ROLE OF MICROBIAL BIOMASS IN SOIL NUTRIENT DYNAMICS ALONG A JHUM CYCLE GRADIENT

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ARUNACHALAM, A. 2003. Role of microbial biomass in soil nutrient dynamics along a jhum cycle gradient. The impact of shifting cultivation (jhum) on soil physico-chemical properties and soil microbial biomass at lowland areas (< 260 m asl) of Arunachal Pradesh, north-east India was investigated by comparing fields under three-, five- and 10-year jhum cycle systems. The pH of the top 0 to 10 cm soil increased after the burn, but gradually decreased during cropping phase. The soil moisture content declined sharply after burning and slowly recovered with time to a level comparable to a mature forest of the locality. C and N concentrations decreased slightly during cropping but recovered with increasing periods of jhum cycling. Microbial biomass C and N were low in soils after burning but increased thereafter. Contribution of microbial biomass to soil organic C was greater in 10-year jhum cycle system while their contribution to total Kjeldahl-N was greater in three-year cycle system. Longer fallow periods favoured greater improvement in humus and some nutrients. A jhum cycle of three to five years, now prevalent in the region, is considered short. Soil nutrient depletion was more in three-year jhum cycle systems.

Key words: Microbial biomass N - shifting cultivation - soil nutrient pool - microbial biomass C

ARUNACHALAM, A. 2003. Peranan biojisim mikrob dalam dinamik nutrien tanih di sepanjang cerun kitaran jhum. Kesan pertanian pindah (jhum) terhadap ciri kimia fizik tanih dan biojisim mikrob tanih di kawasan tanah pamah (< 260 m atas aras laut) di Arunachal Pradesh, timur laut India diselidik dengan membandingkan lapangan yang mempunyai sistem kitaran jhum untuk tiga, lima dan 10 tahun. Kandungan pH tanih pada kedalaman 0 hingga 10 cm meningkat selepas pembakaran, tetapi beransur-ansur berkurangan pada peringkat tebangan. Kandungan lembapan tanih merosot dengan teruk selepas pembakaran dan pulih secara perlahan-lahan ke aras yang setanding dengan hutan matang di kawasan tersebut. Kepekatan C dan N berkurangan sedikit pada masa tebangan tetapi pulih setelah tempoh kitaran jhum meningkat. Kandungan C dan N biojisim mikrob adalah rendah dalam tanih selepas pembakaran tetapi meningkat selepas itu. Sumbangan biojisim mikrob terhadap C organik tanih adalah lebih banyak dalam sistem kitaran jhum 10 tahun manakala sumbangan terhadap jumlah N-Kjeldahl adalah lebih besar dalam sistem tiga tahun. Lebih panjang tempoh tanah terbiar, lebih banyak kandungan humus dan beberapa nutrien. Kitaran jhum antara tiga hingga lima tahun, kini tersebar luas di seluruh kawasan tersebut, dianggap tempoh yang pendek. Kehilangan nutrien tanih lebih banyak berlaku dalam sistem kitaran jhum tiga tahun.

Introduction

Shifting cultivation (swidden agriculture, slash-and-burn agriculture, or locally known as "jhum") is an aimless, unplanned, nomadic movement or an abrupt change in location, which may refer to the cropping areas, the agriculturist or both (Conklin 1957). Jhum has been an indispensable practice for more than 455 000 people in the rugged and inaccessible mountainous environment in the humid tropics of Arunachal Pradesh, India (Anonymous 1971). The jhum system has converted several hectares of forest land to secondary successional communities like fallow land (abandoned crop land), grassland and secondary forests, and has caused loss of species diversity. In Arunachal Pradesh, low available nutrient reserves are the most widespread soil constraints for plant growth (Sanchez 1989). These chemical constraints could be overcome by application of organic or inorganic fertilisers, or by crop rotation and agroforestry. However, the physical constraints (e.g. excessive rainfall) are more difficult to manage as the slash-and-burn agriculture is practised on slopy areas. The availability of nutrients in the soil is further regulated by the type of cropping or vegetation, which also determines the form of organic residues. These organic residues (litter, roots) are decomposed by soil microorganisms to release nutrients. However, the microbial population may take up certain amount of nutrients (i.e. immobilisation) which are then released during mineralisation processes (Maithani *et al.* 1996). Microorganisms act as a "sink" and "source" of available nutrients for plants (Singh *et al.* 1991).

