Biol Fertil Soils (1993) 16:275–281

Biology and Fertility of Soils

Effect of residue placement and chemical fertilizer on soil microbial biomass under tropical dryland cultivation

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Received: 14 December 1992

Abstract. Four treatments (control, chemical fertilizer, wheat straw, and wheat straw + fertilizer) were established on the dryland experimental farm of the Institute of Agricultural Sciences, Banaras Hindu University. Organic C in the different treatments ranged from 0.69 to 0.93%, total N from 0.08 to 0.11%, and total P from 0.018 to 0.021. The application of straw significantly increased the soil water-holding capacity. The maximum effect on the microbial biomass was realized with the straw + fertilizer treatment, followed by straw and then by the fertilizer treatment. During the study microbial biomass C ranged from 144 to 491 $\mu g\, g^{-1}$ dry soil, biomass N from 14.6 to 50.1 $\mu g\, g^{-1}$, and biomass P from 7.2 to 17.6 $\mu g\, g^{-1}$ soil. Microbial biomass C, N and P represented 3.2–4.6% of total C, 2.6–3.8% of total N, and 5.8–8.2% of total P in the soil, respectively, in all cases the highest proportion occurred in the straw + fertilizer treatment and the lowest in the control. Microbial biomass C, N, and P were positively correlated with each other. Microbial biomass C and N increased by 77% in straw + fertilizer-treated plots relative to the control. The increase in microbial biomass P in the straw + fertilizer treatment over the control was 81%. The increase in the microbial biomass is expected to enhance nutrient availability in the soil, as the microbial biomass acts both as a sink and a source of plant nutrients.

Key words: Nutrient dynamics – Dryland agriculture – Reduced tillage – Microbial biomass – Straw application – Fertilization

Soil organisms are the driving force behind nutrient transformations and thus make an essential contribution to soil fertility and ecosystem functioning (Smith and Paul 1990). The soil microbial biomass has a double function in the soil. Firstly, it may act as the agent of transformation, through which pass all the natural organic material that enter the soil. Secondly, the biomass functions as a dynamic pool containing appreciable reserves of N, P, and S (Jenkinson and Ladd 1981). Therefore, changes in the size of the biomass affect the cycling of N and P and their availability to plants (Saffigna et al. 1989). The microbial biomass can also be used as an index for predicting long-term effects of changes in ecosystem conditions (Powlson and Jenkinson 1981). Knowldege of these trends is important because of their implications for the availability of plant nutrients in soil (Saffigna et al. 1989).

Management of the microbial community through residue placement has great potential for the management of the organic matter and nutrients in agroecosystems, especially under dryland conditions. The incorporation of residues into soil creates a favourable environment for microbial activity in soil and increases the microbial biomass. Organic substances supplied to the soil via residues and waste from animals and plant production are used as an energy and nutrient source for microorganisms (Rauhe 1987). In dryland farming systems soil moisture can be conserved through reduced tillage. However, limitations in nutrients and decomposable organic matter can only be overcome by exogenous supplies of plant residue and chemical fertilizers. Information on variations in microbial biomass due to mangement practices is, however, scarce in dryland farming systems in the tropics.

The present study was carried out in a tropical dryland agro-ecosystem to assess the effects of straw and fertilizer inputs, alone and in combination, as (1) microbial biomass C, N, and P levels, and (2) changes in the proportions of microbial biomass C, N, and P in the soil. The interrelationships among microbial C, N, and P were also examined.

