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REGULAR ARTICLE

Nutrient release and fungal succession during decomposition of weed residues in a shifting cultivation system

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ABSTRACT

The litter decomposition and nutrient release pattern of two dominant weeds in a shifting cultivation system were studied. The foliage and root litter of *Ageratum conyzoides* L. and *Spilanthes paniculata* Wall. ex DC. showed a biphasic weight loss pattern with a peak during the initial 60 d of incubation. The decay rate coefficient ('*k*') for foliage and root residues of *Ageratum conyzoides* (6.57 and 2.92) was lower than that of *Spilanthes paniculata*, which registered little difference between root (7.30) and foliage (7.67) residues. Release of nitrogen (N), phosphorus (P) and potassium (K) also followed a biphasic pattern and their release rate coefficients ranged from 3.65-8.03, 4.75-8.40 and 7.3-9.86, respectively. Rapid K release lasted for only 30 d of incubation. However, initial N and P release continued for about 60 d. In the case of *Ageratum conyzoides*' roots, N release was initially slower compared to the later stages. Initial lignin and cellulose concentrations showed a significantly negative correlation with the decay rate coefficient; whereas, N concentration showed a significantly positive correlation with the decay rate coefficient. The microbial population and fungal diversity varied with the decomposition period in the field and mainly depended on litter nutrient concentration. Diversity of fungal species was lowest in roots of *A. conyzoides* and was highest in foliage. Fungal species recorded during the study on plant residues mostly belonged to the Deuteromycetes group. Roots of *Spilanthes paniculata* and foliage of both species had a C:N of < 25 and released more than 90% of N, P and K within 150 d. They can be considered to be good resources for the improvement of soil fertility. Thus, these residues, particularly those of *Spilanthes paniculata*, can play a significant role in soil nutrient enrichment in poorly managed shifting cultivation systems.

Key Words: *weed biomass; litter decomposition; nutrient release; fungal population*.

INTRODUCTION

In agricultural systems the decomposition of plant residues is carried out by microorganisms. The rate of plant residue decomposition depends on the physico-chemical environment, the nature of the decomposer (soil microbe) community (Couteaux et al., 1995; Saetre, 1998) and the biochemical composition of the organic material (Elliott et al., 1993). Most biochemical decomposition of organic materials is carried out by heterotrophic microorganisms, among which fungi are an important group (Shukla et al., 1990). Fungal hyphae penetrate the decomposing material both chemically and mechanically and decompose the more recalcitrant organic matter fractions such as lignin and cellulose. Fungal succession on a natural substratum reflects sequential release of different organic and inorganic nutrients, interaction between each individual and substratum, competition among individual fungi (Kshattriya et al., 1996). Fungal hyphae physically stabilize compost into small aggregates providing the compost with improved aeration and drainage. Microorganism activity and various physico-chemical agents bring about changes in the structure and chemical composition of the organic matter which in turn regulates the species composition of late colonizing microorganisms (Adedji, 1986).

The weeds are ecologically notorious plants because they compete with crops for space and nutrition, which in turn reduces agricultural production and may help to maintain soil fertility in tropical ecosystems after their decomposition in field (Hartemink and Sullivan, 2001). In northeast India shifting cultivation (slash and burn) is a major agricultural system. This system reduces soil fertility in the long run (Arunachalam, 2002). In such cases the decomposition of early successional herbaceous plants may be important in soil organic matter build up as well as in the nutrient budget (Elliot et al., 1993). Traditional hand weeding in the shifting cultivation system of northeast India involves retention of some weed biomass *in situ* that conserves up to 20% of soil nutrients (Ramakrishnan, 1992).

Generally weed species such as *Ageratum conyzoides* L., *Spilanthes paniculata*, *Eupatorium odoratum*, *Mikania micrantha*, and *Dryopteris* sp. are dominant during cultivation and the early successional phase after shifting cultivation in northeastern India (Arunachalam, 2002). Among these, *Ageratum conyzoides* and *Spilanthes paniculata* are major weed species and contribute about 53% of the total biomass produced during the first year fallow phase of shifting cultivation. There is no adequate information on the decomposition and nutrient release patterns of early successional herbaceous plant species, in general, and for weeds in particular (Ramakrishanan, 2002; Hartemink and Sullivan, 2001). The purpose of this study was to assess the decomposition rate, nutrient release pattern and succession of fungal communities associated with decomposing litter of *Ageratum conyzoides* and *Spilanthes paniculata* in the field.