The present study was undertaken to understand the role of microbial biomass in soil nutrient dynamics in fields along a jhum cycle gradient and its relation to soil physico-chemical characteristics. Different jhum cycles aged three to 10 years old were studied and compared with a forest stand.

Materials and methods

Study area

The study area is situated 15 km south of Itanagar, Arunachal Pradesh (latitudes 26° 28' to 29° 30' N, longitudes 91° 31' to 97° 30' E, altitude 260 m asl), north-east India. The study sites (jhum fields and forest) are located in the humid tropical forest belt dominated by tree species like *Mesua ferrea, Terminalia myriocarpa* and *Anthocephalous cadamba.* The ground vegetation is dense and the dominant species growing in the jhum fallows include *Lantana camara,* ragi (*Eluesine coracona*), maize (*Zea mays*), tapioca (*Manihot esculenta*), ginger (*Zingiber officinale*), banana (*Musa sapientum*) and pumpkin (*Cucurbita maxima*). Climate of the area is dominated by four distinct seasons, namely, spring (mid February to mid April), rainy (mid April to September), autumn (October to November) and winter (December to mid February). The average annual maximum and minimum air temperatures are 31.8 and 21.6 °C respectively. Mean annual precipitation of the area is 1800 mm in unimodal distribution resulting in a single cropping season (mid April to

September) per year. All the study sites are located on a slopy area (6° to 13° N). Soils in the locality are formed from the Precambrian quartzite rocks belonging to Shela group.

Three jhum fields, where first year cropping was done after three, five and 10 years of fallow period, were selected for detailed study. Care was taken to locate sites on the same slope. These sites were distributed within 0.5 km distance from one another. In the month of December 1997, these sites were slashed and the residues were allowed to dry up. The slashed material was burned in end February 1999. The fire continued for 24 to 38 hours depending on the availability of slash. Partially burned logs and large branches were subsequently removed manually but stumps remained on the site. Lowland rice was planted with a dibble three to four weeks after burning. Along with paddy, other food species like ragi, maize, potato, brinjal, tomato and *Amaranthus* spp., eight to 12 species altogether, were planted to meet the requirements of a shifting cultivator. In order to compare the experimental outcome, a mature 27-year-old moist deciduous forest plot (1.2 ha) was selected and was treated as control.

Analytical procedures

Five plots (7 × 7 m) for each of the fields under three-, five- and 10-year jhum cycles and for the forest stand were marked for this study. At each sampling date (i.e. 1, 30, 60 and 120 days after burning), five randomly located soil cores (6.5 cm diameter, 0 to 10 cm deep) were obtained from each plot and bulked. The composite samples were then sieved through 2-mm mesh screen and used for all analyses. Soil moisture content was determined gravimetrically by oven-drying 10 g fresh soil for 24 hours at 105 °C. The texture of the soil was determined using a hydrometer, while soil organic C and total Kjeldahl-N (of air-dried and finely ground soil samples) were determined using rapid titration and semi-micro Kjeldahl digestion and distillation procedures following Allen *et al.* (1974) and Anderson and Ingram (1993) respectively. Soil pH was measured in a 1:2.5 fresh soil: water suspension.