Materials and methods

Study site

The experiments were conducted on the dryland farm of the Institute of Agricultural Sciences, Banaras Hindu University at Varanasi. This farm (25°18′N, 80°1′E, 76 m above mean sea level) is on the Gangetic

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plains. The region has a tropical moist subhumid climate with a typical monsoonal character. The year is divisible into a cold winter (November–February), a hot summer (April–June), and a warm rainy season (July–September). October and March are transitional months between the rainy and winter seasons, and between the winter and summer seasons, respectively. The summer is dry and hot, with temperatures ranging between 30 and 45 °C during the day. May is the hottest month, with an average maximum temperature of more than 40 °C. Warm conditions (24–36 °C) and a high relative humidity (70–95%) prevail during the rainy season. During the winter season, temperatures fall to 10–25 °C and January is the coldest month of the year. The annual rainfall averages 1100 mm, 85% of which occurs during the rainy season from the SW monsoon. July and August are the rainiest months. About 55 rainy days occur in the annual cycle, and there is an extended dry period of about 9 months (Fig. 1).

The Inceptisol soil of the study area is deep, flat alluvial, pale brown, silty loam, and has a neutral reaction (Table 1). In general, the soil is well drained, moderately fertile, low in available N, and medium in available P and exchangeable K. This soil has been characterized as Banaras Type III by Agarwal and Mehrotra (1952).

Experimental design and treatments

The experiment was designed to vary the quality of nutrient input in soils by using wheat (*Triticum aestivum*) straw and chemical fertilizer, singly and in combination. The fertilizer was a rapid nutrient-delivery, high-quality resource and the straw was a slow nutrient-releasing, poor quality resource (Swift 1987); therefore straw+fertilizer represented a medium quality resource. Four treatments with three replicates were established in a randomized block design as (1) control; (2) chemical fertilizer (urea, superphosphate, and muriate of potash to give 80 kg N ha^{-1}, 40 kg P ha^{-1}, and 30 kg K ha^{-1}, respectively; (3) wheat straw (2 kg m^{-2}) with the amount of N equivalent to that under treatment 2; and (4) wheat straw+fertilizer (straw at 1 kg m^{-2}+fertilizer at 50% of treatment 2). The percentage chemical composition of the wheat straw applied was (mean±SE) 37.8±1.3 C, 0.48±0.02 N, 0.09±0.05 P, 0.14±0.01 Ca, 0.95±0.04 K, 0.12±0.01 Na, with a C:N ratio of 75.5±1.7 (Singh 1992).

Applications of fertilizer, straw, and straw+fertilizer were made once each year before the rainy season, initially on 24 June 1990 and then again on 30 June 1991. The wheat straw was lightly incorporated into the soil whereas the fertilizer was surface-applied. There was no fertilizer application in the winter crop period. Beginning June 1990, the crop sequence studied was fallow (June–October), lentils (*Lens esculenta* var. Pant 209; 8 November to 13 March), summer fallow (March–June), rice (*Oryza sativa* var. Akashi; 17 July to 26 October), lentils (20 November to 17 March).

The plots were 5 m×4.2 m in size, with a 0.5-m strip separating each treatment block. Minimum tillage was practised after the start of the experiment. Analysis of variance was used to test the effects of the four treatments on the data recorded. The four treatments were regarded as distinct (non-factorial) strategies. Treatment means were compared using the least significant difference procedure at the 5% level of significance. All statistical analyses were done by using the SPSS/PC+ program for microcomputers (Statistical Package for the Social Sciences 1986).

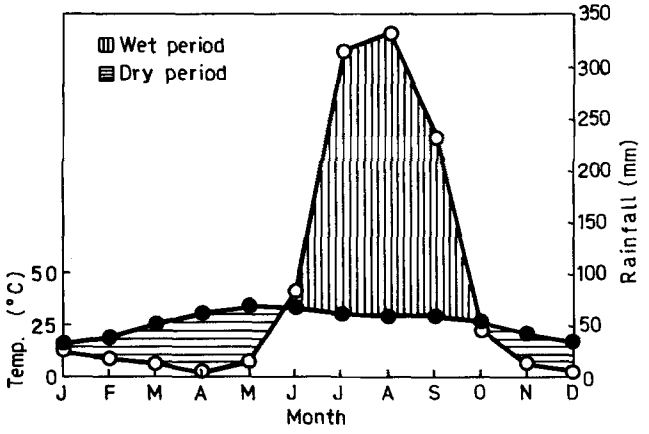

Fig. 1. Ombrothermic diagram for the study area. *Solid circles* represent monthly mean temperature (*Temp.*) and *open circles* rainfall

