0.5
0.3
0.1
80
120
160
200
240
Julian days
C
Arginine ammonification / FEC
1993
Organic
Conv 4 yr
Arginine activity / FEC
0.0170
0.0130
0.0090
0.0050
80
120
160
200
240
Julian days

Fig 7

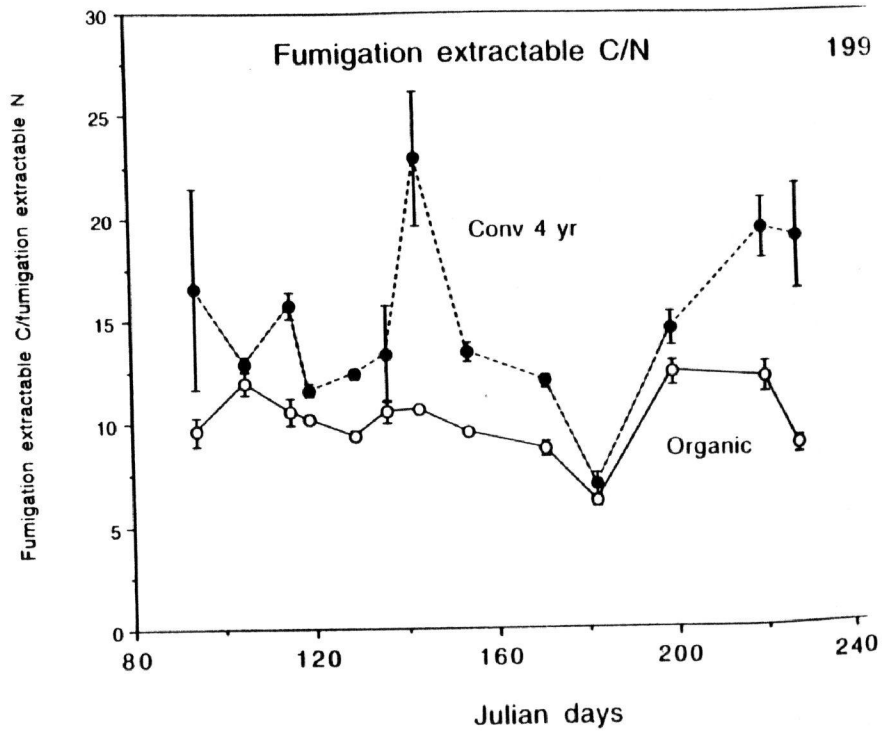

Fumigation extractable C/N
199
Fumigation extractable C/fumigation extractable N
30
25
20
15
10
5
0
Conv 4 yr
Organic
80
120
160
200
240
Julian days

Fig 8

Table 1. Tomato production practices in 1993

Operation	Cropping System			
	Organic	Low input	Conv 4 yr	Conv 2 yr
Planting date	JD* 109	JD 109	JD 69	JD 69
Method of planting	Transplants	Transplants	Seeding	Seeding
Fertilizer				
Preplant and/or Starter	Vetch/oats cover crop 121 kg N ha^{-1} Turkey manure (1% N) 67 kg N ha^{-1} Fish powder (12-0.25-1) 4.5 kg ha^{-1} Seaweed (3-0.25-0.15) 4.7 L ha^{-1}	Vetch/oats cover crop 176 kg N ha^{-1}	Mineral fertilizer (6-20-20) 112 kg ha^{-1}	Mineral fertilizer (6-20-20) 112 kg ha^{-1}
Sidedress	Fish powder (12-0.25-1) 4.5 kg ha^{-1} Seaweed (3-0.25-0.15) 9.4 L ha^{-1}	Mineral fertilizer (8-24-6) 94 kg ha^{-1}	Mineral fertilizer (34-0-0) 134 kg ha^{-1}	Mineral fertilizer (34-0-0) 134 kg ha^{-1}
Herbicides			Gramoxone Devrinol	Gramoxone Devrinol