Microbial C was estimated in fresh soil by chloroform-fumigation incubation method (Jenkinson & Powlson 1976) with modifications suggested by Srivastava and Singh (1988). The soils were preincubated for seven days at room temperature to allow microbial activity to settle. Field moist soil samples (100 g) were fumigated with alcohol-free liquid chloroform for 24 hours and, to remove the chloroform vapour, a vacuum pump was used. The soil samples were then adjusted to 60% of water holding capacity (WHC) and transferred to rectangular glass jars, each with two beakers, one containing 20 ml deionised water to prevent soil drying during incubation and the other, 50 ml of 1 N NaOH. Unfumigated soil (1 g) was then added into each jar, after which the jars were sealed and incubated at 25 ± 1°C for 10 days. After 10 days, the residual alkali was titrated against 1 N HCl in order to determine the amount of CO_2 that evolved in the fumigated soil samples. The same soil was further incubated for the another 10 days. The titrated values for this second incubation were treated as controls (Merckx *et al.* 1985). The C-flush

was calculated as the difference between the values obtained from fumigated and unfumigated soil samples (Maithani *et al.* 1996). The microbial carbon was calculated as C-flush/0.45 (Anderson & Ingram 1993).

Microbial N was determined using chloroform-fumigation extraction technique (Brookes *et al.* 1985). Fresh soil samples (100 g) were put into 500 ml conical flasks and mixed thoroughly with 1 ml alcohol-free chloroform before incubation at 25 ± 1 °C for 24 hours. For the same period, a set of unfumigated soil samples were also incubated. Following this, chloroform vapour from the fumigated samples was removed using a vacuum pump. Both fumigated and unfumigated samples were then extracted in 0.5 N K_2SO_4. The solutions obtained were made up to 50 ml and distilled in semi-micro Kjeldahl distillation system and titrated against N/140 HCl using boric acid indicator to determine the amount of ammonia gas evolved. The microbial N was calculated following Brookes *et al.* (1985):

Microbial N = Fumigated values – unfumigated values/0.54

Statistics

The data collected from each of the three sites were analysed using ANOVA (fixed effects model) to test whether variations due to different time periods and sites were significant. Tukey's test was carried out to compare the mean values of microbial C and N between stands. The percentage data of microbial C and N were transformed using arc sin transformation (Zar 1974) and then subjected to Tukey's test at probability level $p < 0.05$. Correlation analyses were used to study the relationship between microbial C and N and between microbial biomass and some edaphic variables.

Results

Physical and chemical properties of soil

The soil was sandy loam at all sites. Bulk density of the soil at 0 to 10 cm depth was 1.09, 1.12 and 1.02 g cm^{-3} under three-, five- and 10-year jhum cycles respectively and 1.27 g cm^{-3} in the forest (Table 1). Soil pH declined with time after burning under all three jhum cycles. WHC increased significantly ($p < 0.05$) from 33.29% in the three-year jhum cycle system to 41.32% in the 10-year cycle system and it was 47.93% in mature forest soil. Soil organic matter was generally high in the study sites (3.65 to 8.78%) with minimum value at 120 days after burning in three-year jhum cycle system and maximum in the soil immediately analysed after burning in 10-year-old jhum cycle system. The variation between the latter and the mature forest was significant ($F = 22.16$, $p < 0.01$). Similar trend was observed in total Kjeldahl-N. Consequently, the C/N ratio increased from 8.8 in three-year jhum cycle system to 10.5 and 10.8 in 10-year-jhum cycle system and mature forest respectively (Table 1).

Table 1 Soil physico-chemical properties of the study sites (0–10 cm soil)

Ecosystem (jhum cycle period)	Days after burning	WHC (%)	BD (g cm^{-3})	Textural class	pH	SMC (%)	SOC (%)	SOM (%)	TKN (%)	C/N
Jhum field	1	33.29	1.09	SL	6.6	28.3	2.39	4.12	0.31	7.71
(3-year cycle)	30				6.2	30.3	2.39	4.12	0.29	8.24
	60				5.9	31.7	2.29	3.95	0.27	8.48
	120				5.4	34.3	2.12	3.65	0.20	10.60
	Mean				6.0	31.2	2.29	3.96	0.27	8.78
Jhum field	1	34.17	1.12	SL	6.3	26.9	3.21	5.38	0.39	8.23
(5-year cycle)	30				5.9	28.3	3.19	5.50	0.27	11.81
	60				5.9	33.9	2.93	5.05	0.23	10.39
	120				6.0	37.1	3.01	5.19	0.32	9.41
	Mean				6.0	31.6	3.09	5.28	0.30	9.96
Jhum field	1	41.32	1.02	SL	5.7	26.1	4.69	8.09	0.43	10.91
(10-year cycle)	30				5.2	32.1	3.84	6.62	0.32	12.00
	60				5.0	32.9	3.72	6.41	0.41	9.07
	120				5.0	37.8	4.03	6.95	0.41	9.83
	Mean				5.2	32.2	4.07	7.02	0.39	10.45
Forest (control)	-	47.93	1.27	SL	5.3	37.3	5.09	8.78	0.47	10.83

