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Soil microbial biomass and activity in organic tomato farming systems: Effects of organic inputs and straw mulching

Cong Tu, Jean B. Ristaino, Shuijin Hu*

Department of Plant Pathology, North Carolina State University, Raleigh, NC 27695, USA

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Abstract

Organic farming is rapidly expanding worldwide. Plant growth in organic systems greatly depends on the functions performed by soil microbes, particularly in nutrient supply. However, the linkages between soil microbes and nutrient availability in organically managed soils are not well understood. We conducted a long-term field experiment to examine microbial biomass and activity, and nutrient availability under four management regimes with different organic inputs. The experiment was initiated in 1997 by employing different practices of organic farming in a coastal sandy soil in Clinton, NC, USA. Organic practices were designed by applying organic substrates with different C and N availability, either in the presence or absence of wheat–straw mulch. The organic substrates used included composted cotton gin trash (CGT), animal manure (AM) and rye/vetch green manure (RV). A commercial synthetic fertilizer (SF) was used as a conventional control. Results obtained in both 2001 and 2002 showed that microbial biomass and microbial activity were generally higher in organically than conventionally managed soils with CGT being most effective. The CGT additions increased soil microbial biomass C and activity by 103–151% and 88–170% over a period of two years, respectively, leading to a 182–285% increase in potentially mineralizable N, compared to the SF control. Straw mulching further enhanced microbial biomass, activity, and potential N availability by 42, 64, and 30%, respectively, relative to non-mulched soils, likely via improving C and water availability for soil microbes. The findings that microbial properties and N availability for plants differed under different organic input regimes suggest the need for effective residue managements in organic tomato farming systems.

Keywords: Microbial biomass; Microbial activity; N mineralization; Organic mulching; Organic farming

1. Introduction

Organic farming has been expanding at annual rate of ca. 20% in the last decade (Lotter, 2003), accounting for over 24 million hectares worldwide (Willer and Yussefi, 2004), and has become a mainstream practice for some crops (Anon, 2004). In comparison with conventional farming, organic farming has potential benefits in promoting soil structure formation (Reganold et al., 1987; Pulleman et al., 2003), enhancing soil biodiversity (Doles et al., 2001; Mäder et al., 2002; Oehl et al., 2004), alleviating environmental stresses (Horrigan et al., 2002; Macilwain, 2004), and improving food quality and safety (Reganold et al., 2001; Giles, 2004). Because nutrient supply and pest control largely depend on organic inputs and biological processes in organic systems (Rigby and Cáceres, 2001; Watson et al., 2002), organic farming avoids the inputs of synthetic chemicals and their consequences. The build-up of a large and active soil microbial biomass, therefore, is critically important for sustaining the productivity of soils in organic farming systems. Soil microbes, the living part of soil organic matter, function as a transient nutrient sink and are responsible for releasing nutrients from organic matter for use by plants (e.g. N, P, and S) (Smith and Paul, 1990; Dalal, 1998; Friedel et al., 2001). It has been shown that microbial biomass N contributes to the primary N source of potentially mineralizable N in soil (Myrold, 1987; Bonde et al., 1988).

Soil microbes typically are C-limited (Smith and Paul, 1990), and lower microbial biomass in soils from conventional agroecosystems is often due to reduced organic C in

* Corresponding author. Address: 840 Method Road Unit 4, Campus Box 7903, Raleigh, NC 27695-7903, USA. Tel.: +1 919 515 2097; fax: +919 513 1279.

E-mail addresses: cong_tu@ncsu.edu (C. Tu), shuijin_hu@ncsu.edu (S. Hu).

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the soil (Wardle, 1992; Fließbach and Mäder, 2000). The quantity and quality of organic inputs are the most important factors affecting microbial biomass and community structure. High amounts of organic inputs often result in high microbial biomass (Fließbach and Mäder, 2000; Peacock et al., 2001). In a long term experiment, García-Gil et al. (2000) found microbial biomass C to be 33% higher in soils receiving municipal solid waste compost at an annual rate of 80 t ha^{-1} than at 20 t ha^{-1}. Quality of organic inputs also impacts the size of microbial biomass. Carbon and N concentrations and their ratios have been extensively used to measure the substrate quality (Cheshire and Chapman, 1996; Mueller et al., 1998; Martens, 2000; Seneviratne, 2000). A high content of easily decomposable organic C can lead to fast growth of soil microbes, likely resulting in higher microbial biomass and activity. For example, Chowdhury et al. (2000) observed that a manure compost with high easily decomposable C was more effective than saw-dust and rice husk composts in enhancing soil microbial biomass C. However, how different organic inputs influence microbial biomass and N supply in organic tomato farming systems is not well understood.