Soil characterization

Physicochemical characteristics of the soil (0–10 cm depth) were evaluated at the end of the experiment. Particle-size analysis was done by using sieves of different mesh sizes and a Bouyocucos hydrometer (Anderson and Ingram 1989). Bulk density was determined by using a soil corer and measuring the weight of dry soil per volume unit to a depth of 10 cm. Soil pH was measured by using a glass electrode (1:2; soil:water ratio) and water-holding capacity by perforated circular brass boxes (Piper 1944). Organic C in the soil was analyzed by dichromate oxidation and titration with ferrous ammonium sulphate (Walkley 1947). The soil was digested in a triple acid mixture of $HClO_4$, HNO_3, and H_2SO_4 (1:5:1), and the digest was analysed for P by a phosphomolybdic acid blue colour method (Jackson 1958). Total Na and K were measured by using a flame photometer (Systronics Modiflame 127) and Ca by a Perkin-Elmer (373 AAS) atomic absorption spectrophotometer (Allen et al. 1976).

Soil collection and processing for microbial biomass analysis

Microbial biomass was evaluated twice for each crop, once during the seedling stage and again during the grain formation stage. Two soil samples (0–10 cm depth) were collected from each replicate plot and composited. The soil was sieved through a 2-mm mesh screen after visible plant debris and fauna had been removed. Samples from different replicate plots were analysed separately.

The soil pre-incubated before measuring microbial biomass C. It was spread overnight in a thin layer between two sheets of polyethylene, with the moisture content adjusted to 40% water-holding capacity, then transferred to polyethylene bags and incubated for 7 days at 25 °C in a large airtight container that held two vials, one containing 20 ml distilled water to maintain 100% relative humidity, and the other containing soda lime to absorb CO_2. The container was aerated every day be opening the lid for few minutes. After 1 week, the soil was taken out, mixed, and analysed for soil microbial biomass C, N, and P by fumigation–extraction methods (Brookes et al. 1982, 1985; Vance et al. 1987). Preconditioned soil samples (50 g) were saturated with purified liquid $CHCl_3$ for 10–20 h (Srivastava and Singh 1988). The $CHCl_3$ was subsequently removed by evacuation and then the soil was extracted with 0.5 MK_2SO_4 (1:4, soil:extractant) for 30 min for the biomass C and N estimates. For biomass P, another soil sample was extracted with 0.5 $MNaHCO_3$ for 30 min. Extracts of unfumigated preconditioned soil samples were also obtained.

Microbial biomass determination

Organic C was determined in the soil extracts of fumigated and unfumigated samples by dichromate digestion as described in Vance et al. (1987). Biomass C (MB-C) was then estimated from the equation: MB-C = 2.64 Ec (Vance et al. 1987), where Ec is the difference between C extracted from the fumigated and non-fumigated soils, both expressed as μg C g^{-1} oven dry soil (Jenkinson 1988).

On the same K_2SO_4 soil extracts used for the biomass C determination, biomass N was determined as total N using the Kjeldahl digestion procedure (Brookes et al. 1985). The flush of total N (K_2SO_4-extractable N in unfumigated soil subtracted from that of fumigated soil) was divided by a k_N (fraction of biomass N extracted after $CHCl_3$ fumigation) value of 0.54 (Brookes et al. 1985; Srivastava et al. 1989).