WHC - water holding capacity, BD - bulk density, SMC - Soil moisture content, SOC - soil organic carbon, SOM - soil organic matter, TKN - total Kjeldhal nitrogen, SL - sandy loam

Values are the means of five replicated analyses (n = 5).

Microbial C and N

Microbial biomass C was lowest (933 μg g^{-1}, 30 days after burning) in three-year jhum cycle system and highest (1240 μg g^{-1}, 120 days after burning) in five-year jhum cycle system (Table 2). The variation between the latter and forest (1288 μg g^{-1}) was not significant ($F = 1.82$, $p < 0.5$). Microbial biomass N was high under 10-year jhum cycle (82 to 123 μg g^{-1}) and low under three-year jhum cycle (45 to 72 μg g^{-1}). Nevertheless, microbial C and N decreased significantly ($F = 18.93$, $p < 0.01$) on the 30th day after burning, after which it again increased steadily until the 120th day. Microbial N was, however, significantly lower in the forest ($F = 8.09$, $p < 0.05$) compared with that under 10-year jhum cycle. The ratio of microbial C to N ranged from 15 to 21, 14 to 17 and 10 to 12 in three, five- and 10-year jhum cycle systems respectively, while it was 14.3 in the forest soil. The proportion of microbial C to soil organic C increased with longer jhum cycle and was highest (3.95%) in the forest soil. The ratio was generally greater 30 days after burning irrespective of the jhum cycle period. Similarly, the ratio of microbial N to total Kjeldhal-N averaged 4.71, 4.24 and 3.83% under three-, five- and 10-year jhum cycles respectively, and was 5.21% in the forest soil (Table 2).

Microbial C and N was negatively correlated to soil pH, whereas they were positively correlated with WHC, soil organic C and total Kjeldahl-N (Table 3). Based on "r" values, it was concluded that soil organic C and total Kjeldahl-N were related to microbial C and N.

Table 2 Microbial carbon (MBC) and nitrogen (MBN) after burning in jhum fields and in forest

Ecosystem (jhum cycle period)	Days after burning	MBC ($\mu g\ g^{-1}$)	MBN ($\mu g\ g^{-1}$)	MBC/MBN	Contribution of MBC to SOC (%)	Contribution of MBN to TKN (%)
Jhum field	1	1101.32	72.31	15.23	2.17	4.29
(3-year cycle)	30	932.91	44.73	20.86	2.56	6.48
	60	971.22	56.97	17.05	2.36	4.74
	120	1009.31	60.32	16.73	2.10	3.32
	Mean	1003.69	58.58	17.47	2.29	4.71
Jhum field	1	1191.17	80.20	14.85	2.69	4.86
(5-year cycle)	30	1011.23	60.13	16.82	3.15	4.49
	60	987.31	71.99	13.71	2.97	3.19
	120	1239.73	72.31	17.14	2.43	4.43
	Mean	1107.39	71.16	15.63	2.81	4.24
Jhum field	1	1239.43	123.31	10.05	3.78	3.49
(10-year cycle)	30	981.32	81.97	11.97	3.91	3.90
	60	1109.32	91.33	12.15	3.35	4.49
	120	1143.99	119.86	9.54	3.52	3.42
	Mean	1118.52	104.12	10.93	3.64	3.83
Forest (control)	-	1287.64	90.20	14.28	3.95	5.21