Organic mulching directly provides organic C inputs to soil, and has been used to effectively suppress weeds and reduce soil erosion in organic farming systems (Bilalis et al., 2003; Jordan, 2004). It is also effective in conserving soil moisture and buffering drastic changes in soil temperature (Pinamonti, 1998; Naeini and Cook, 2000), which can be of special importance in sandy soils where large fluctuations of soil moisture and temperature often occur. In the coastal areas of the eastern United States where the present experiment was conducted, the generally sandy soils, coupled with high rainfall and warm weather, facilitate organic C turnover in soil (Grisi et al., 1998; Sierra et al., 2001). In this area, therefore, the identification of management practices that can buffer moisture and temperature fluctuation can be important in maintaining soil microbial biomass over the short term and soil organic matter over the long term.

This experiment is a part of a long-term study that aims at linking microbial parameters with suppression of soilborne pathogens in organic tomato farming systems in the coastal plains of the eastern USA (Bulluck and Ristaino, 2002). The specific objectives were to (1) examine how different regimes of organic management impact microbial biomass and activities, and (2) determine how the resulting changes in microbial activities influence nutrient (N) availability for plants. Here we present our results obtained in 2001 and 2002 on soil microbial biomass, activity and N availability.

2. Materials and methods

2.1. Experimental description

The long-term field experiment was set up in 1997 at the Horticultural Crops Research Station (HCRS) in Clinton, NC, USA. The field soil is an Orangeburg sandy loam (Fine-loamy, kaolinitic, thermic Typic Kandiudults in US Soil Taxonomy) with 770 g kg^{-1} sand, 170 g kg^{-1} silt and 60 g kg^{-1} clay. Its original pH was 5.6 and organic C was 5.0 g kg^{-1}. The field experiment was a randomized split-plot design with tillage followed by bare soil (Non-mulch) and tillage followed by application of surface straw mulch (Mulch) as main plots, and different soil amendments as subplots. Subplots consisted of six planting rows that were 7.6 m long and 1.6 m wide. There were four replicates for each treatment. No tillages were applied for all plots during the plant growing seasons. The subplots were one conventional control with a synthetic fertilizer (SF, obtained from Royster-Clark, Tarboto, NC, USA) and three organic substrate treatments with different organic quality (as indicated by C/N ratio and extractable C content). The organic substrates used in this experiment were composted cotton gin trash (CGT) (Cotton Ginning and Sales, Goldsboro, NC, USA), animal manure (poultry and swine manure, AM) (the Animal and Poultry Waste Management Center, Raleigh, NC, USA), and rye/vetch green manure (RV) (Table 1). The conventional control system received inputs of a synthetic fertilizer while the organic systems received only organic inputs. No pesticides or fungicides were applied in any of the systems. At the initiation of the experiment, granulated dolomite lime was applied once at a rate of 2511 kg ha^{-1} to obtain a soil pH of approximately 6.2. The nitrogen input for each treatment was standardized at 112 kg N ha^{-1} of plant-available N except the RV plots. From 1997 until 2002 (except 2000), subplot soils were amended each May with SF, CGT and AM at a rate of 67 kg N ha^{-1} (in form of granula), 62,250 kg DW ha^{-1},

Table 1
Selected properties[a] of organic substrates used in the experiment (average for 2001 and 2002)

Organic substrate	Total Organic C/N	SMR (CO_2 - mg kg^{-1} d^{-1})	MBC (mg kg^{-1})	MBN (mg kg^{-1})	NMN (mg kg^{-1})	Extr-C (mg kg^{-1})	Extr-N (mg kg^{-1})	Bio CN (mg kg^{-1})	PAN (g kg^{-1})
CGT	16.7	290	4113	145	−29	2623	1225	29	1.80
AM	9.1	191	3965	406	−486	4855	1045	10	4.01
RV	16.3	ND	ND	ND	ND	ND	ND	ND	ND

SMR, soil microbial respiration; MBC, soil microbial biomass carbon; MBN, soil microbial biomass nitrogen; NMN, net mineralizable nitrogen; Extr-C, soil extractable carbon; Extr-N, soil extractable nitrogen; Bio CN, ratio of microbial biomass C to biomass N; PAN, plant available nitrogen; CGT, cotton gin trash; AM, animal manure; RV, rye-vetch cover crop; ND, not determined.