Biomass P was determined as inorganic P in the $NaHCO_3$ extracts of fumigated and unfumigated soils determined by an ammonium-molybdate–stannous chloride method (Olsen et al. 1954; Sparling et al. 1985). Biomass P was calculated by dividing the flush of inorganic P

($NaHCO_3$-inorganic P in fumigated soil minus that in the unfumigated soil) by a k_P value of 0.40, assuming that 40% of P in the soil microbial biomass is released as inorganic P by $CHCl_3$ (Brookes et al. 1982). Biomass P was corrected for P fixation by measuring the recovery of exogenously added inorganic P as KH_2PO_4 (equivalent to 20 mg P g^{-1} soil) as suggested by Brookes et al. (1982).

Results

The physicochemical properties of the control and treated soils are reported in Table 1. The soil texture was silty loam, with bulk density ranging from 1.31 to 1.35 g cm^{-3}. Organic C, total N, and total P ranged from 0.69 to 0.93%, 0.08 to 0.11%, and 0.018 to 0.021%, respectively. The application of straw significantly increased the water-holding capacity of the soil. Most of the nutrients exhibited an increasing trend in pool size which might lead ot increased nutrient supplies in the soil in the long-term.

The treatments in the present study resulted in similar response patterns for biomass C, N, and P, although there were significant differences with time (Figs. 2, 3, 4). There was a wide seasonal variation in the microbial biomass C, N, and P values. The maximum effect on inputs on the microbial biomass was realized under the straw+fertilizer treatment, followed by straw, and then by the fertilizer treatment. During the study, biomass C ranged from 194 to 279 μg g^{-1} dry soil for the control, from 183 to 460 for the fertilizer, from 258 to 466 for the straw, and from 267 to 491 μg g^{-1} for the straw+fertilizer treatment (Fig. 2).

Biomass N ranged from 19.6 to 28.3, from 14.6 to 35.7, from 32.0 to 39.4, and from 33.4 to 50.1 μg g^{-1} soil in the control, fertilizer-, straw- and straw+fertilizer-treated plots, respectively (Fig. 3).

Biomass P also reached a maximum in the straw+fertilizer treatment. It ranged from 7.2 to 12.9, from 7.3 to 13.7, from 11.7 to 15.2, and from 11.7 to 17.6 μg g^{-1} soil for the control, fertilizer-, and straw- and straw+fertilizer-treated plots, respectively (Fig. 4).

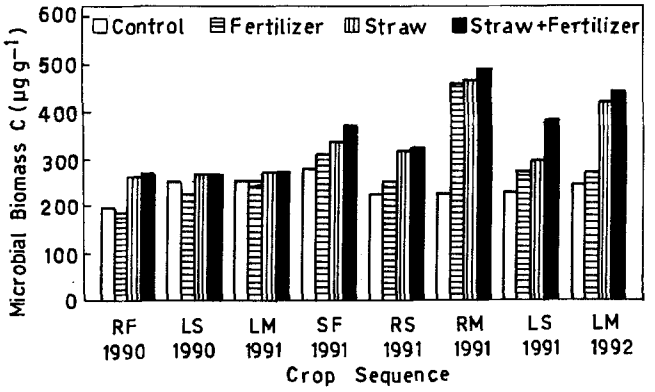

Fig. 2. Response by soil microbial biomass C (μg g^{-1} dry soil) to straw and/or fertilizer application during different crop and fallow periods; *RF*, rainy fallow; *LI*, lentil seedling stage; *LM*, Lentil grain formation stage; *SF*, summer fallow; *RI*, rice seedling stage; *RM*, rice grain formation stage

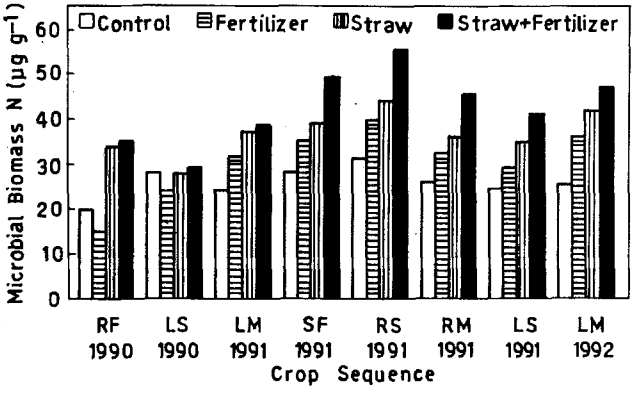

Fig. 3. Variations in soil microbial biomass N (μg g^{-1} dry soil) during different crop and fallow periods following different treatments. For abbreviations of crop sequences, see Fig. 2