MATERIALS AND METHODS

SITE

The study was carried out in a shifting cultivation (jhum) field managed under a 3-year cycle by the Chakma community located in the western periphery of Namdapha National Park (altitude 150–300 msl, latitude 26°40′N and 27°40′N and longitude 95°11′E and 97°10′E) in the Changlang District of Arunachal Pradesh. Annual rainfall is between 1,400 and 2,500 mm. The temperature and relative humidity ranges between 5 a nd 37ºC and 47 and 93%, respectively, over the year. November to January is the winter season and mid-May to September is the humid, rainy season (Figure 1). The total number of rainy days in a year with more than 2.5 mm rain was ca. 150. Geologically, the area is of recent origin and owes its formation to the Himalayas in the Pleiocene period of the Tertiary age. The geological formations include Tertiary and Quaternary sequences that extend from Nagaland to Upper Assam (Chauhan et al., 1996).

The contribution of *Ageratum conyzoides* and *Spilanthes paniculata* to total standing crop biomass of the system after crop harvest and after one year of fallow are given in Table 1.

Table 1. Contribution of weed species to the total plant density and biomass in a shifting cultivation system under a 3 year cycle (values in parentheses are percentage of total biomass).

Species	After harvesting the crops		After one year fallow	
	Density (plants m^{-2})	Biomass (kg ha^{-1})	Density (plants m^{-2})	Biomass (kg ha^{-1})
Ageratum conyzoides	9.33	172 (45)	21.42	898 (40.2)
Bidens pilosa	3.73	37 (9.7)	2.95	32 (1.4)
Borreria hispida	1.13	8 (2.1)	1.64	12 (0.5)
Dryopteris sp.	1.07	12 (3.1)	2.28	45 (2.0)
Eupatorium odoratum	0.53	4 (1)	8.92	587 (26.3)
Mikania micrantha	2.13	11 (2.9)	3.25	118 (5.3)
Oxalis paniculata	6.73	4 (1)	2.22	7 (0.3)
Polygonum cinense	1.13	16 (4.2)	1.64	58 (2.6)
Sonchus arvensis	3.73	24 (6.3)	2.31	34 (1.5)
Spilanthes paniculata	5.73	68 (17.8)	18.63	306 (13.7)
Tridex sp.	2.80	2 (0.5)	10.31	65 (2.9)
Others	5.18	24 (6.3)	8.53	73 (3.3)
Total	43.22	382	84.10	2235

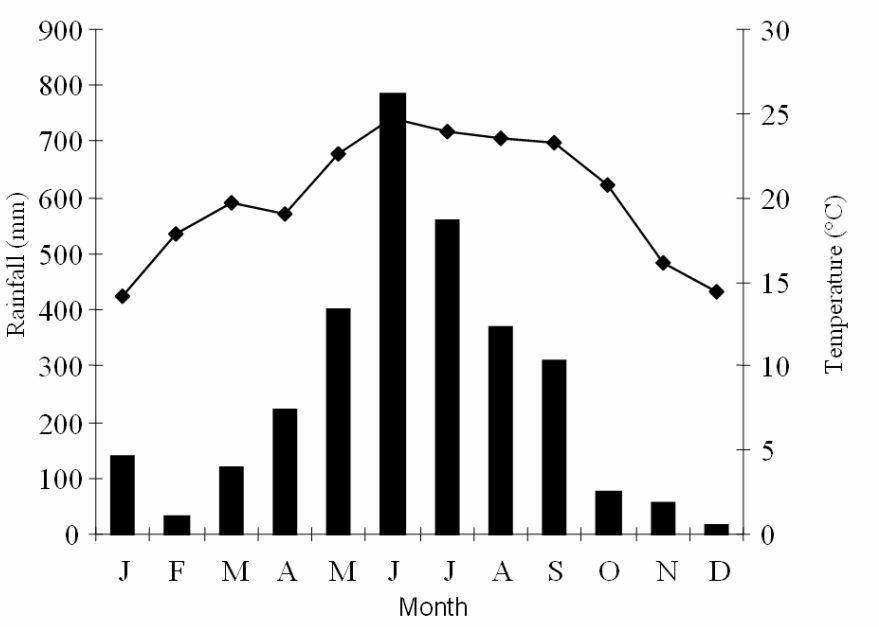

Figure 1. Climatogram of the study area.