[a] The properties of the substrates were measured with the same methods as those used for soils.

and 28,000 kg DW ha^{-1}, respectively, leading to different inputs of extractable organic C to soils. Both organic and inorganic amendments were incorporated to depths of 30 cm soil with a Ferguson Tilrovator with a 1.6-m bedshaper (Suffolk, VA, USA). The conventional systems received additional synthetic fertilizer of 45 kg N ha^{-1} at the first flower cluster. For the RV treatment, rye/vetch cover crops were planted by broadcast at a seeding rate of winter rye at 56 kg ha^{-1} and hairy vetch at 28 kg ha^{-1} every fall, and were mowed and incorporated into depth of 30 cm soil in the following spring without additional N supply. The N input for the RV treatment was estimated at 45 kg ha^{-1} y^{-1} by multiplying total plant biomass (estimated average of 4000 kg ha^{-1}) by the N concentration (average of 11.4 g kg^{-1}). Two weeks after amendment incorporation, tomato plants were transplanted to each subplot with an exception of 2000. In the year 2000, no amendments were applied, and all plots were planted with Sudan-grass as a cover crop due to financial difficulty. For the surface mulched main plots, a 5–7 cm layer of wheat straw was applied to the soil surface two weeks after plant transplanting.

Plant-available N (PAN) of a substrate was estimated from the organic and inorganic N in the substrate according to the equation:

$$PAN = K_1 \times [Org - N] + K_2 \times [NH_4 - N] + [NO_3 - N].$$

Where [Org−N] is the concentration of organic N in the substrate as estimated by subtracting [NH_4−N] from the total Kjeldahl N concentration as determined by the method of Bremner and Mulvaney (1982); [NH_4−N] and [NO_3−N] are the concentrations of ammonium N and nitrate N determined by the method of Keeney and Nelson (1982), respectively; K_1, and K_2 refer to the fraction of organic N that can become plant-available, and the fraction of [NH_4−N] expected to be plant-available in the year of application, respectively. Based on the estimates by Evanylo (1994) for compost in the mid-Atlantic region of the US, we used a value of 0.10 for K_1, and 1.0 for K_2 (Bulluck et al., 2002).

2.2. Soil sampling

Soil samples were collected from 0–15 cm layer in each subplot in June (one week after transplanting) and August (immediately after final harvesting) in both 2001 and 2002. One composite sample consisting of 24 cores (2.5 cm diameter) was collected from the center four rows of each subplot but approximately 1 m away from the ends of the rows. For mulched subplots, the wheat straw was removed from the sampling areas before coring to avoid contamination with surface organic substrates. All samples were immediately stored in sealed plastic bags in a cooler and transported to laboratory. The field-moist samples were sieved with a 3-mm screen and stored in sealed plastic bags at 4 °C for microbial analysis. All microbiological determinations were performed within one week of sampling.

2.3. Sample analyses

2.3.1. Soil moisture

Upon sieving, soil subsamples (10.0 g) were weighed into aluminum dishes. These dishes were placed in a 105 ± 1 °C oven for 48 h, and the dry weight was then recorded. Gravimetric soil moisture was the difference in soil weights before and after oven drying (Gardner, 1986).

2.3.2. Soil extractable C and extractable N

Soil extractable organic C was estimated by equilibrating 20.0 g dry weight equivalent soil with a 50 ml of 0.5 M K_2SO_4 solution (Hu et al., 1997). The concentrations of C in the solutions were then determined using a total organic carbon (TOC) analyzer (TOC-5050A, Shimadzu Corporation, Kyoto, Japan). To estimate extractable N in soil, 10.0 g dry weight equivalent soil samples were shaken with 100 ml of 1 N KCl solution (Hart et al., 1994). The concentrations of NO_3^- and NH_4^+ in the extracts were, respectively, determined with QuikChem® methods 10–107–04–1–A and 10–107–06–2–A on a Lachat flow injection analyzer (Lachat Instruments, Milwaukee, WI, USA).

2.3.3. Soil microbial biomass

Microbial biomass C (MBC) and microbial biomass N (MBN) were determined by the chloroform-fumigation-extraction method (Vance et al., 1987; Ross, 1992). Twenty (20.0) grams (dry weight equivalent) of soil were fumigated with ethanol-free chloroform for 48 h. Both fumigated and non-fumigated soils were extracted with 50 mL of 0.5 M K_2SO_4 by shaking for 30 min on an end-to-end shaker. The TOC analyzer was used to determine the organic C (C_{org}) in the extracts. The MBC was calculated as follows:

$$MBC = (C_{org} \text{ in fumigated soil} - C_{org} \text{ in non-fumigated soil})/k_{ec}$$

Where, $k_{ec} = 0.33$, the factor used here to convert the extracted organic C to MBC (Sparling and West, 1988).

