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Microbial biomass in red soils and its significance in plant availability of nitrogen*

YAO Huai-ying(姚槐应), HE Zhen-li(何振立), HUANG Chang-yong(黄昌勇)

(*Department of Soil Science & Agricultural Chemistry, Zhejiang University, Hangzhou 310029, China*)

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Abstract: A series of laboratory and pot experiments carried out to examine the role of soil microbial biomass in red soils' nitrogen availability and productivity showed that soil available N (N_A), dry matter yield (DMY) of ryegrass, and plant uptake of nitrogen were each closely correlated with microbial biomass-C (C_{mic}) or -N (N_{mic}), suggesting that soil microbial biomass is a very important nitrogen pool available to plants in red soils. After correction for the substrate effect, the computed turnover of the N_{mic} in three tested soils ranged from 63 to 250 days. Soils with low N_{mic} or light texture generally had higher N_{mic} turnover rate than those with high N_{mic} or heavy texture. These results showed that soils with low N_{mic}, microbial biomass could also play an important role in the availability of nitrogen to plants due to these soils' high turnover rate.

Key words: Microbial biomass N, Nitrogen availability, Red soil, Ryegrass, turnover rate
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INTRODUCTION

Red soils occupying approximately 20% of the total land area of China and supporting 43% of the Chinese population are highly weathered and subjected to severe erosion, so nutrients released from minerals in them are very limited. Therefore, biological processes are very crucial for sustaining the fertility of the red soils. Soil microbial biomass may contribute to the availability of nutrients to plants in two major ways. Firstly, microbial biomass is an important nutrient pool potentially available to plants. Secondly, microbial turnover acts as a dynamic source of soil available nutrients for plants (Smith and Paul, 1991). However, little information is available on the nitrogen availability to plants in relation to microbial biomass and its turnover in red soils. Information is also needed to clarify soil and biological factors affecting microbial biomass and its turnover in these soils. This study was aimed at examining the relationship of nitrogen availability to microbial biomass and its turnover in red soils of different fertility status on the basis of laboratory analysis and greenhouse experiments.

MATERIALS AND METHODS

Soils

All the soils used were Ultisols with kaolinite, chlorite and Fe and Al oxides as dominant clay minerals. The soils covered a wide spectrum of soil fertility, i.e., from the severely-eroded (unarable) to long cultivated soil. Some agrochemical properties of the tested soils are shown in Table 1. Moist soil with all plant roots was passed through a 2-mm sieve, and then had its moisture content adjusted to 70% field-holding capacity prior to soil microbial biomass-C and -N measurement by the fumigation-extraction method (Brookes et al., 1985; He et al., 1997).

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Measurement of soil microbial biomass nitrogen turnover

Three soils of different texture and microbial biomass contents were selected for this study. Fresh moist soils were pre-incubated at 25 ℃ and 100% relative humidity for 3 days, and then glucose at 2500 C mg/kg, ^{15}N-labeled ammonium sulfate [$(NH_4)_2SO_4$ with 11.385% ^{15}N atom excess], at 100 N mg/kg, and potassium dihydrogen phosphate at 50 mg P kg^{-1}, were added to subsamples of the soils, whose moisture was adjusted to 70% field-holding capacity. Soil samples with and without substrate were then incubated 11, 22, 29, 44, 58, and 75 days respectively, and then sampled for analysing microbial biomass-C and -N and ^{15}N activity in microbial biomass. The ^{15}N activity was determined by mass spectroscopy. The turnover rate of soil microbial biomass N was obtained by fitting the experiment data to the first-order kinetic model ($Y_t = Y_0 e^{-kt}$, where Y_0 and Y_t are the N_{mic} at time zero and t, respectively and k is rate constant) after correcting for the substrate effect.

Greenhouse pot experiments

Pot experiments were carried out in a greenhouse. One and a half kg of oven-dried test soil with moisture content adjusted to 70% field capacity was put into a 2-L plastic container. After three days, 100 pre-soaked and sterilized ryegrass seeds were sown. Each of 70 healthy seedlings were kept in a pot one week after germination. No fertilizer was applied to either the soils or the plants throughout the experiments. There were three replications for each of the soils. After 40 days' growth, the whole ryegrass plants were harvested by cutting the shoot, and carefully separating roots from the soil. Shoots and washed roots were oven-dried and weighed to obtain dry matter yield. The plant samples were ground to pass through a 1-mm sieve and digested with H_2SO_4-H_2O_2 for analyzing plant N concentration.