* JD=Julian day

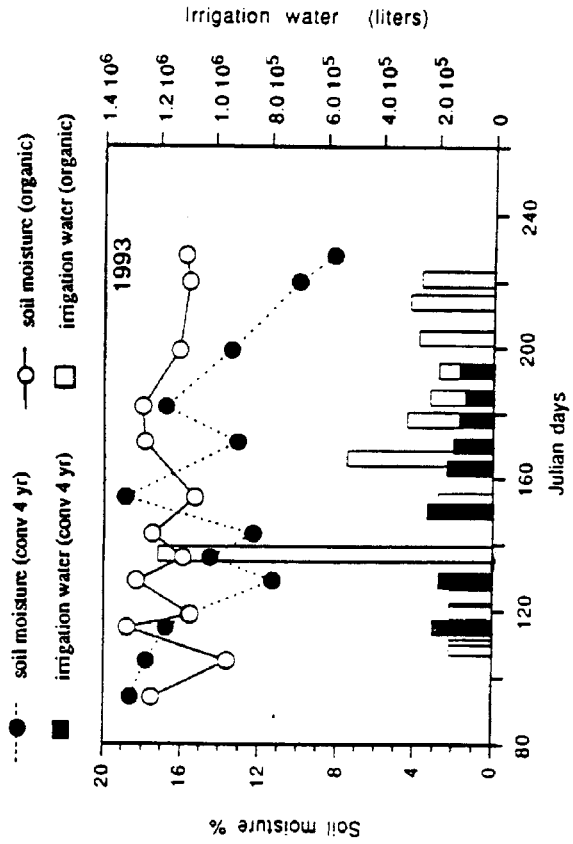


Fig 9

Table 2. Fumigation extractable carbon at two sampling depths in September 1992

Cropping system	Fumigation extractable C (µg/g soil) at 0 - 15 cm	at 15 - 30 cm
Conv 4 yr	55.49 a*	21.48 c
Conv 2 yr	47.42 a	28.78 b
Organic	93.00 b	23.85 bc
Low input	105.95 b	35.28 a

*Each value is a mean of three replicates. Means followed by the same letter within each column are not statistically different according to Fisher's PLSD test (p=0.05).

Table 3. Carbon and nitrogen inputs for three tomato cropping systems

		Cropping system Organic	Low input (kg/ha)	Conv 4 yr
1992 Carbon	Crop residues	2520	1760	1362
	Cover crop	1509	1596	
	Manure	1882		
	Total	[illegible]	[illegible]	[illegible]
Nitrogen	Crop residues	92	42	24
	Cover crop	101	101	0
	Manure	101	0	0
	Fertilizer	2	34	141
	Total	296	177	165
	C:N of inputs	19.9	18.9	8.2
1993 Carbon	Crop residues	1436	1398	1318
	Cover crop	3424	2126	0
	Manure	3276	0	0
	Total	8136	3524	1318
Nitrogen	Crop residues	43	39	39
	Cover crop	121	176	0
	Manure	67	0	0
	Fertilizer	1	10	141
	Total	232	225	180
	C:N of inputs	35.1*	15.6	7.3

* The cover crop in the organic system had a large population of volunteer oats which led to a higher than normal C/N ratio. Also, in 1993 the manure has a higher proportion of straw than in previous years. Thus, the organic system had a substantially higher C and lower N than the low input system.

Table 4. Linear correlation coefficients of 1993 soil microbial and nitrogen data from conv 4 yr and organic systems

Variables	Number of observations	Correlation coefficient (r)*
FEC , PMN	94	0.550
FEC , soil NH_4-N	104	-0.216
FEC , soil NO_3-N	104	-0.244
FEN , PMN	94	0.522
FEN , soil NO_3-N	100	-0.269
PMN , soil NH_4-N	94	-0.279
PMN , soil NO_3-N	94	-0.236
AA , soil NO_3-N	76	-0.318
SIR , soil NH4-N	88	-0.371
SIR , soil NO_3-N	88	-0.446
Soil NH_4-N , soil NO_3-N	104	0.876

* significant at the 0.05 probability level

Table 5. Linear correlation coefficients of combined data from 1992 and 1993 indicating relationships among soil moisture, temperature, microbial and nitrogen parameters.

Variables	Number of observations	Correlation coefficient (r)*
Soil moisture , FEC	124	0.423
Soil moisture , FEN	96	0.479
Soil moisture , C/N	96	0.589
Soil moisture , SIR	32	0.396
Soil moisture , SIR/FEC	32	0.560
Soil moisture , AA/FEC	24	0.404
Soil temperature , FEC	117	-0.438
Soil temperature , FEN	89	-0.354
Soil temperature , C/N	89	0.296
Soil temperature , soil NH_4-N	117	-0.192

* significant at the 0.05 probability level