The concentration of N in the extractant was determined on the Lachat flow injection analyzer after digestion using alkaline persulfate oxidation (Cabrera and Beare, 1993). The MBN was calculated using the equation:

$$MBN = (\text{total N in fumigated soil} - \text{total N in non-fumigated soil})/k_{en}.$$

Where, k_{en} is 0.45, the factor used to convert the extracted organic N to MBN (Jenkinson, 1988).

2.3.4. Soil microbial respiration

Microbial activity was measured as the heterotrophic respiration in the absence of plant roots by an

Table 2
Results of the ANOVA for the effects of mulch and organic substrates on soil microbiological related measures

Sources	Extr-C	Extr-N	MBC	MBN	NMN	SMR	Bio CN	Soil moisture
Amendment (A)	***	***	***	***	***	***	ns	**
Mulch (M)	**	ns	*	*	*	*	ns	*
A×M	ns	ns	ns	ns	ns	ns	ns	ns
Year (Yr)	*	**	ns	ns	***	ns	**	**
Yr×A	***	***	**	*	***	**	ns	ns
Yr×M	*	ns	*	*	*	*	ns	ns

Extr-C, Soil extractable carbon; Extr-N, Soil extractable nitrogen; MBC, Soil microbial biomass carbon; MBN, Soil microbial biomass nitrogen; NMN, Net mineralizable nitrogen; SMR, Soil microbial respiration; Bio CN, Microbial biomass C to N ratio. ns, not significant at $P < 0.05$; *, **, and *** significant at $P < 0.05$, 0.01, and 0.001, respectively.

incubation-alkaline absorption method (Coleman et al., 1978). Sub-samples of sieved soil equivalent to 20.0 g dry weight were adjusted to moisture of about 60% water holding capacity (Alef, 1995), which was measured according to the method described by Forster (1995), and placed in 1–l Mason jars with a suspended beaker containing 5 mL of 0.5 N NaOH. The jars were incubated at 25 °C in the dark immediately after sealing. On the day 7 after the incubation, the beaker was replaced with one containing fresh NaOH solution, and the jars were incubated for additional 7 d. The CO_2 trapped in NaOH was titrated with 0.1 N HCl. Microbial respiration was estimated as mg CO_2 kg^{-1} soil d^{-1} by averaging the data.

2.3.5. Net nitrogen mineralization

Net nitrogen mineralization was determined using the method described by Hart et al. (1994). Briefly, soil samples of 10.0 g dry weight equivalent were weighed into Erlenmeyer flasks. The flasks were covered with plastic wrap pierced with a small hole to minimize water loss yet maintain gas exchange, and the soils were incubated for 28 d in the dark at room temperature. Soil moisture was maintained at approximately 60% water holding capacity by monitoring the weight change and adding water weekly during the incubation period. Soil NH_4^+ and NO_3^- were extracted with 1 N KCl at a 1:10 of soil to solution ratio, and their concentrations were determined with the Lachat flow injection analyzer. Net mineralized N in soil was the difference between KCl-extractable inorganic N contents before and after incubation.

2.4. Data analysis

A split–split plot ANOVA with mulch (or non-mulch) as the main plot factor, different organic inputs as the subplot factors, and year as the sub-subplot factor was performed with the General Linear Models (GLM) routine of the Statistical Analysis System (SAS Institute Inc., 1999). If the treatment main effect was significant, and interactions were non-significant, mean separation was carried out using the LSD procedure on main effect means for treatments. If treatment and year interaction was significant, the LSD was applied to treatment means separately for each year. Correlation analysis was also performed to test for relationships between variables. The microbial biomass and activity data for June and August within a single year were averaged because no significant differences were observed.

3. Results

3.1. Soil extractable C, extractable N and soil moisture

Organic practices significantly impacted soil extractable C (Table 2). Highest extractable C levels (52–76 mg kg^{-1}) occurred in plots amended with CGT, followed by AM (36–54 mg kg^{-1}), RV (30–33 mg kg^{-1}), and SF (28–29 mg kg^{-1}) (Fig. 1). Compared to the non-mulching treatments, surface mulching increased soil extractable C with a significant rise observed in 2002 (Table 3). Soil extractable C was 32% higher in 2002 than in 2001 (Table 3). There were significant interactions between year and amendment, and year and mulch. However, no interactions were observed between mulch and amendments (Table 2).