LITTER DECOMPOSITION

Aboveground foliage and roots of *Ageratum conyzoides* and *Spilanthes paniculata* were collected immediately after harvest of shifting cultivation fields. Plant samples were air-dried for three weeks and subsequently cut into to 5 cm pieces. The litter bag technique was used to study the decomposition rate (Bocock, 1963). For each residue type, 40 litter bags (1 mm mesh; 15 cm x 15 cm) were prepared, and 5 g of air-dried sample was placed in each bag. Part of each sample was oven dried to determine moisture content. Litter bags containing foliage were placed randomly in the field, while those containing the roots were buried in the top 0-5 cm of the same field. Litter bags were retrieved (7 replicate bags of each litter type) monthly and taken to the laboratory in sterilized polythene bags. Five bags were used to determine mass loss. The remaining bags were used for microbial analysis. Adhering extraneous matter visible to unaided eyes was carefully removed from each litter bag by brushing and washing in a 200 μm mesh sieve. Each litter sample was oven-dried at 80˚C for 48 hours. The mass remaining was expressed as a percentage of the initial oven dry weight of the material

FUNGAL ISOLATION

The two litter bags kept aside for isolation of bacteria and fungi were washed gently in sterilized water to remove surface contamination. The litter was then cut into small pieces of 10 mm and placed in a 250 ml conical flask containing 100 ml of sterilized distilled water and then shaken on a horizontal shaker (120 throws min^{-1} and 1.5 cm displacement) to obtain a homogenous suspension. The dilution plate method was used to isolate litter micro-flora. A minimum of 10^{-5} dilution was used for bacteria and 10^{-3} for fungi. One ml of litter suspension from the dilution was spread into the sterilized Petri-dishes containing 20 ml of cooled rose Bengal agar (Martin, 1950) and nutrient agar (Johnson and Curl, 1972) media for isolation of fungi and bacteria, respectively. The initial microbial population associated with the litter was also estimated before putting the bags into the field. No attempt was made to identify the bacteria. However, fungal species were identified using Barnett and Hunter (1972) and Domsch et al. (1980)

LITTER CHEMICAL ANALYSIS

For chemical analyses, oven-dried litter samples were ground with a Wiley mill and through a 0.5 mm screen. The plant litter used for the decomposition study was initially analyzed for carbon (C), N, P, K, sodium (Na), sulfur (S), lignin and cellulose. During the subsequent field incubation only N, P and K were analyzed. Carbon and S were estimated by a CHNOS analyzer (Leco Company, USA). Nitrogen was determined by the semi-micro Kjeldahl procedure (Allen et al., 1974). After an acid wet oxidation in HNO_3 + H_2SO_4 + $HClO_4$, P was determined according to the molybdenum blue method and K was estimated by flame photometry (Allen et al., 1974).

STATISTICAL ANALYSIS

The decay rate coefficient (k) was calculated by using the model [$k = \ln (X_1/X_0)/t$] (Olson, 1963), where, t_{50} and t_{99} were calculated using the formulae $t_{50} = 0.693/k$ and $t_{99} = 5/k$, respectively (Singh and Sekhar, 1989). Where k is the decay rate coefficient, X_1 is the weight remaining at time t and X_0 is initial sample weight. Nitrogen, P and K values were substituted at the place of residue weight to get nutrient release rates coefficient as k_N, k_P and k_K, respectively. The effect of initial litter chemistry and climatic factors (rainfall and temperature) on the decay rate (% day^{-1}) were tested using the linear regression function, $Y = a + bX$ (Zar, 1974). Polynomial equations were used to characterize the observed decay pattern (Zar, 1974).