1–60 days covered summer; 61–120 days fell under rainy season
Values are means of five replicated analyses (n = 5).
SOC = soil organic carbon, TKN = total Kjeldhal nitrogen

Table 3 Relationships between soil physico-chemical properties and microbial carbon (MBC) and nitrogen (MBN)

Relationship	Equation	r	p
Soil pH × MBC	Y = 6.08 – 0.0005X	-0.66	0.002
SOC × MBC	Y = 2.21 + 0.001X	0.79	0.001
TKN × MBC	Y = 0.26 + 0.0001X	0.71	0.001
WHC × MBC	Y = 32.61 + 0.008X	0.64	0.002
Soil pH × MBN	Y = 6.10 – 0.007X	-0.76	0.001
SOC × MBN	Y = 2.09 + 0.026X	0.95	0.001
TKN × MBN	Y = 0.25 + 1.89X	0.90	0.001
WHC × MBN	Y = 32.18 + 0.13X	0.88	0.001

n = 20, df =18
SOC = soil organic carbon, TKN = total Kjeldhal nitrogen, WCH = water holding capacity

Discussion

Temporal variation in soil properties

Physico-chemical properties of soil underwent several changes subsequent to burning in all three sites under the three different jhum cycle periods. This might have resulted from micro-environmental changes due to increased insulation and temperature and subsequent changes in soil moisture and atmospheric air humidity.

For example, the slight reduction in soil moisture immediately after burning was attributed to destruction of foliage and litter layer from the soil surface which resulted in exposure of mineral soil to direct sunlight and infiltration. Consequently, soil water storage capacity was immediately reduced owing to greater evaporation. Soil water status in burned areas appeared less favourable for plant growth than in the unburned areas. However, with greater accumulation of detrital matter with increasing jhum cycle period, a gradual increase in WHC and SMC was observed. The soil was acidic but declined with time after burning. Lower pH may be attributed to the increase in basic cations released after burning (Arunachalam *et al.* 1994). Nevertheless, the changes in soil pH is usually temporary and depends upon the amount of ash released, original soil pH, chemical composition of the ash, soil texture and mean annual rainfall.

The increase in soil organic matter with increasing jhum cycle period may be attributed to the greater production and accumulation of litter and fine roots. In this context, Ramakrishnan and Toky (1981) reported that after an initial period of depletion of organic matter during cultivation, there is a period of recovery of humus in the soil derived from the slash of harvested crops and weeds. The greater organic carbon content immediately after burning could be due to accumulation of ash in the surface of the soil. The increase in total Kjeldhal-N with the increase in jhum cycle period was attributed to the similar reason. Eventually, the C/N ratios of 9.96 and 10.45 in the five- and 10-year jhum cycle systems respectively indicate the fertile nature of soil compared with that under the three-year jhum cycle (8.78).

Dynamics of microbial C and N

The values of microbial biomass carbon obtained in the present study (1004 to 1119 $\mu g\ g^{-1}$) are within the reported range (61 to 2000 $\mu g\ g^{-1}$) for tropical and temperate forest soils (Vance *et al.* 1987, Henrot & Robertson 1994). However, the values are relatively higher than the range (334 to 1088 $\mu g\ g^{-1}$) recorded for forest stands regrowing after tree cutting in the humid subtropics of north-east India (Maithani *et al.* 1996). Holland (1995) reported that microbial C under systems without tillage in Georgia, USA was 447 $\mu g\ g^{-1}$. The shifting cultivation systems in our study too had no tillage but the microbial C contents were much higher. This could be explained by the different climatic regime of the systems; the former was a plain land agriculture in a temperate country. The values obtained for microbial biomass nitrogen are within the reported values (52 to 125 $\mu g\ g^{-1}$) of coniferous forest soils (Martikainen & Palojarvi 1990) and of evergreen forests (42–242 $\mu g\ g^{-1}$), but lower than those (132 to 240 $\mu g\ g^{-1}$) of a moist deciduous forest (Diaz-Ravina *et al.* 1988). The values in our study are, however, comparable to that of a regrowing subtropical humid forest (58 to 124 $\mu g\ g^{-1}$) in this part of the country (Maithani *et al.* 1996). Greater microbial biomass C and N values were recorded in soils under 10-year jhum cycle system. Relatively, dense growth of plants and greater accumulation of detrital matter (litter and fine roots) during fallow period of the 10-year jhum cycle system could have considerably increased