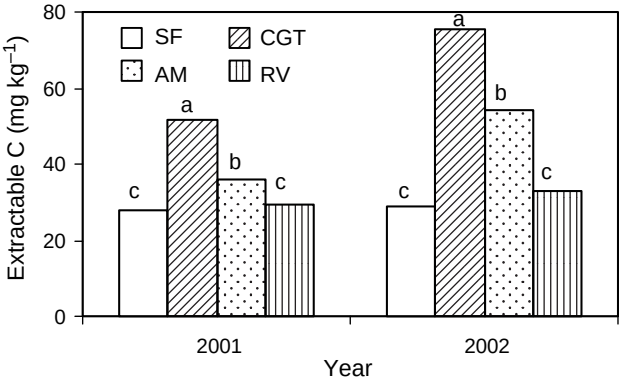

Fig. 1. Soil extractable C as influenced by additions of organic substrates in 2001 and 2002 (SF, Synthetic fertilizer; CGT, Cotton gin trash; AM, Animal manure; RV, Rye/vetch cover crop). The bars with different letters within a year are significantly different ($P < 0.05$).

Table 3
Means for microbial measurements in soils with mulch and non-mulch treatments in 2001 and 2002

Treatment	Extr-C		Extr-N		MBC		MBN		NMN		SMR	
	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
Non-mulch	35.7a	39.9b	3.77b	8.95a	176.1a	162.5b	27.8a	21.2b	4.76a	11.0b	27.7b	24.5b
Mulch	36.8a	55.9a	5.23a	9.79a	197.0a	283.1a	30.5a	40.4a	4.94a	15.5a	31.4a	54.1a
Mean	36.3	47.9	4.50	9.37	186.6	222.8	29.2	30.8	4.85	13.2	29.5	39.3

Extr-C, Soil extractable carbon; Extr-N, Soil extractable nitrogen; MBC, Soil microbial biomass carbon; MBN, Soil microbial biomass nitrogen; NMN, Net mineralizable nitrogen; SMR, Soil microbial respiration. Unit: CO_2 mg kg^{-1} d^{-1} for SMR and mg kg^{-1} for all others. The values with the same letter within a column are not significantly different at $P<0.05$ (LSD). Means of mulch and non-mulch within a year.

Soil extractable N was also highest (7.6–16.3 mg kg^{-1}) in soils amended with CGT, followed by AM (3–15 mg kg^{-1}), SF (3–7 mg kg^{-1}), and RV (3–4 mg kg^{-1}) (Fig. 2). Mulching tended to increase soil extractable N compared to the non-mulching (Tables 2 and 3). Significantly higher extractable N was detected in 2002 than in 2001 (Table 3).

Both straw mulching and incorporation of organic materials increased soil moisture with more obvious effects in the drier year in 2002. The soil moisture was 16–27% higher in the mulched than in the non-mulched soils. The differences between mulch and non-mulch treatments were greater in 2002 than in 2001 (Table 4). CGT, AM and RV treatments increased soil moisture by 25–58%, 11–13%, and 8–12%, respectively, relative to the SF treatment (Table 4).

3.2. Microbial biomass C and N

Microbial biomass C significantly differed among soils with different amendments (Table 2). The greatest MBC was found in the plots treated with CGT (272–371 mg kg^{-1}), followed by the AM (191–195 mg kg^{-1}) and RV (149–177 mg kg^{-1}), while the lowest MBC values were recorded in plots amended with SF (134–147 mg kg^{-1}) (Fig. 3). Mulching with wheat straw increased MBC significantly compared to the non-mulching (Tables 2 and 3). Although MBC did not show significant difference between 2001 and 2002, there were significant interactions between year and amendment, and year and mulch. The MBC was significantly correlated with extractable C, MBN, NMN, microbial respiration, and extractable N (Table 5).