RESULTS AND DISCUSSION

The initial mineral concentration in both weeds is given in Table 2. The *Ageratum conyzoides* had higher concentrations of C, K and lignin, and *Spilanthes paniculata* had a slightly higher cellulose and N concentration in foliage and root. Carbon concentration varied significantly ($P < 0.05$) between the foliage of *Ageratum conyzoides* (37.0%) and *Spilanthes paniculata* (33.5%). Similarly, there was a marked difference in the residue N content in both the species. Roots had a relatively higher lignin concentration than foliage. There was no significant difference in the cellulose concentration in the foliage and root litter of both species. There were negligible differences in the P, S and Na concentrations amongst the residues. The minimum (18.42) C:N ratio was in foliage of *Spilanthes paniculata* and the maximum (37.52) in roots of *Ageratum conyzoides*. The lignin:N ratio followed a similar trend to the C:N ratio. The decay rate coefficients of foliage and root residues for both species are given in Tables 3 and 4. The decay rate during the first 60 d of the study was faster, but later it was slow and uniform (Figure 2). The decay rate coefficient (k) did not differ much between foliage and root residues of *Spilanthes paniculata*. However, in *Ageratum conyzoides* the foliage decomposed almost three times faster than the roots. Generally, residue mass loss was faster in *Spilanthes paniculata* than in *Ageratum conyzoides*. The quality of litter as determined by initial chemical composition affected the decomposition rate and, thus, influenced the turnover rate of the originally bound nutrients, especially N (Myers et al., 1993; Arunachalam et al., 2003). It has been reported that substrates with a C:N of < 25 tend to release nutrients faster than residues with a C:N > 25 (Myers et al., 1993). Roots of *Ageratum conyzoides* can be considered a low quality resource compared with the other plant material with a C:N ratio of 37.57 and lignin at 20.17%, which slowed decay and nutrient release. Two phases of decay rate were observed for legume crop residues in a shifting agricultural system (Arunachalam et al., 2003).

A decline in decomposition rate after a rapid decay phase can be attributed to a higher percentage of recalcitrant fractions like cellulose and lignin, which controlled decay rate by being resistant to enzymatic attack and by physically interfering with degradation of other chemicals in the cell wall (Bloomfield et al., 1993). There was a negative correlation between lignin and decay rate ($r = -0.930$; $P < 0.001$).

Initial bacterial and fungal populations were low in the litter samples. However, after field incubation there was a rapid increase in numbers observed (Figure 3). Maximum fungal propagules and bacteria were observed in the decomposing residues of *Ageratum conyzoides* after 60 d and 120 d of incubation, respectively. In *Spilanthes paniculata* residues, maximum microbial populations (bacteria and fungi) were recorded at 90 d. Terrestrial decomposition is mediated by microbes. Generally, litter decomposition is faster initially due to the utilization of readily available energy sources by the microbes, a loss of water-soluble components and non-structural carbohydrates, and the removal of residue particles by the soil microflora (Swift et al., 1979; Bloomfield et al., 1993). The increased microbial populations after placing the residues in the soil may be due to a suitable biophysical environment that increased the surface area for microbial colonization and the organic matter as their energy source (Anderson and Domsch, 1985) and other nutrients. The initial concentration of C, N and K showed significant, positive correlations with microbial population. However, P, Na, lignin, and lignin:N showed significant negative correlations. The gradual increase in microbial population and fungal diversity with decomposition period may also have been due to improved moisture levels, temperature moderation and nutrient concentration. When the nutrient concentration fell by ca. 20% of the original value, the microbial population decreased (Figure 4). There was a significant ($P < 0.005$) binomial relationship between fungal population with N concentration ($r = 0.562$) and rainfall ($r = 0.528$) and an exponential relationship with K ($r = 0.489$) (Table 6). Deka and Mishra (1984) reported that fungal species composition is regulated by climatic factors and substrate

nutrient concentration. Variation in fungal population in this work may be due to different litter nutrient concentrations.

Table 2. Initial elements concentration (%) and element ratio of the weed residues (values in parentheses are ± SE; n = 5).