the levels of organic matter and nutrients in the soil. Shortening of jhum cycle (e.g. as in three-year jhum cycle system) resulted in least accumulation of detrital matter that may affect the growth of microbial population, leading to low microbial C and N (Table 2). Both microbial C and N were highest just one day after burning in all the three jhum systems. This was attributed to the burning, by which large amounts of nutrients from the microbes were released. Similar results have been reported earlier (Arunachalam *et al.* 1994).

Seasonally, the study of microbial biomass covered only two seasons in an annual cycle, namely, summer (up to 60 days after burning) and rainy (61 to 120 days after burning) seasons. Peak values of microbial biomass during summer could be due to greater nutrient retention (i.e. immobilisation) in soil microbial biomass. Greater demand for nutrients by plants during rainy season, when majority of the plants are at their peak vegetative growth, limits the availability of nutrients to soil microbes, thereby reducing immobilisation in microbial biomass (Sarathchandra *et al.* 1984, Singh *et al.* 1991).

A significant positive correlation between microbial C and N ($Y = 57.11 + 0.029X$, $r = 0.794$, $df = 18$, $p < 0.001$) indicates that the dynamics of these two elements were closely interlinked in soils under shifting cultivation. As a result of this, both microbial C and N showed gradual build-ups in the soil with prolonging jhum cycle. This is in contrast with the findings of Fenn *et al.* (1993) who reported an insignificant increase in soil biomass along a fire-induced chaparral chronosequence in San Diego County, California. Significant positive correlations between microbial N and total soil N (Table 3) indicate a close relationship between microbial biomass and the status of soil nutrient pool. Thus, microbial biomass are qualitative indicators of soil fertility. They are the main labile fractions of soil organic matter and act both as sink and source of plant available nutrients. Though microbial N values are comparable to other studies, the greater level of carbon in the soil biomass increased the ratio of microbial C to N (10.9 to 17.5). Interestingly, the ratio increased with the shortening of jhum cycle period. This could be due to the fact that full restoration of nitrogen level after forest clearing and/or burning takes more time. Also lower levels of N and its mineralisation rate in the soil cause insufficient detrital matter accumulation and population of microbes. Substantiating this, the microbial biomass was low under three-year jhum cycle where the contribution to soil organic C was the least (2.3%) compared with the other sites, while the contribution to soil total Kjeldhal-N was highest (4.7%). The percentages for contribution of microbial biomass to soil organic C varied between 2.3 and 3.6 in the jhum fields, while that to total Kjeldhal-N varied between 3.8 and 4.7%, which are well within the reported range (1.5 to 5.3%) for tropical soils (Theng *et al.* 1989, Luizao *et al.* 1992). The percentages for contribution of microbial C to soil organic C were 0.73 to 1.74% in soil of forest regrowths of three different ages (seven, 13 and 16 years old) in this part of the country (Maithani *et al.* 1996), which are very low compared with the values observed in the jhum fields. Similarly, contribution of microbial N to total Kjeldhal-N (3.84–5.21%) in this study is higher than the range (2 to 6%) reported for agricultural soils (Brookes *et al.* 1985).

It is concluded that soil nutrient level was depleted due to shortening of jhum cycle as evidenced by low levels of organic matter and nitrogen under three-year jhum cycle system compared with five- and 10-year sites. The significant positive correlations between soil C and microbial C, and soil N and microbial N (Table 3) clearly indicate that the microbes were useful indicators of organic matter and nitrogen turnover in agricultural fields.

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