Similar to MBC, microbial biomass N decreased in order of the CGT treatment (40–48 mg kg^{-1}) > AM treatment (28–29 mg kg^{-1}) > RV treatment (24–26 mg kg^{-1}) > SF treatment (21–23 mg kg^{-1}) (Fig. 4). Mulching enhanced MBN by 45% compared to the non-mulch plots (Table 3). There were no differences in the MBN between 2001 and 2002 (Tables 2 and 3). Significant interactions existed between amendment and year, and mulch and year. The MBN was significantly correlated with extractable C, MBC, extractable N, microbial respiration and net mineralizable N

Table 4
Moisture content (g kg^{-1}) of soils in different treatments

Year	Non-mulch	Mulch		
2001	86.1a	100a		
2002	37.6b	47.8a		
	Soil amendment			
	SF	CGT	AM	RV
2001	89.5b	112a	101ab	100ab
2002	35.8c	56.7a	39.7b	38.7bc

The values with the same letter in within a year are not significantly different at $P<0.05$ (LSD). SF, Synthetic fertilizer; CGT, Cotton gin trash; AM, Animal manure; RV, Rye-vetch cover crop.

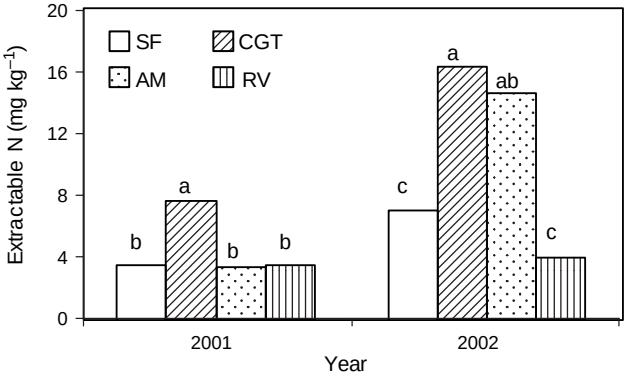

Fig. 2. Soil extractable N as influenced by additions of organic substrates in 2001 and 2002 (SF, Synthetic fertilizer; CGT, Cotton gin trash; AM, Animal manure; RV, Rye/vetch cover crop). The bars with different letters within a year are significantly different ($P<0.05$).

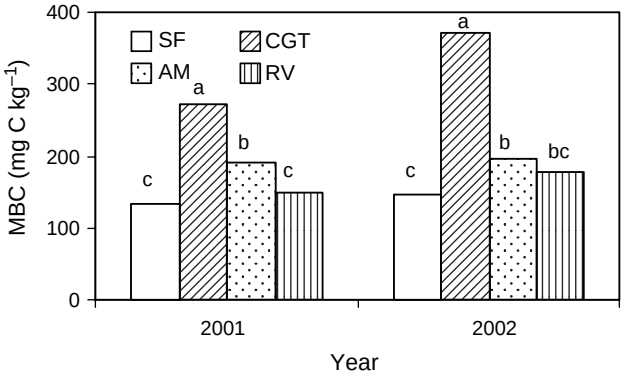

Fig. 3. Microbial biomass carbon (MBC) in soils amended with synthetic fertilizer (SF), cotton gin trash (CGT), animal manure (AM), and rye/vetch cover crop (RV) in 2001 and 2002. The bars with different letters within a year are significantly different ($P<0.05$).

Table 5
Linear correlationship among microbial C and N, net mineralizable N, microbial respiration, and extractable C and N of soils over both 2001 and 2002

	MBC	MBN	NMN	Extr-C	Extr-N	SMR
MBC	1	0.838***	0.727***	0.804***	0.257*	0.822***
MBN		1	0.615***	0.638***	0.303*	0.777***
NMN			1	0.782***	0.506***	0.576***
Extr-C				1	0.335**	0.757***
Extr-N					1	0.200
SMR						1

MBC, Soil microbial biomass carbon; MBN, Soil microbial biomass nitrogen; NMN, Net mineralizable nitrogen; Extr-C, Soil extractable carbon; Extr-N, Soil extractable nitrogen; SMR, Soil microbial respiration. *, **, *** represent significance at $P<0.05$, 0.01, 0.001, respectively ($n=64$).

(Table 5). In general, soil amendments and mulching did not significantly impact the microbial biomass C to N ratios (Tables 2).

3.3. Soil microbial respiration

Mulching with wheat straw significantly enhanced soil microbial respiration, increasing it by 13% in 2001 and 120% in 2002 compared to the non-mulched soils (Tables 2 and 3). The CGT-amended plots had the highest soil microbial respiration with 41–64 mg CO_2 kg^{-1} d^{-1}, next for AM- (36–37 mg CO_2 kg^{-1} d^{-1}) and RV-amended plots (20–33 mg CO_2 kg^{-1} d^{-1}), and the least for SF-amended plots (22–24 mg CO_2 kg^{-1} d^{-1}) (Fig. 5). There were year-mulch and year-amendment interactions (Table 2). The microbial respiration had also significant correlations with MBC, MBN, NMN, and extractable C (Table 5).

