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SHORT COMMUNICATION

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Relationships of soil microbial biomass carbon and organic carbon with environmental parameters in mountainous soils of southwest China

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Abstract The relationships between microbial biomass C, organic C, and environmental parameters were studied in soils under corn (*Zea mays*. L) in the mountainous areas of southwest China. Three yellowish-red (Ultisols), yellow (Ultisols) and yellowish-brown (Alfisols) soils were relatively weathered, leached and impoverished, with most having a low input of aboveground corn residues. Seasonal changes in soil microbial C at 0–10 cm depth were significant at each sampling site, with the highest value (120 g C m^{-2}) in winter, and lowest value in summer (21 g C m^{-2}). Microbial biomass C was significantly and negatively correlated with site elevation and positively correlated with mean annual temperature. The seasonal change in microbial biomass C was significantly correlated with total soil organic C. The decline in microbial biomass C estimated as a percentage of the total soil organic C was negatively correlated with the elevation above sea level, ranging from 3.9±0.9% below 600 m to 1.4±0.5% above 1,500 m, suggesting higher turnover rates of soil microbial biomass C at warmer air temperatures. Temperature influenced the decomposition of organic C in soils mainly through its effects on microbial biomass C, and the microbial biomass C/organic C ratio appears to be a sensitive index of the change in organic matter content of soil.

Keywords Soil microbial biomass carbon · Soil organic carbon · Environmental parameters · Mountainous areas · China

Introduction

The content of soil organic matter affects the stability of agroecosystems and is controlled by many factors, such as cultivation (Burke et al. 1989). However, it is difficult to monitor small changes in soil organic matter in the short term because of large background C concentrations and the natural variability of soils (Sparling 1992). A wide range of methods has been proposed to identify and quantify the labile components of soil organic matter (Biederbeck et al. 1994), including measurements of microbial biomass (Carter 1986), and specific components such as carbohydrates (Angers et al. 1993). Over short periods, changes in microbial biomass C can be a sensitive index of changes in the content of soil organic matter (Powlson et al. 1987).

Much information is available on the response of microbial biomass C in soils under different management (e.g. Ross 1990; Chander et al. 1997) or different moisture regimes (Salinas-Garcia et al. 1997). However, very few studies have been conducted in subtropical mountainous areas, where the amount of plant residues returning to soils is comparatively low. Our previous studies have suggested that higher air temperature stimulates turnover rates of soil microbial biomass C (Piao et al. 2000a; 2000b).

In the present study our objectives were to: (1) identify the relationships between seasonal changes in microbial biomass C and environmental parameters at sites with different mean annual temperatures; and (2) evaluate the ratio of microbial biomass C to soil organic C as an index of changes in soil organic matter in the mountainous areas of southwest China.

Materials and methods

Sites, soil sampling and handling

Twelve terrace fields on slopes at different elevations above sea level were chosen as the sampling sites (Table 1). The sites were in mountainous terrain, a transitional zone from low land to hills

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Table 1 The description of sampling points in Guizhou Province of southwest China. *ND* Not determined, *SMBC* soil microbial biomass C

No.	Location	Position	Sea-level elevation (m)	Annual average air temperature (°C)	Annual precipitation (mm)	Organic C (g kg^{-1})	Total N (g kg^{-1})	pH (H_2O)	Clay (%)	Silt (%)	Bulk density (g cm^{-3})	Ratio of lost SMBC to soil organic C (%)
M1	Jingdong	25°49′N, 108°36′E	250	18.4	1000	13.0	0.8	5.41	22.5	65.0	1.13	3.79
M2	Bakai	25°49′N, 108°30′E	280	18.1	1200	14.7	1.2	6.13	33.5	60.3	1.18	2.95
M3	Zhaima	26°04′N, 108°43′E	570	16.2	1100	10.2	1.4	4.86	32.2	54.6	1.39	5.03
M4	Jichang	25°44′N, 107°35′E	900	15.7	950	16.4	1.2	5.90	68.6	25.9	1.16	3.04
M5	Taojiang	26°16′N, 108°07′E	960	14.6	1400	12.0	0.3	4.58	16.8	74.0	1.09	4.45
M6	Panjiang	26°30′N, 107°10′E	1000	15.2	1171	23.5	ND	5.04	37.0	45.8	0.98	1.69
M7	Jinzhu	26°30′N, 106°39′E	1140	14.3	1122	20.3	1.0	7.24	45.8	45.2	1.16	1.76
M8	Yanjiao	26°20′N, 105°23′E	1200	15.2	1213	46.2	2.8	6.84	41.2	43.8	1.27	0.40
M9	Dingqi	26°08′N, 105°41′E	1230	15.2	1402	24.2	ND	5.82	34.6	39.0	1.42	0.85
M10	Jinzhong	26°46′N, 104°23′E	2110	11.6	1027	15.7	ND	4.70	52.6	32.0	1.25	1.94
M11	Xiaohai	26°56′N, 104°10′E	2210	10.4	1028	25.8	1.5	6.59	37.2	42.0	1.02	1.36
M12	Guanfeng hai	26°58′N, 103°59′E	2240	10.4	990	46.3	1.9	7.29	32.8	41.7	0.75	0.70