Immediately after the beginning of the experiment in the rainy season fallow, the application of straw significantly increased biomass C, N, and P during 1990 (Table 2). Although the application of fertilizer slightly

Table 1. Effect of fertilizer and straw incorporation on soil physicochemical properties, 22 months after treatment

Soil property	Control	Fertilizer	Straw	Straw + fertilizer	LSD
Soil texture					
Sand (%)	31.7 ± 0.9	33.7 ± 0.3	31.0 ± 0.6	32.3 ± 0.3	1.9
Silt (%7	64.8 ± 0.8	63.2 ± 0.4	65.1 ± 0.4	64.9 ± 0.4	1.3
Clay (%)	3.5 ± 0.3	3.2 ± 0.2	3.9 ± 0.5	2.8 ± 0.1	0.9
pH (H_2O)	6.76 ± 0.05	6.89 ± 0.03	7.03 ± 0.04	6.8 ± 0.03	0.14
Bulk density (g cm^{-3})	1.35 ± 0.01	1.40 ± 0.02	1.32 ± 0.07	1.31 ± 0.03	0.13
WHC (%)	40.5 ± 0.3	41.2 ± 0.2	42.8 ± 0.4	41.6 ± 0.7	1.5
Organic C (%)	0.77 ± 0.05	0.69 ± 0.02	0.93 ± 0.09	0.77 ± 0.08	0.22
Total N (%)	0.10 ± 0.01	0.08 ± 0.01	0.11 ± 0.02	0.11 ± 0.01	0.04
C:N ratio	7.7 ± 0.7	8.7 ± 1.0	9.1 ± 0.9	7.5 ± 1.0	3.0
Total P (μg g^{-1})	177 ± 6	194 ± 4	181 ± 4	188 ± 7	17
K (μg g^{-1})	7547 ± 125	7791 ± 167	8012 ± 152	7614 ± 167	1176
Na (μg g^{-1})	717 ± 12	836 ± 24	810 ± 14	830 ± 25	130
Ca (μg g^{-1})	1147 ± 63	1271 ± 33	1253 ± 20	1160 ± 29	131

Means ± SE, $n = 3$ replicates. LSD, Least significant difference ($P < 0.05$); WHC, water-holding capacity

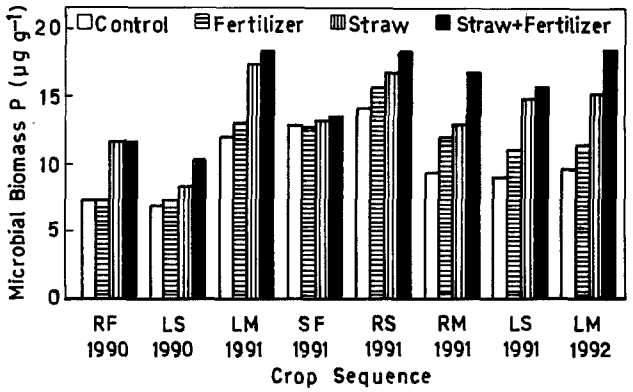

Fig. 4. Response by microbial biomass P ($\mu g\, g^{-1}$ dry soil) during different crop and fallow periods following input of straw and/or fertilizer. For abbreviations of crop sequences, see Fig. 2

reduced microbial biomass C and N during the initial rainy fallow, differences from the control were not significant. During the lentil crop period, differences in biomass C due to the straw and straw + fertilizer applications were not statistically significant from the control. During the summer fallow biomass C and N values were significantly higher in the residue-treated plots than in the control. After the second straw and fertilizer application in June 1991, the most prominent effects on biomass C and N were observed during the rice crop phase. A significant treatment effect on microbial biomass P was evident only during 1992 in the lentil crop.

