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Calculation of microbial growth efficiency from ^{15}N immobilization

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Abstract. Microbial growth rate was estimated by multiplying ^{15}N immobilization by an estimated microbial C:N ratio. This growth rate, in combination with measurements of respiration, was used to calculate growth efficiency. Growth rates and efficiencies were calculated for grassland and cultivated soils of three textures. Calculated efficiencies (Y_c), assuming a microbial C:N ratio of 7, ranged from 32 to 54. Cultivated soils tended to have higher Y_c values than did grassland soils. This calculation depends on several hard-to-verify assumptions, but yields numbers that should be of great interest in comparative studies.

Introduction

The microbiota plays an essential role in transformations of organic and inorganic substances in ecosystems. Efforts to measure the amount, activity and growth rate of the microbiota have been a major theme in microbial ecology for many years (Jenkinson & Powlson 1976; Anderson & Domsch 1973; Voroney & Paul 1984; Fairbanks et al. 1984). The chloroform fumigation-incubation method (CFIM) has become virtually the standard method for measurement of microbial biomass in soils (Jenkinson & Powlson 1976) and has been used to investigate a wide variety of questions (Kassim et al. 1981; Schimel et al. 1985; Brookes et al. 1986). Concurrently, research has continued on the details of the technique (Shen et al. 1984). A limitation of the CFIM is that it measures the amount of microbial biomass, but microbial activity can only be inferred. A coupled technique for measurement of microbial activity parameters would be useful in studies of organic matter and nutrient cycling; many current soil organic matter models explicitly simulate microbial growth and turnover (Hunt 1977; Van Veen et al. 1984).

I present a method for estimating microbial growth from the uptake of ^{15}N. The method assumes that C is incorporated into growing biomass at a fixed C:N ratio, and in combination with the CFIM procedure can provide estimates of microbial growth rate, and growth efficiency (Y_c). Data to

illustrate the method are taken from Schimel (1986) and Schimel et al. (1985). The experimental procedures are described briefly below.

Methods

Soils were collected from the summit positions of three paired grassland and cultivated toposequences in Southwestern North Dakota (USA) following harvest on the cultivated portions of the study sites. The study sites were located on:

- a coarse-textured sandstone-derived soil,
- a loamy siltstone-derived soil and,
- a fine-textured shale-derived soil,

and are described in detail in Schimel et al. (1985), and Schimel (1986). The soils were from the 0–10 cm depth increment and were very dry at the time of collection. Soils were preincubated for 2 days and then incubated at field capacity and 25 °C in sealed jars, containing alkali traps for determination of CO_2 evolution, following addition of 99% atom percent 10 mg/kg ^{15}N as $(NH_4)_2SO_4$. At day four, the incubations were sampled for CO_2, and inorganic N and ^{15}N as described in Schimel (1986). Microbial biomass C, N and ^{15}N were determined by the CFIM procedure after 12 days moist preincubation, using the equation of Voroney (PhD thesis, University of Saskatchewan, 1983) to calculate K_N. Simultaneous control respiration rates were determined but were not used in the calculation of biomass. ^{15}N determinations were carried out by Isotope Services, Inc. (Los Alamos, New Mexico, USA). This paper presents additional analysis of data presented in full in Schimel (1986).

N immobilization was calculated from isotope dilution using the equations of Kirkham & Bartholomew (1954), assuming insignificant remineralization of added isotope. This assumption appeared to be met for the first four days of incubation (Schimel 1987). Microbial growth, G, was calculated by multiplying the immobilization rate, i (see Table 1), by the expected C:N ratio of the new biomass. The resulting units were mg C/kg. This assumes that the uptake of N (immobilization) is a consequence of microbial growth, and that N demand is stoichiometrically related to carbon metabolism. Microbial growth rates were calculated assuming C:N ratios of 5, 7 and 9. The C:N ratio of the microbial biomass measured by the CFIM procedure did not vary significantly with soil or treatment and averaged 5.8 (Table 2). Values for the expected C:N ratio were chosen to bracket the measured value. Growth efficiency (Y_c) was calculated as $Y_c = G/(G +$

CO_2 evolution) for growth rates calculated assuming the above three microbial C:N ratios (see Table 3). Maintenance respiration from the resting fraction of the population was assumed to be negligible. Metabolites are not included explicitly in this calculation.

