# NOTES

## MICROBIAL BIOMASS DURING REVEGETATION OF LANDSLIDES IN THE HUMID TROPICS

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Landslides eliminate or reduce regeneration and result in an impoverished soil seed bank, low soil nutrients, unstable substrate and lack of mycorrhizal inoculums (Myster & Fernandez 1995). Although landslides have limited potential to revegetate rapidly compared with tree-cut sites, regeneration is limited by climate and soil nutrients (Gauriguata 1990). Restoring soil nutrients to these sites could facilitate the regeneration of native species and ecosystem reconstruction generally (Chadwick *et al.* 1999). Soil microbial biomass has a tremendous potential to accumulate and conserve plant nutrients in biologically active form (Jenkinson & Ladd 1981, Singh *et al.* 1989). In disturbed forests, the contribution of microbial biomass to soil organic matter and nutrient pools increases along a disturbance gradient (Arunachalam *et al.* 1996). Following timber harvest, the contribution of microbial biomass to soil nutrient pool has been shown to increase with stand age (Maithani *et al.* 1996). This paper reports that microbial biomass and its contribution to the total soil organic matter decrease with site age during the first four years of revegetation after a landslide. This trend indicates that conservation of soil nutrients in microbial biomass is crucial in the initial stages of natural revegetation following landslides. Thus, restoration of the degraded soils is contingent upon nutrient retention in and conservation of microbial biomass.

Four sites recovering from landslides (six months, and one, three and four years after disturbance) and a control site (a hilly tract where landslides had not occurred for the past 10 years) were selected in a moist tropical deciduous forest of Arunachal Pradesh (latitude 26° 28' to 29° 30' N and 91° 31' to 97° 30' E), India. The sites are pseudo-replicated by age. There was no plot–level replication, as similar sites could not be identified. The size of the selected sites varied from 100–725 $m^2$. The soils at these sites are derived from Precambrian quartzite rocks of the Shela group, sandy loam in texture, shallow, leached, slightly acidic (pH 5–6), with moderate water holding capacity (28–40%). The annual rainfall averages 1800 mm, of which more than 80% falls during the monsoon season (late May till September). October till February is cold and dry while March to mid-May is hot and dry.

The landslide sites were dominated by *Phyllostachys assamica* and pteridophytes including *Equisetum diffusum, Selaginella wallichii, Lycopodium clavatum* and *Gleichenia longissima.* In general, monocots such as *Imperata cylindrica* and *Phyllostachys* sp. were abundant and was greater on the landslides, while dicot herbs dominated the control site (Table 1). Vegetation analysis was done in 1999 according to standard methods given in Misra (1968). The species richness index was calculated as $(S–1)/\log_e N$, where $S$ is the number of species and $N$ is the number of individuals, and the species diversity index was calculated as $\sum (n_i/N) \log_e (n_i/N)$, where $n_i$ is the importance value index (IVI) of each species and $N$ is the total importance

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value (Magurran 1988). Nomenclature of plant species was based on Hooker (1872–1897).

From each site, 15 soil samples down to a depth of 15 cm were collected in February 1999 and 2000 using a soil auger. The soil samples were analysed for various physico-chemical properties following standard methods (Anderson & Ingram 1993). Microbial biomass C and N were determined following chloroform-fumigation extraction procedures (Anderson & Ingram 1993). Field moist soil samples (15 g) were placed in 50 ml beakers and kept in a vacuum desiccator containing a 100 ml beaker with 25 ml alcohol-free chloroform. Another desiccator was maintained without chloroform (unfumigated). A vacuum was applied to the fumigated treatment until the chloroform boiled rapidly, then the desiccator was kept under darkened conditions for 72 h at room temperature. The soil samples were transferred to 250 ml conical flasks and extracted with 0.5 M $K_2SO_4$ after shaking for 20 min in a rotatory shaker at 110 rpm. The extracts were filtered through a Whatman No. 42 filter paper and the filtrates (10 ml) were digested using $H_2SO_4$ in a block digestor at 145–155 °C for 20 min. The digest was titrated against ferrous ammonium sulphate (0.2 N) using 1,10 phenanthroline monohydrate as the indicator. The C flush was determined as the difference between the values for fumigated and unfumigated soil samples and the microbial C was calculated as: C flush × 2.64 (Joergensen *et al.* 1995). For microbial biomass N, the filtrates (10 ml) were acid-digested and steam-distilled and titrated against N/140 HCl using boric acid indicator. For microbial P, soils were extracted in 0.5 N $NaHCO_3$, filtered through Whatman filter paper no. 42 and determined colorimetrically using molybdenum blue method (Anderson & Ingram 1993). In all cases, the values of unfumigated samples were subtracted from fumigated ones to get values of microbial N and P and divided by factors of 0.54 for microbial N and 0.40 for microbial P (Maithani *et al.* 1996).