Assessment of the overall treatment effects indicated mean microbial biomass C, N, and P levels in the order straw + fertilizer, straw, fertilizer, control (Table 3). Table 4 shows estimates of biomass C, N and P as fractions of the respective total contents in soil; relative to the control these fractions, which increased with every amendment, reached a maximum in the straw + fertilizer treatment.

Strong positive relationships among microbial biomass C, N, and P were obtained (Fig. 5a–c). Biomass C accounted for 69% of the variability in biomass N and 63% of the variability in biomass P.

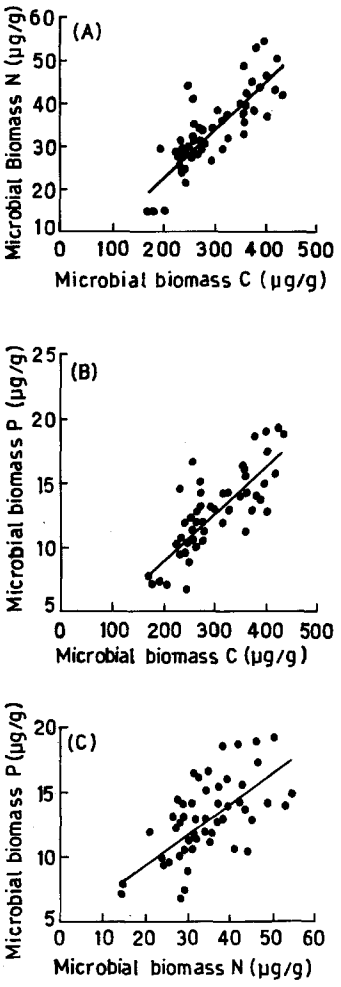

Fig. 5 A–C. Relationships among microbial biomass parameters: **A** microbial biomass N and microbial biomass C ($y = 0.33 + 0.11x$ ($R^2 = 0.69$); **B** microbial P and microbial biomass C ($y = 1.81 + 0.04x$ ($R^2 = 0.63$); **C** microbial P and microbial biomass N ($y = 4.59 + 0.24x$ ($R^2 = 0.48$)

Table 2. Per cent increase in microbial biomass, C, N, and P as a result of the application of chemical fertilizer and straw, singly or in combination compared with the control

Treatment	1990 Rainy fallow	1991 Lentil crop	1991 Summer fallow	1991 Rice crop	1992 Lentil crop
Microbial biomass C					
Fertilizer	−6	−6	+12	+45*	+14
Straw	+33*	+6	+21*	+59*	+51*
Straw + fertilizer	+39*	+7	+34*	+66*	+77*
Microbial biomass N					
Fertilizer	−26	+6	+25*	+26*	+30*
Straw	+72*	+24	+38*	+39*	+84*
Straw + fertilizer	+77*	+29*	+75*	+77*	+77*
Microbial biomass P					
Fertilizer	+1	+7	−0.8	+16	+20*
Straw	+62*	+36*	+4	+26	+60*
Straw + fertilizer	+63*	+52*	+5	+49*	+81*

*$P < 0.05$

Discussion

The mean values of microbial biomass C in the present study (243–355 $\mu g\, g^{-1}$ dry soil, Table 3) are comparable to the range of values (180–346 $\mu g\, g^{-1}$ dry soil) reported in forest-derived croplands under similar climatic con-

Table 3. Microbial biomass C, N, P and their ratios

Treatment	Biomass ($\mu g\, g^{-1}$)			C:N	C:P	N:P
	C	N	P			
Control	243	25.6	10.4	9.9	25.3	2.7
Fertilizer	279	30.0	11.3	9.7	25.6	2.7
Straw	329	36.3	13.9	9.2	25.2	2.8
Straw + fertilizer	355	42.2	15.5	8.6	24.0	2.9