3.4. Net N mineralization

Net N mineralization was highest (11–25 mg N kg^{-1}) in the plots amended with CGT in both years, while much less N was mineralized in the RV plots during incubation, which was basically similar to that in the SF plots (Fig. 6). Compared to the SF, AM amended soils released 50% less N in 2001, but 112% more N in 2002, although these levels were significantly lower than that for the CGT amended soils (Fig. 6). Surface mulching had higher net N mineralization than the non-mulching did, with significant differences observed in 2002 only (Tables 2 and 3). Net N mineralization was almost two times higher in 2002 than in 2001 in all soils. The net mineralizable N was significantly positively correlated with extractable C, MBC, MBN, extractable N and microbial respiration (Table 5).

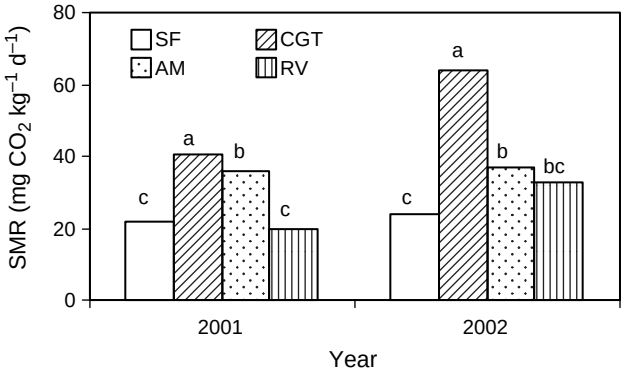

Fig. 5. Effects of organic substrate additions on soil microbial respiration (SMR) in 2001 and 2002 (SF, Synthetic fertilizer; CGT, Cotton gin trash; AM, Animal manure; RV, Rye/vetch cover crop). The bars with different letters within a year are significantly different ($P<0.05$).

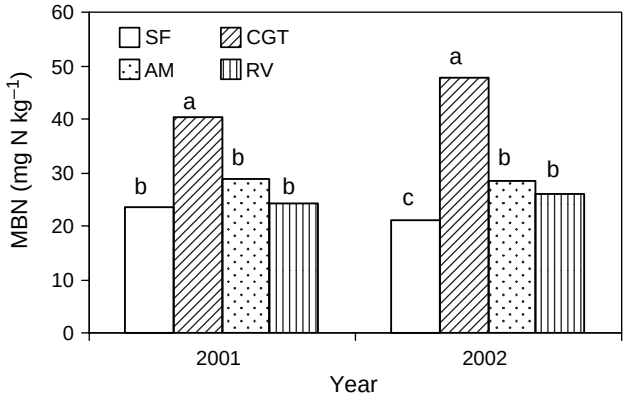

Fig. 4. Microbial biomass nitrogen (MBN) in soils amended with synthetic fertilizer (SF), cotton gin trash (CGT), animal manure (AM), and rye/vetch cover crop (RV) in 2001 and 2002. The bars with different letters within a year are significantly different ($P<0.05$).

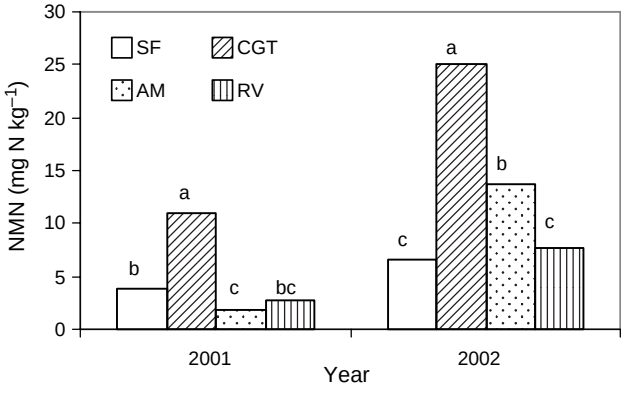

Fig. 6. Effects of organic substrate additions on soil net mineralizable nitrogen (NMN) in 2001 and 2002 (SF, Synthetic fertilizer; CGT, Cotton gin trash; AM, Animal manure; RV, Rye/vetch cover crop). The bars with different letters within a year are significantly different ($P<0.05$).