Clay + silt content and water holding capacity increased gradually during revegetation (Table 1). Soil organic C, total N, inorganic N (ammonium and nitrate) and available P also showed an increasing trend with the progression of vegetation recovery on the landslides. Variations in soil C, N and available P from 1999 to 2000 was negligible, while those of inorganic N were significant ($p < 0.05$). The concentrations of ammonium and nitrate were much lower when compared with a tropical forest (1.2–4.0 and 0.4–5.6 $\mu g\ g^{-1}$) or savanna (2–5 and 0.4–0.8 $\mu g\ g^{-1}$) (Singh *et al.* 1989). This illustrates that landslides can be detrimental to soil fertility, as in the process the top soil is removed exposing the nutrient poor subsoil, requiring the ecosystem to develop nutrient conservation mechanisms (Pandey & Singh 1985). The significantly high amount of available P in the control site suggests that most P in the exposed mineral soil is biologically unavailable. Since P is released into the soil solution almost entirely from the weathering and breakdown of primary minerals in parent rock material (Pandey & Singh 1985), landslides are important sites in replenishing the supply of biologically active phosphorus to the vegetated soils. Long-term studies of soil P transformation on recent landslides and along chronosequences may better explain this hypothesis (Crews *et al.* 1995).

Microbial C, N and P showed a decreasing trend at least up to three years of revegetation (Table 1), and they are highest in six-month-old site. This correlation indicates that nutrients immobilised in microbes are an important source of plant available nutrients in the soil during the initial part of the revegetation process. A sharp decline in microbial biomass C, N and P one year after landslide disturbance may be attributed to increased competition for nutrients between the microbial population and the establishing plants. Organic substrate available from the parent soil in the landslide site may also decrease with age resulting in low microbial biomass and activity (Arunachalam & Arunachalam 1998). The rapid turnover of microbial biomass, especially N could help sustain the nutrient supply in the soil and facilitate plant growth during initial stages of recovery (at least up to one year). In low N soils, microbial biomass is as effective as nitrate-N in supplying N to the crops

**Table 1** Vegetation and soil properties of landslide areas

| Property | Age of site | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 6 months | | 1 year | | 3 years | | 4 years | | Control | |
| | 1999 | 2000 | 1999 | 2000 | 1999 | 2000 | 1999 | 2000 | 1999 | 2000 |
| Monocots | 15.33 | | 20.00 | | 55.33 | | 61.16 | | 6.00 | |
| Dicots | 14.50 | | 20.50 | | 7.00 | | 24.00 | | 14.50 | |
| Pteridophytes | — | | 9.00 | | 38.33 | | 7.00 | | 4.33 | |
| Species richness index | 2.035 | | 2.598 | | 0.710 | | 2.847 | | 2.025 | |
| Species diversity index | 2.123 | | 2.323 | | 1.502 | | 2.195 | | 1.974 | |
| Texture | | | | | | | | | | |
| Sand (%) | 94.22 | 93.99 | 94.75 | 95.16 | 83.10 | 87.15 | 88.45 | 89.13 | 77.82 | 80.54 |
| | (1.14) | (1.21) | (2.32) | (1.89) | (0.91) | (0.67) | (0.12) | (1.23) | (1.19) | (0.88) |
| Silt + Clay (%) | 5.78 | 6.01 | 5.25 | 4.84 | 16.90 | 12.85 | 11.55 | 10.87 | 22.18 | 19.46 |
| | (0.87) | (0.01) | (0.12) | (0.24) | (0.45) | (0.9) | (0.27) | (0.34) | (0.12) | (0.16) |
| Water holding capacity (%) | 28.10 | 29.12 | 33.60 | 31.14 | 34.70 | 37.61 | 40.60 | 38.97 | 34.70 | 33.99 |
| | (1.12) | (0.91) | (2.11) | (1.67) | (1.23) | (2.80) | (2.54) | (3.11) | (1.87) | (1.13) |
| Soil moisture content (%) | 12.00 | 19.11 | 17.20 | 19.21 | 17.40 | 19.45 | 16.10 | 19.23 | 17.60 | 21.43 |
| | (0.91) | (0.12) | (0.32) | (0.23) | (1.01) | (0.54) | (0.12) | (0.12) | (0.27) | (0.09) |
| Soil pH | 6.59 | 6.11 | 5.96 | 5.55 | 5.29 | 5.68 | 6.27 | 6.19 | 6.16 | 6.04 |
| (1:2.5 w/v $H_2O$) | (0.05) | (0.03) | (0.01) | (0.01) | (0.03) | (0.06) | (0.01) | (0.04) | (0.04) | (0.01) |
| Organic C (%) | 0.30 | 0.12 | 5.40 | 5.48 | 0.40 | 0.52 | 0.50 | 0.56 | 1.02 | 1.07 |
| | (0.002) | (0.011) | (0.036) | (0.030) | (0.022) | (0.028) | (0.050) | (0.048) | (0.043) | (0.038) |
| Total N (%) | 0.30 | 0.03 | 0.02 | 0.04 | 0.04 | 0.04 | 0.06 | 0.06 | 0.06 | 0.06 |
| | (0.002) | (0.002) | (0.001) | (0.001) | (0.002) | (0.001) | (0.003) | (0.003) | (0.001) | (0.002) |

(continued)