Values are means of all sampling dates

Table 4. The proportions of soil organic C, total N, and total P as biomass C, N, and P, respectively

Treatment	Biomass as per cent of soil		
	Organic C (%)	Total N (%)	Total P (%)
Control	3.2	2.6	5.8
Fertilizer	4.0	3.8	5.9
Straw	3.5	3.3	7.7
Straw + fertilizer	4.6	3.8	8.2

Values are means of all sampling dates

ditions (Srivastava and Singh 1989). Microbial biomass C ranges of 115–1231 $\mu g\, g^{-1}$ have been reported by Anderson and Domsch (1989) and Insam et al. (1989) and 61–1620 $\mu g\, g^{-1}$ by Srivastava and Singh (1988). The mean values for biomass N in the present study (25.6–42.2 $\mu g\, g^{-1}$, Table 3) are comparable with the ranges 20–46 $\mu g\, g^{-1}$ reported by Srivastava and Singh (1989) and 16.6–87.1 $\mu g\, N\, g^{-1}$ by Azam et al. (1989). The present biomass P values (10.4–15.5 $\mu g\, g^{-1}$), however, are lower than those reported by Perrott and Sarathchandra (1989) (20–88 $\mu g\, g^{-1}$).

In the present study the application of straw increased the levels of microbial biomass in the soil, as also observed by Saffigna et al. (1989), Schnürer et al. (1985), Bonde et al. (1988), Ocio and Brookes (1990), and Ocio et al. (1991), but the maximum effect on the microbial biomass was realized with the straw + fertilizer treatment. In tropical soils, with levels of organic C and nutrients, the fertilizer applications probably satisfied nutrient but not C requirements. While straw alone, with a high C:N ratio, probably decomposes and releases nutrients slowly, when supplemented with fertilizer it probably decomposes more rapidly. By the end of the present study, the straw + fertilizer treatment had increased biomass C and N by 77% whereas biomass P was increased by 81% (Table 2). Saffigna et al. (1984, 1989) reported smaller increases in soil biomass C and N (10–23%) and P (40–60%) following the incorporation of straw into Australian soils. In a 27-year-long field trial in Swedish soils, however, Schnürer et al. (1985) found substantial increases in biomass C and N (56 and 103%, respectively) in straw + fertilizer-treated plots. At Rothamsted Experimental Station, Ocio et al. (1991) also observed that biomass values were higher in soils treated with straw + N than with straw alone.

Although the size of the soil microbial biomass is mainly potentially related to C inputs, other mitigating factors can suppress the growth and activity of the native microflora (Smith and Paul 1990). Constraint factors include N, P, and S, water potential, soil aeration and pH, substrate quality, clay type, and osmotic pressure. N is the nutrient most likely to limit microbial growth (Beare et al. 1989). According to Perrott and Sarathchandra (1989), the soil P status may also influence microbial growth indirectly through its effect on plant root growth, and consequently influence the amount of C released by roots; it is well established that exudates and root remains are substrates for microbial growth in the soil. In the present study, soil microbial biomass C, N, and P means increased due to fertilizer treatment during the study period (Table 2). Jenkinson and Rayner (1977) reported similar at 11–18% increase in biomass C with long-term fertilizer application, and Shen et al. (1989) reported a 14–33% increase. Schnürer et al. (1985) found that treatments without additional N contained less biomass C than the corresponding treatment with additional inorganic N.