Properties	*Ageratum conyzoides*		*Spilanthes paniculata*	
	Foliage	Roots	Foliage	Roots
Elements				
C	37.01(±1.29)	34.14(±1.47)	33.53(±1.16)	31.62(±1.65)
N	1.69(±0.088)	0.91(±0.030)	1.82(±0.072)	1.65(±0.054)
P	0.22(±0.008)	0.27(±0.009)	0.23(±0.007)	0.27(±0.011)
K	1.69(±0.035)	1.27(±0.036)	1.15(±0.035)	0.97(±0.048)
S	0.14(±0.002)	0.11(±0.001)	0.11(±0.001)	0.12(±0.003)
Na	0.43(±0.021)	0.60(±0.010)	0.42(±0.010)	0.49(±0.021)
Lignin	13.71(±0.51)	20.17(±0.68)	11.51(±0.96)	13.19(±0.31)
Cellulose	23.64(±0.91)	21.84(±0.61)	26.16(±0.38)	23.79(±0.31)
Ratio of elements				
C:N	21.90	37.52	18.42	19.16
C:P	168.23	126.44	145.78	117.11
C:K	21.90	26.88	29.16	32.60
N:P	7.68	3.37	7.91	6.11
N:K	1.00	0.72	1.58	1.70
Lignin:N	8.11	22.16	6.32	7.99
Lignin:P	62.32	74.70	50.04	48.85
Lignin:K	8.11	15.88	10.01	13.60

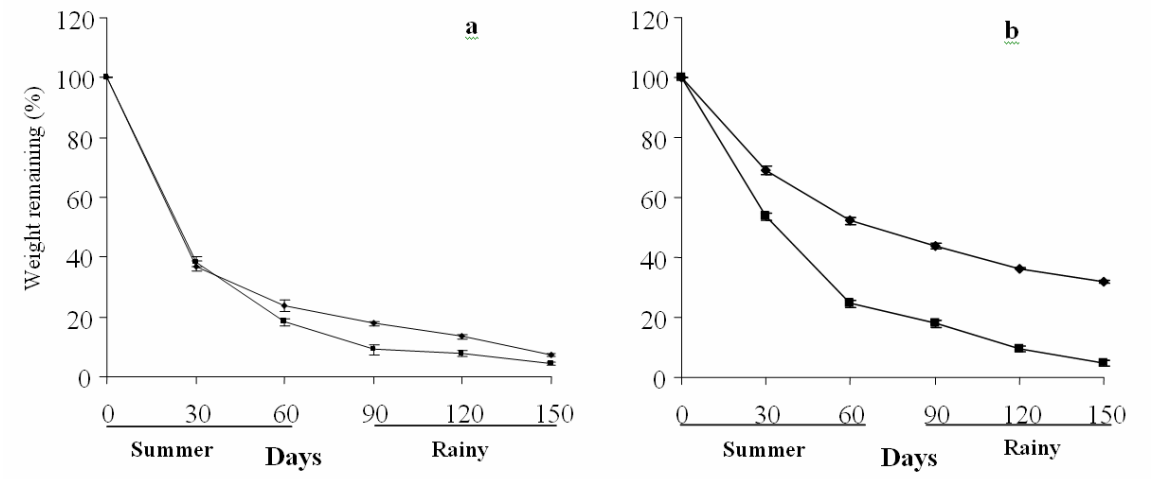

Figure 2. Mass remaining at different stages of decomposition in (a) foliage and (b) roots of ♦ *Ageratum conyzoides* and ■ *Spilanthes paniculata*.

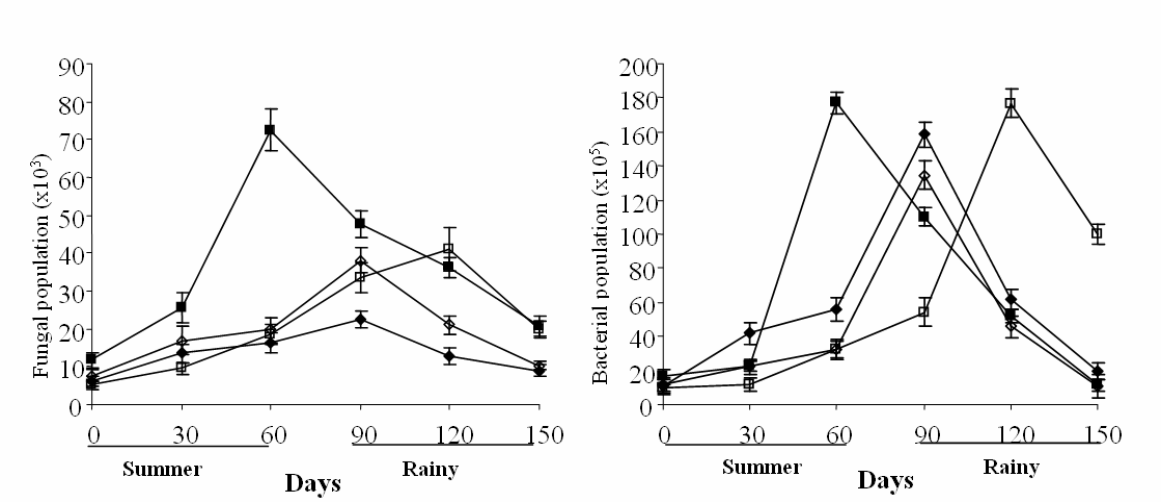

Figure 3. Microbial population during decomposition of *Ageratum conyzoides* (■ foliage and □ root) and *Spilanthes paniculata* (◆ foliage and ◇ root).