in the eastern part of the Yunnan-Guizhou Plateau, southwest China. The plots, designated M1–M12, differed in size, but all were approximately 10 m^2 in area and used for growing maize (*Zea mays* L.). Mean annual air temperatures ranged from 18.4°C at M1 to 10.4°C at M12 and were negatively correlated with elevation above sea level (r=–0.98, P<0.001). Most of the Guizhou Province has a total annual precipitation >1,100 mm, with no regular changes with elevation above 900 m. The distribution of soil types varies with elevation. Yellowish-red soils (Ultisols, USDA) were developed at altitudes below 600 m above sea level, yellow soils (Ultisols) 600–1,500 m, and yellowish-brown soils (Alfisols) above 1,500 m.

Ploughing was carried out in early spring, with a tillage depth of about 20 cm. Ridges were made and corn seeds were placed in small holes with corn ash and small amounts of inorganic fertilizer. Harvesting times varied because of temperature differences among the 12 sites. After harvesting, the M5–M12 sites were kept fallow, whereas the M1–M4 sites were planted with vegetables. The estimated amounts of plant residues (roots and weeds) incorporated into the soils were 0.91±0.14 Mg C ha^{-1} year^{-1} at the M10–M12 sites, 1.26±0.25 Mg C ha^{-1} year^{-1} at the M5–M9 sites, and 1.45±0.29 Mg C ha^{-1} year^{-1} at the M1–M4 sites. Soil samples were collected in autumn 1997, winter 1997, and summer 1998. At each sampling time, three cores (5 cm diameter, 0–10 cm depth) were randomly taken between rows, and combined to give one sample for each site. Plant debris, stones and roots were removed, and the soil was mixed thoroughly without sieving. Soil microbial biomass C was determined on field-moist samples within 48 h after sampling. Cylindrical cores of soil with known volume were also taken for each site for bulk density determination, and then the soil was oven-dried to a constant weight at 105°C. Ultrasonic dispersion and size fractionation by sieving and sedimentation, and scanning photo sedimentograph (Analysette 20) were used for determining the contents of silt and clay.

Microbiological and chemical analyses

Microbial biomass C was determined by the chloroform fumigation-extraction technique (25 g soil; fumigation for 24 h at 25°C, and subsequent extraction with 100 ml 0.5 M K_2SO_4 for 1 h) (Voroney et al. 1993). The unfumigated control soil was extracted in the same manner. Organic C in the extracts was measured by dichromate oxidation, and microbial biomass C was calculated according to Voroney et al. (1993). The organic C concentration in the unfumigated extracts was used as an estimate of the soluble organic C concentration of the soil (Deluca and Keeney 1994).

Air-dried soils were passed through a 100-mesh screen and soil organic C and total N determined with an element analyser (Perkin Elmer 2400 II CHNS/O analyser).

Differences between means were tested for their significance by using linear regression and variance analysis at P=0.05.

Results

At each of the 12 sampling sites, the microbial biomass C content was highest in winter, reaching 120 g C m^{-2} at site M2, and lowest in summer, being only 21 g C m^{-2} at site M12, and was significantly correlated with both elevation and mean annual temperature (Table 2). We found no correlation between microbial biomass C and soil moisture, which was similar in autumn (32.5±5.4%), winter (31.6±6.2%) and summer (33.4±3.3%) samples. At our sites, clay content ranged from 17% (M5) to 69% (M4) of mineral material (Table 1), and silt contents from 26% (M4) to 74% (M5), but neither microbial biomass C nor soil organic C was significantly correlated with them. However, microbial biomass C was signifi-

Table 2 Correlation coefficients (*r*) between soil organic C (SOC), SMBC, or SMBC/SOC ratios and site environmental factors

		Elevation	Precipitation	Annual average air temperature (°C)	pH	Total N
SOC (g C m^{-2})		0.364	0.157	–0.256	0.595*	0.907***
SMBC (g C m^{-2})	Autumn	–0.758**	0.054	0.790**	0.060	0.342
	Winter	–0.791**	–0.020	0.749**	–0.308	–0.179
	Summer	–0.576*	0.096	0.626*	0.121	0.436
SMBC/SOC (%)	Autumn	–0.831***	–0.042	0.766**	–0.454	–0.534
	Winter	–0.713**	–0.014	0.620*	–0.570	–0.611*
	Summer	–0.733**	–0.013	0.681*	–0.378	–0.396

P*<0.05,*P*<0.01, ****P*<0.001

cantly correlated (*r*=0.648, *P*<0.02) with the content of fine clay (<0.5 µm) in the autumn samples, but not in the winter and summer samples.