RESULTS AND DISCUSSION

The tested soils varied greatly in fertility as shown by the difference in organic carbon, total N and available N (Table 1). Microbial biomass C (C_{mic}) in the soils ranged from 20.2 to 425.8 mg/kg, accounting for, on the average, 1.88% of total organic C (C_{org}) (Table 2). The fertile soil (No.8) contained 20 times more C_{mic} than the infertile eroded soil (No.1). Microbial biomass N (N_{mic}) varied from 4.0 to 52.6 mg/kg, accounting for, on the average, 2.88% of total N (N_T) or 28.8% of available N (N_A) in the soils (Table 2). The N_{mic} in the fertile soil was 11 times that in the infertile soil. The average C/N ratio of microbial biomass (7.21) was about 3.5 units lower than that of soil (10.85), indicating that microbial biomass N was potentially available to the plants.

Table 1 Basic properties of the tested soils

Soil No	Land use history	pH (H_2O)	Organic C (g/kg)	Total N (mg/kg)	Available N (mg/kg)	Soil C/N
1	Eroded-unarable	4.47	1.72	210	32.2	8.19
2	Upland-3 yr	6.57	4.81	430	59.8	11.18
3	Citrus orchard-4 yr	4.96	4.99	480	63.7	10.40
4	Citrus orchard-7 yr	4.70	14.54	1730	113.0	8.40
5	Citrus orchard-12 yr	5.62	16.46	1820	116.2	9.04
6	Paddy-15 yr	5.04	18.84	1530	130.2	12.31
7	Tea orchard – 30 yr	4.64	26.33	2040	170.8	12.91
8	Forest-38 yr	5.67	29.14	2030	193.0	14.35

Table 2 Dry matter yield of ryegrass, plant N uptake, soil microbial biomass-C and -N

Soil No	Microbial biomass C (mg/kg)	% of tatal org. C[a]	Microbial biomass N (mg/kg)	% of total N[a]	% of Available N[a]	Microbial C/N ratio	Plant N uptake (mg/pot)	Ryegrass yield (g/pot)
1	20.2 ± 2	1.17	4.0 ± 0.3	1.90	12.4	5.05	22.7 ± 1.7	1.66 ± 0.2
2	152.2 ± 10	3.16	23.7 ± 1.5	5.51	39.6	6.42	49.4 ± 3.2	3.50 ± 0.4
3	129.9 ± 8	2.60	19.0 ± 1.2	3.96	29.8	6.84	34.3 ± 2.6	2.17 ± 0.2
4	235.3 ± 15	1.62	31.9 ± 2.5	1.84	28.2	7.38	64.4 ± 5.9	4.05 ± 0.4
5	264.6 ± 20	1.61	35.2 ± 2.5	1.93	30.3	7.52	123.9 ± 10	7.33 ± 0.6
6	361.9 ± 22	1.92	45.2 ± 3.0	2.95	34.7	8.01	107.9 ± 9.0	7.82 ± 0.8
7	400.2 ± 30	1.52	47.9 ± 3.2	2.35	28.0	8.36	165.5 ± 15	9.62 ± 1.0
8	425.8 ± 35	1.46	52.6 ± 4.1	2.69	27.3	8.10	158.4 ± 16	7.88 ± 0.8

[a] Percentage of C_{mic} in total organic C, and percentage of N_{mic} in total N or available N

Soil microbial biomass-C was closely related to soil fertility as found for other soils (Brookes et al., 1984). The effect is largely due to the close correlation between C_{org} and C_{mic}. A good relationship between crop yield and soil microbial biomass had also been reported from three experiments (Insam et al., 1991). In the present study, the C_{mic} was highly correlated with C_{org} ($r = 0.971$), N_T ($r = 0.903$) and N_A ($r = 0.974$), whereas the N_{mic} was highly correlated with C_{org} ($r = 0.954$), C_{mic} ($r = 0.996$), N_T ($r = 0.898$) and N_A ($r = 0.963$). These results showed that both C_{mic} and N_{mic} were closely related to soil fertility; and that soil microbial N may serve as an important pool of nitrogen available to plants in highly weathered soils. The results from pot experiments were in good agreement with the soil fertility measurements. Both dry matter yield (DMY) and N uptake of the ryegrass were highly correlated with C_{mic} ($r = 0.938$ and 0.938, respectively) and N_{mic} ($r = 0.921$ and 0.923, respectively). Soil organic matter and total N content are generally considered as the most important soil fertility factors in relation to crop yields. This study showed that the correlation between ryegrass DMY and C_{mic} was better than that between the DMY and Corg; and that the correlation between N uptake and N_{mic} was better than that between N uptake and N_T. Consequently, microbial biomass constitutes an important available N pool in red soils.