(Table 1 - continued)

| Property | Age of site | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 6 months | | 1 year | | 3 years | | 4 years | | Control | |
| | 1999 | 2000 | 1999 | 2000 | 1999 | 2000 | 1999 | 2000 | 1999 | 2000 |
| Ammonium ($\mu g\ g^{-1}$) | 0.0008 | 0.0056 | 0.0044 | 0.0075 | 0.0046 | 0.0079 | 0.0047 | 0.0076 | 0.015 | 0.021 |
| | (0.0001) | (0.002) | (0.002) | (0.001) | (0.001) | (0.002) | (0.002) | (0.003) | (0.002) | (0.002) |
| Nitrate ($\mu g\ g^{-1}$) | 0.253 | 0.203 | 0.253 | 0.206 | 0.277 | 0.302 | 0.285 | 0.303 | 0.587 | 0.518 |
| | (0.019) | (0.016) | (0.002) | (0.02) | (0.03) | (0.01) | (0.02) | (0.02) | (0.04) | (0.03) |
| Available P ($\mu g\ g^{-1}$) | 0.665 | 0.689 | 0.781 | 0.836 | 0.838 | 0.889 | 1.413 | 1.480 | 5.625 | 4.791 |
| | (0.052) | (0.048) | (0.065) | (0.068) | (0.053) | (0.049) | (0.09) | (0.06) | (0.41) | (0.29) |
| Microbial C ($\mu g\ g^{-1}$) | 200.00 | 98.89 | 88.88 | 82.22 | 44.44 | 37.78 | 22.22 | 27.78 | 488.89 | 492.10 |
| | (15.2) | (5.31) | (5.16) | (5.28) | (3.03) | (2.58) | (1.09) | (1.38) | (12.17) | (19.11) |
| Microbial N ($\mu g\ g^{-1}$) | 104.20 | 28.70 | 38.93 | 20.30 | 21.11 | 18.90 | 21.22 | 23.33 | 21.64 | 25.18 |
| | (4.86) | (2.02) | (20.31) | (1.97) | (1.43) | (1.09) | (1.86) | (1.92) | (1.02) | (2.01) |
| Microbial P ($\mu g\ g^{-1}$) | 6.65 | 5.20 | 4.05 | 4.10 | 3.95 | 4.35 | 5.30 | 9.63 | 30.00 | 26.31 |
| | (0.39) | (0.23) | (0.30) | (0.21) | (0.22) | (0.22) | (0.32) | (0.58) | (1.01) | (1.11) |
| Microbial C: Organic C | 6.67 | 8.24 | 2.22 | 1.71 | 1.11 | 0.72 | 0.44 | 0.50 | 4.79 | 4.59 |
| Microbial N: Total N | 34.73 | 9.57 | 19.47 | 5.08 | 5.28 | 7.23 | 3.54 | 13.89 | 3.61 | 4.19 |
| Microbial P: Available P | 85.26 | 75.47 | 51.86 | 49.04 | 47.13 | 48.93 | 37.51 | 65.07 | 53.34 | 54.92 |

(Jensen *et al.* 1997). For instance, in the highly impoverished soils of the landslides, the contribution of microbial N to total N was 14 times greater than nitrate-N in the soils. This further strengthens the hypothesis that microbial biomass acts as a reservoir of N immediately after disturbance and perhaps facilitates revegetation. In a disturbed pine forest in this region, Arunachalam *et al.* (1996) reported that N immobilisation is greater in microbial biomass and so contributes significantly to the soil total N pool when compared with the litter and fine root inputs. This could partially explain the relatively lower decline (~50%) in soil N after landslide as compared with the decline in soil C (~97%). The present results disagreed with earlier findings in a disturbed *Pinus kesiya* forest (Arunachalam *et al.* 1996) that the microbial biomass was positively correlated with water holding capacity, soil organic C, total N and available P in the soil. The ratio of microbial C/N was lower in landslide soils (1–4) as compared with the control site (20–22). Earlier studies with bamboo patches also revealed lower microbial C/N (2–3) as compared with a grassland (Arunachalam & Arunachalam 2002). Such results may have been due to the inherent sampling errors confounded by patchy revegetation on the landslides.

The contribution of microbial biomass to the soil nutrient pool was highest in the young recovering site (up to one year). A large contribution of microbial biomass to the soil nutrient pool, particularly with reference to C in the control site, indicated the possible development of detritus (litter and fine roots), which have been reported to play a crucial role in C cycling of tropical ecosystems (Kundu 1990, Arunachalam & Arunachalam 1998). Interestingly, our data for 1999 showed an 'upshock' in the percentage contribution to total soil nutrient pool immediately after landslide disturbance and a gradual decrease during revegetation. On the contrary, in the year 2000 the percentage of microbial N and P to respective soil nutrients showed a gradual increase after three years and one year of vegetation regrowth respectively. This also shows that the N and P recovery is faster and highly dynamic as compared with C in microbial biomass. Thus, it appears that landslides are critical zones in the humid tropics where soil nutrient cycling through microbial biomass turnover is more significant than perhaps the detrital biomass such as litter and fine roots and could affect the revegetation in these impoverished sites.

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