4. Discussion

Results from the present experiment demonstrated that difference in C inputs (including quantity and quality) can significantly impact microbial biomass and activity in organic tomato systems. Over the period of the experiment, organic amendments generally increased soil microbial biomass C and activity (microbial respiration) as compared to the SF control, with the effectiveness being in order of CGT > AM > RV, which was consistent with the amount of C applied to the soils. Stimulation of microbial biomass and activities by organic C inputs has been well documented in various organic substrates such as cattle manure compost, saw-dust compost and rice husk compost (Chowdhury et al., 2000), wheat straw and farmyard manure (Goyal et al., 1999), dairy shed effluent (Zaman et al., 1999), and municipal solid waste compost and cow manure (García-Gil et al., 2000; Peacock et al., 2001). However, various qualities of organic substrates may differentially impact soil microbes since substrate composition has profound influences on microbial utilization of C and nutrients in the substrate (Cheshire and Chapman, 1996; Martens, 2000). Increases in easily decomposable organic C observed in soil after additions of CGT with a moderate total C/N ratio likely contributed to the enhanced microbial biomass and activity (Smith and Paul, 1990). The effects of AM addition on microbial biomass and activity were less significant because extractable C inputs were lower although N inputs were standardized.

The differences in microbial biomass and activity under different organic amendments may have implications for nutrient availability to crops. High microbial biomass and activity often lead to high nutrient availability to crops (Zaman et al., 1999; Tu et al., 2003; Wang et al., 2004), through enhancing both the microbial biomass turnover and the degradation of non-microbial organic materials. Our results showed that enhanced soil microbial biomass and activity were associated with high net N mineralization (potential N availability for plants). In another study conducted at the same field site as our research study, Bulluck et al. (2002) found that numbers of free-living nematodes (both bacterivorous and fungivorous) were significantly higher in organically managed relative to conventionally managed soils. We suggest that the high N mineralization rate observed in the CGT treatment in our study may also be partially due to enhanced activity of the soil fauna, such as free-living nematodes. Enhanced N mineralization by stimulated microbial biomass and activity has also been observed in previous experiments at other locations. For example, a field trial showed that in reduced tilled soil 22% more mineralized N in the upper 30 cm was associated with the enhanced microbial biomass as compared to ploughed soil (Hoffmann et al., 1997). The enhanced N mineralization may substantially stem from the turnover of microbial biomass as Bonde et al. (1988) estimated that microbial biomass contributed to 55–89% of total mineralized N during a 40-week incubation period. Enhancement of microbial biomass and activities and potential N availability may reflect the plant productivity. In our experimental site, the tomato fruit yields over both years were about 50% higher in the CGT than in the SF treatment and yields in the AM plots were about 20% higher in 2002, as compared to that in SF plots. However, the yields were 40–50% lower in RV than in the SF plots, likely because nutrient inputs from cover crops were insufficient for tomato growth (Ristaino, unpublished data).

Our results also showed that the straw-surface mulching enhanced microbial biomass and activity and potential N supply. Such effects of mulching may stem from improvements of soil C and water availability. In addition to direct C inputs (Pinamonti, 1998; Tiquia et al., 2002), organic mulching also improves soil moisture through reducing soil surface evaporation (Franzluebbers et al., 1995; Martens, 2001), thus mitigating the disruptive effect of soil drying on microbes especially in dry season. Compared to 2001, the greater beneficial effects of mulching on soil microbes were observed in our experiment in 2002, when it was very dry during August. This is of special importance in sandy soils, as these soils generally have low water holding capacity. However, the mulching effects may become less significant when soil moisture is high due to excessive raining (Prado and Airoldi, 1999).

One may argue that there is no necessity of mulch in organic tomato farming systems in terms of microbial activity because organic matter inputs in these systems are often high. However, our results indicated that organic mulching had beneficial effects on soil microbes likely through buffering the extreme fluctuations in soil moisture and temperature. In addition, surface mulching provides other benefits through reducing soil erosion and nutrient losses (Shock et al., 1997; Erenstein, 2002), and suppressing weeds as weed control poses a major challenge in many organic farming systems (Bilalis et al., 2003; Jordan, 2004).

In summary, our results indicated that additions of CGT and AM can enhance microbial biomass and activity, and N supplies for plants. Surface mulching was effective in sustaining soil microbial biomass and activity in our highly sandy soil. These results indicate that the amounts and quality of organic C inputs can profoundly impact microbial properties and N availability for plants, highlighting the needs for effective residue management in organic tomato farming systems.

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