As Table 5 shows, the diversity of fungal communities was greater in *Ageratum conyzoides* foliage followed by roots of *Spilanthes paniculata*. The least diversity was in *Ageratum conyzoides* roots. From decomposing *Spilanthes paniculata* foliage, sixteen different microfungi species were isolated including sterile forms. Initial fungi isolated from undecomposed plant parts were *Cladosporium macrocarpum*, *C. cladosporioides*, *Mortierella elongata*, *Geotrichum candidum*, *Penicillium canescens*, *Nigrospora sphaerica*, *Chrysosporium merdarum*, *Metarrhizium* sp. and *Verticillium* sp. *Penicillium bravicompactum*; *Monilia* sp., *Verticillium* sp., *Cladosporium cladosporioides* were common fungal species. *Arthroderma tuberculatum*, *Cladosporium herbarum*, *Metarrhizium* sp., *Mortierella gamsii*, *M. bisporalis*, *M. wolfii*, *Mucor racemosus*, *Trichoderma koningii*, *Penicillium chrysogenum*, *P. coccosporum*, *Botrytis cinera*, *Fusarium sporotrichioides*, *Staphylotrichum coccosporiodes*, *Chalaropsis* sp., and *Nectria ventricosa* were only isolated from one type of decomposing plant material. *Nigrospora sphaerica* was restricted to roots only. *Acrimonium butyri*, *Arthoderma tuberculatum*, *Aspergillus flavus*, *A. fumigatus*, *Cercospora* sp., *Cladosporium herbarum*, *Humicola fuscoatra*, *H. grisea*, *Monilia* sp., *Penicillium frequentans*, *P. coccosporum*, *P. fellutanum*, *P. brevicompactum*, *Trichoderma koningii*, *Staphylotrichum coccosporiodes*, *Cercospora* sp., *Chalaropsis* sp., *Chrysosporium* sp., *M. verticillata*, *M. wolfii*, *Oidiodendron* sp. and some sterile forms were sporadically isolated.

Fungal species *Mucor racemosus*, *Verticillium alboatrum*, V. nigrescens, *Aspergillus niger*, Penicillium chrysogenum, Botrytis cinera, Fusarium sporotrichoides, *Oidiodendron griseum*, *Mortierella bisporalis* and *Nectria ventricosa* were late colonizers and appeared between 120 and 150 d. *Fusarium* sp., *Mucor* sp., *Penicillium* sp. and *Rhizopus* sp. were reported as early successional microfungi in decomposing crop residues in the temperate region of northeast India (Shukla et al., 1990). In this work the early successional fungal community was *Mortierella* sp., *Geotrichum* sp., *Cladosporium* sp., *Nigrospora* sp., *Penicillium* sp. and *Verticillium* sp. The cellulose decomposing capability of *Penicillium* sp. is well known, which may be the cause of the frequent occurrence of *Penicillium brevicompactum*. The sterile forms isolated during the later stages (90 d on) of decomposition are possibly Basidiomycetes, which do not produce fruiting bodies on agar media but are responsible for lignin decomposition and were dominant during the later stages of litter decay. Due to heavy rain the soluble compounds were released rapidly in the initial stages and increased the concentration of recalcitrants which favored the growth of deuteromycetes. On the other hand, the abundance of this class of fungi throughout the decomposition process favored faster decay and nutrient release.

Generally, foliage N concentration decreased with decomposition period. At the end of the study it was 1.06% in *Ageratum conyzoides* and 1.02% in *Spilanthes paniculata* (Figure 4). However, in roots N concentration initially increased and then gradually decreased after 90 and 60 d, respectively, in *Ageratum conyzoides* and *Spilanthes paniculata*. Root P concentration in both weed species did not vary till 30 d. In *Ageratum conyzoides* foliage P concentration increased during the initial 30 d, while in *Spilanthes paniculata* it decreased throughout the study. A rapid decline in K concentration was observed during the initial 30 d of decomposition. Thereafter, the concentration decreased constantly (Figure 4).