At the 12 localities studied, differences in the ratio of microbial biomass C to soil organic C were correlated negatively with elevation and positively with mean annual temperature (Table 2). At some sampling times, the correlations between the microbial biomass C/soil organic C ratio and elevation or temperature were more significant than those between microbial biomass C or soil organic C alone and elevation (Table 2). As in other soils (Sparling 1992) the ratio of microbial biomass C to soil organic C may, therefore, be a more sensitive parameter to monitor organic matter dynamics than either microbial biomass C or soil organic C considered alone.

Differences in the soluble organic C extracted by 0.5 M K_2SO_4 between winter and summer samples (data not shown) were significantly correlated (*r*=0.626, *P*<0.05) with mean annual temperatures. The differences in microbial biomass C between winter and summer samples were inversely related to the soil organic C contents (*r*=–0.792, *P*<0.002). These results seem to indicate that more soil organic C (including plant residues) is immobilized into microbial biomass C at warmer than at the cooler sites.

The decline of microbial biomass C estimated as a percentage of the total soil organic C was also negatively related to elevation: below 600 m (the range of mean annual temperature was 16.2–18.4°C) the value was 3.9±0.9%, at 600–1,500 m (14.3°C–15.7°C) it was 2.0±1.4%, and above 1,500 m (10.4°C–11.6°C) the value was 1.4±0.5% (Table 1). This find suggests higher turnover rates of soil microbial biomass C at the sites with warmer air temperatures.

Discussion

Inputs of plant residues have an obvious influence on seasonal changes of soil microbial C (Chander et al. 1997). In some of the sites studied, the amount of corn residues incorporated into the soil was smaller than the residue of weeds, which were removed at regular intervals and incorporated into the soil. The values of microbial biomass C of summer and autumn samples would therefore be expected to be greater than those of winter samples. However, we observed an opposite relationship so other mechanisms must be responsible for the decline of microbial biomass C during summer. Wardle et al. (1999) reported that a large weed biomass caused a large increase in microbial biomass and respiration. After 3 years of a 7-year experiment, the microbial biomass was positively correlated with weed biomass and negatively with crop plant biomass, and the effect was supposed to be due to the higher decomposition of weed than crop residues. It may be possible that the increases of microbial biomass C with decreasing elevation can be ascribed to increases in inputs of roots and weeds into the soil with decreasing elevation.

Our observations are similar to those of Salinas-Garcia et al. (1997), who reported that microbial biomass C decreased from planting time to flowering, and then increased at harvest to values similar to those at planting. They ascribed such a seasonal pattern to a temporary drought that occurred before and during flowering.

The decrease in the contents of soil organic C with increasing mean annual temperature in the 12 sites studied is thought to be due to increased decomposition rates, and it agrees with the behaviour reported by McDaniel and Munn (1985).

Changes in the microbial biomass C/soil organic C ratio reflect the input of organic matter to soils, the efficiency of microbial incorporation, C losses from the soils, and the stabilization of organic C by the soil mineral fractions (Sparling 1992). Seasonal differences in the ratio of microbial biomass C to soil organic C contents were correlated with elevation and temperature, showing that turnover in microbial biomass may be also governed by atmospheric temperature.

Relationships between annual precipitation and the content of soil organic C of topsoils have been established for many regions (Spain et al. 1983). The increase in organic C with precipitation reflects the increase in plant productivity, and hence the increase of plant C to soil (Burke et al. 1989). However, there is no relationship between soil organic C or microbial biomass C and precipitation, probably because of the small amount of plant residues being incorporated into the soils.

Soil organic C contents were significantly correlated with total N and pH, but microbial biomass C and its seasonal changes were not correlated with either pH or total N content (Table 2). Insam et al. (1991) also suggested that N availability has little effect on microbial biomass C, although their results showed some relationship between microbial biomass C and total N of soil.

In conclusion, soil microbial biomass C was significantly correlated with mean annual temperature, probably because of associated differences in the root and weed inputs into the soil. These inputs would have been higher at the warmer sites than at the cooler sites because of higher plant production at the higher temperatures. In the ecosystems studied, the relationship between the differences in microbial biomass C between winter and summer and soil organic C content demonstrates that temperature influenced the decomposition of organic C in soils mainly through its effects on microbial biomass C.

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