Soil microorganisms collectively represent a relatively labile pool of C, N, P, etc. The turnover of these elements through the microbial biomass plays an important role in nutrient flow. Nitrogen from the nitrogenous substrate assimilated by microorganisms constantly moves through the biomass pool, leaving it either as gaseous losses of nitrogen or forming a complex sequence of microbial metabolites. At steady state, the quantity of biomass formed per unit time equals the quantity decomposed. Consequently the turnover time of soil microbial biomass N can be considered as the time required to synthesize or decompose an amount of biomass N equivalent to the original level. In this study, a high value of C: N of the added substrate caused the labelled ammonium sulfate to be decomposed in a short time. The addition of nitrogenous substrate can accelerate the turnover of the native soil biomass N for the first few days, so day 22 was defined as the start day to estimate microbial turnover. The ^{15}N abundance in N_{mic} peaked at day 22 of incubation and then gradually declined. The decrease in ^{15}N-labeled N_{mic} from day 22 to day 75 of incubation was well described by first-order reaction, with correlation coefficients (r^2) from 0.97 to 0.99 (Table 3). After correction for the amount of ^{15}N-labeled N_{mic} synthesized from microbial metabolites and

substrate effect, the turnover rates of N_{mic} were 250, 89, and 63 days, respectively for the long cultivated red clayey soil (soil No 7), the recently cultivated red clayey soil (soil No 3) and red sandy soil (soil No 2). The corresponding annual fluxes of nitrogen through the microbial biomass were 69, 78, and 137 mg/kg (or 140 to 270 kg/ha). For the sandy soil, the annual flux of N through microbial biomass turnover was about 2.5 times that of extractable soil available N (Table 1). This finding agrees with field observation that plant-availability of N was higher in the sandy than in the clayey soil. Obviously, microbial biomass serves as an important dynamic N source available to plants in the red soils.

The microbial turnover rate of nitrogen was related to N_{mic} and soil texture. Soil with light texture (soil No 2) tended to have a higher turnover rate of N_{mic} than the clayey soil (soil No 3) at comparable N_{mic}. This conclusion was agreement with the results obtained by Van Veen et al. (1985). The shorter turnover time of microbial biomass nitrogen in the sandy soil was beneficial to the availability of nitrogen. As for the clayey soil, the longer turnover time was beneficial to the accumulation and retaining of soil nitrogen. On the other hand, soil with low N_{mic} (No 3) tended to have a higher turnover rate than the high N_{mic} soil (No 7) with a similar texture, suggesting that the soils with low N_{mic} still had relatively high annual fluxes. Therefore, N_{mic} and its turnover rate are important indices of nitrogen availability in red soils.

Table 3 Modelling of ^{15}N decline in microbial biomass and turnover rate of soil microbial biomass-N

Soil No	Decline rate in ^{15}N-labelled N_{mic} ($^{15}N_{mic}$)D and the amount of ^{15}N-labelled N_{mic} synthesized from metabolites ($^{15}N_{mic}$) S (N mg/kg)								First-order equation		Turnover rate[b]		Turnover period
	22 – 29		22 – 44		22 – 58		22 – 75 d						
	($^{15}N_{mic}$)D	($^{15}N_{mic}$)S	($^{15}N_{mic}$)D	($^{15}N_{mic}$)S	($^{15}N_{mic}$)D	($^{15}N_{mic}$)S	($^{15}N_{mic}$)D	($^{15}N_{mic}$)S	$Y_t = Y_0e^{-kt}$	r^2	(k/d)	(k_c/d)	(d)
2	1.43	0.01	6.60	1.67	9.82	1.58	11.52	1.56	$Y_t = 31.8e^{-0.0221t}$	0.99	0.0221		
									($Y_t = 32.9e^{-0.0283t}$)[a]	0.99	0.0283	0.0159	63
3	2.55	0.03	6.56	1.45	9.09	1.87	11.43	2.05	$Y_t = 27.6e^{-0.0164t}$	0.99	0.0164		
									($Y_t = 28.2e^{-0.0218t}$)[a]	0.99	0.0218	0.0112	89
7	1.68	0.03	2.70	0.53	3.78	0.80	5.17	1.24	$Y_t = 24.4e^{-0.0046t}$	0.97	0.0046		
									($Y_t = 25.3e^{-0.0060t}$)[a]	0.99	0.0060	0.0040	250

[a] First-order equation after correction for the amount of ^{15}N-labelled N_{mic} synthesized from metabolites. [b] k, turnover rate constant from first-order equation and k_c, turnover rate constant corrected for substrate treatment.

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