Reviewing the available studies, Smith and Paul (1990) estimated that biomass C accounted for 2–5% of total C in soil, biomass N for 1–5% of total N, and biomass P for 2.7–19.1% of total P; these wide ranges reflect differences in soil, vegetation cover, management, and in sampling and analytical methods (Anderson and Domsch 1989). The biomass C, N, and P values obtained in the present study (3.2–4.6% of total C, 2.6–3.8% of total N, 5.8–8.20% of total P, Table 4) are within the above ranges. In nearby croplands derived from forest clearings, Srivastava and Singh (1989) reported 1.9–3.3% of total C as biomass C, 2–4% of total N as biomass N, and 9–19% of total P as biomass P. In some Pakistani soils, Azam et al. (1989) reported 2.6–8.1% of total N as biomass N.

The soil microbial biomass responds more quickly to the changes in management than does the amount of organic matter in the soil, which is relatively slow to change. Thus, the ratio of biomass C to total organic C will increase with time if the input of organic matter to a soil is increased (Anderson and Domsch 1989). The ratio of microbial C to soil C thus serve as sensitive criteria to indicate the type of variation in soil C (Beck 1984). In the present study an increase in biomass C per unit soil C was brought about by straw and fertilizer applications (Table 4). Similarly, Powlson et al. (1987) observed an increase in the ratio of biomass C to soil organic C with the incorporation of straw. In a long-term experiment with different inputs, Bonde et al. (1988) reported that the ratio of microbial biomass C to total organic C was 3.3% in control plots whereas it increased to 4.4% in straw + fertilizer-amended plots. Like C, residue retention tends to increase the proportion of soil organic N and P in the microbial biomass (Saffigna et al. 1989).

The relationships among microbial biomass C, N, and P (Fig. 5a–c), though strongly positive, showed a substantial number of scattered points around the linear plot. Soil microflora is a composite of several groups of organisms which are related to each other through their feeding activity. Each microbial group may have a different C:N or C:P ratio and the predominance of one group may result in the prevalence of a particular ratio. This may explain the presence of the scattered points. Different C:N ratios occur as a result of changes in microbial populations during the decomposition of incorporated straw (Tate et al. 1988). When straw is incorporated into soil, the soil food web changes. Surface-placed straw is generally fungally dominated, while incorporation of the straw shifts the food web towards bacterial dominance (Hendrix et al. 1986). The C:N ratio of fungal hyphae is often in the range 7–12 whereas that of bacteria is usually between 3 and 6 (Jenkinson 1976; An-

derson and Domsch 1980). Thus it is expected that with time, the incorporation of straw will reduce the C:N ratio of the microbial biomass. This trend was evident in the present study, as straw incorporation reduced the C:N ratio, although not significantly, by 7%, whereas the combined input of fertilizer + straw reduced it significantly by 13% C (Table 3). Powlson et al. (1987) and Saffigna et al. (1989) found that crop residues decreased the C:N and C:P ratios of the soil microbial biomass, although the differences were not significant.

The present biomass C:N and C:P ratios ranged from 8.6 to 9.9 and from 24.0 to 25.6, respectively, and are comparable with those reported in the literature. In nearby natural and derived ecosystems the biomass C:N ratio ranged from 7.5 to 10.3 (Srivastava and Singh 1989; Raghubanshi 1991). Dalal and Mayer (1987), studying Australian arable soils, reported a biomass C:N ratio of 8.7–13.2. Brookes et al. (1984) reported a mean biomass C:P ratio of 25 for 14 cultivated soils (range 11–36). Sarathchandra et al. (1984) also reported a mean C:P ratio of 25 for New Zealand pasture soils. The C:P ratios reported for a variety of soils in similar climate vary from 17 to 30 (Srivastava et al. 1989; Raghubanshi 1991).

In conclusion, straw + fertilizer application increased the soil microbial biomass substantially, perhaps by removing C and nutrient limitations. The increase in the microbial biomass is expected to enhance the nutrient availability in soil as this pool acts both as a sink and source of plant nutrients.

Acknowledgments. We thank Dr. A.S. Raghubanshi for suggestions and the Ministry of Environment and Forests for funding support through a project granted to Professor J.S. Singh.

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