Table 1. N mineralization, immobilization, and respiration from three soils (from Schimel 1987).

Site	Treatment	Gross N min.	Net N min.	N immobilization (i)[a]	CO_2 Evolution
		$mg\,N\,kg^{-1}\cdot d^{-1}$			$mg\,C\,kg^{-1}\cdot d^{-1}$
Sandstone	Grass	5.5 ± 0.5	1.4 ± 0.9*	4.1 ± 0.6	43 ± 1.7
	Crop	6.4 ± 0.8	2.6 ± 0.7	3.8 ± 0.2	23 ± 5.4
Siltstone	Grass	6.7 ± 0.2	1.2 ± 0.0	5.5 ± 0.3	64 ± 1.1
	Crop	6.5 ± 1.4	2.9 ± 0.6	3.6 ± 0.8	39 ± 3.7
Shale	Grass	6.4 ± 0.1	1.2 ± 0.9	5.2 ± 1.0	62 ± 1.3
	Crop	6.0 ± 0.1	3.3 ± 0.4	2.7 ± 0.3	27 ± 8.5

* ±SD; [a]see text.

Table 2. CFIM biomass.

Site	Treatment	$CHCl_3$ Microbial biomass C
		$mg\,C\,kg^{-1}$
Sandstone	Grass	954 ± 141
	Crop	606 ± 129
Siltstone	Grass	1559 ± 144
	Crop	631 ± 159
Shale	Grass	1824 ± 58
	Crop	978 ± 131

Table 3. Estimated microbial growth rates and growth efficiencies, assuming three C:N ratios.

Site	Treatment	Estimated microbial growth ($mg\,C\,kg^{-1}\cdot d^{-1}$)			Computed efficiencies (Y_c) (%)		
		C:N = 5	C:N = 7	C:N = 9	C:N = 5	C:N = 7	C:N = 9
Sandstone	Grass	20.8 ± 3.2	29.1 ± 4.4	37.4 ± 5.7	32. ± 3	40 ± 3	46 ± 3
	Crop	19.0 ± 1.1	26.6 ± 1.6	34.2 ± 2.0	45 ± 5	54 ± 5	59 ± 5
Siltstone	Grass	27.5 ± 1.5	38.5 ± 2.1	49.5 ± 2.7	31 ± 1	38 ± 6	44 ± 1
	Crop	17.9 ± 4.1	25.0 ± 5.8	32.2 ± 7.5	39 ± 2	48 ± 2	54 ± 2
Shale	Grass	26.2 ± 5.1	36.7 ± 7.1	47.2 ± 9.2	29 ± 4	36 ± 4	42 ± 4
	Crop	13.5 ± 1.6	19.0 ± 2.2	24.4 ± 2.8	25 ± 1	32 ± 2	38 ± 2

Results

Calculated growth efficiencies range from 29 to 59, depending upon treatment and assumed C:N ratio. These are in accordance with values reported in the literature (reviewed in Payne & Wiebe 1978; and Holland & Coleman 1987). The higher values may reflect active populations following rewetting of the soils. Values calculated assuming a C:N ratio of 7 are in best agreement with the ranges reported in natural systems, and were used in subsequent calculations of active:total ratios. Note that there is a tendency for Y_c values to be higher in cultivated than grassland soils, perhaps reflecting a difference in substrate quality (Schimel 1986).

Calculations presented in this note appear to produce reasonable estimates of several critical parameters governing the behavior of organic matter in soil. These calculations would not be valid if growth was occurring primarily on organic N. The reasonable estimates of Y_c suggest that organic N was not the source of a high proportion of assimilated N. The calculation assumes that immobilization occurs at a fixed C:N ratio, and that the label is uniformly mixed with the N source for growth. It further assumes that maintenance respiration is a small or negligible component of the measured CO_2 flux. Because the results of the computations depend critically on several hard-to-verify assumptions, they should be applied with caution and may be of most value in comparative studies. Knowledge of G and Y_c are critical to modeling soil organic matter dynamics (Chapman & Gray 1986; Hunt & Parton 1986) and the simple model proposed in this note can aid in their determination.

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