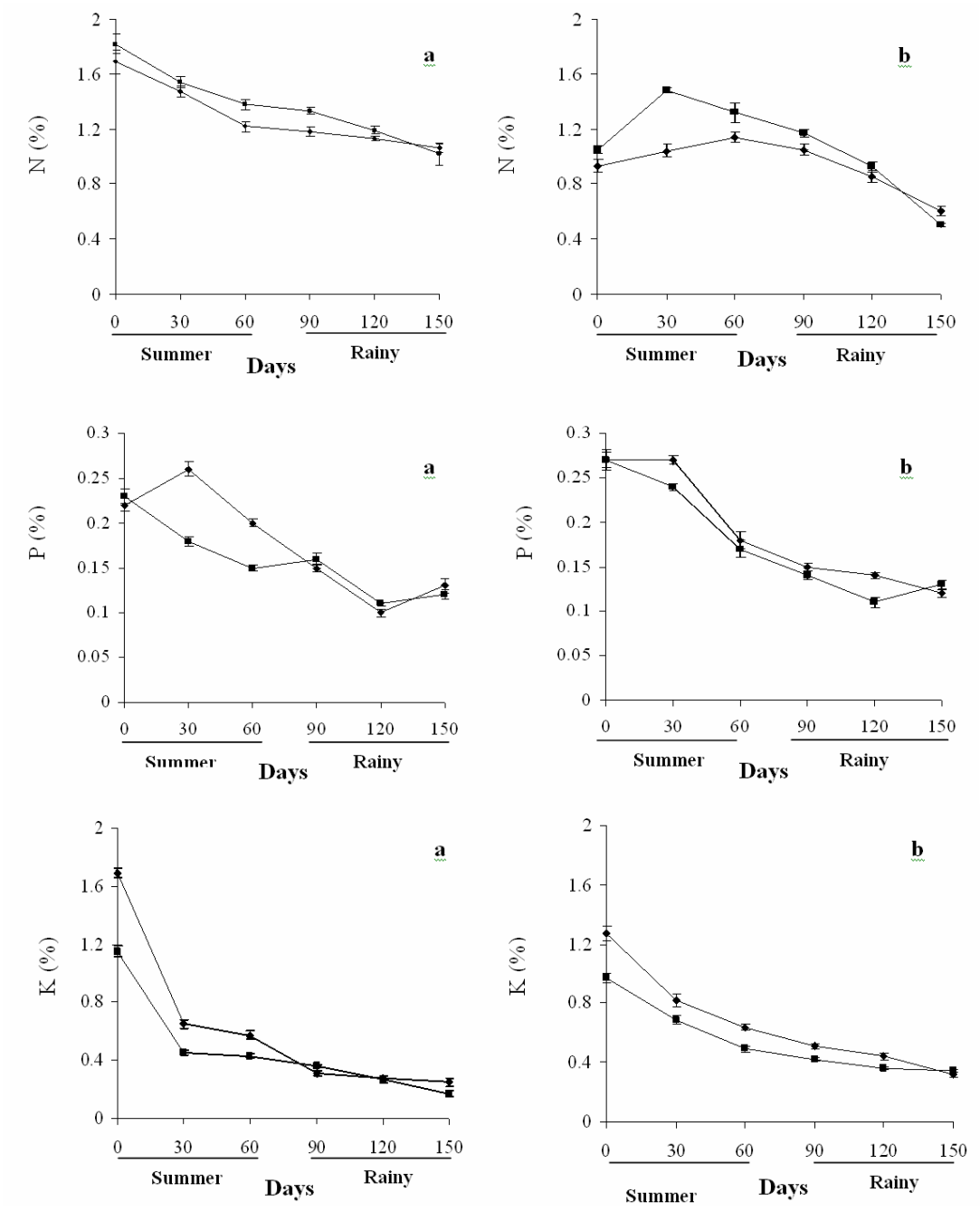

Figure 4. Elements (N, P and K) concentration during different stages of decomposition in (a) foliage and (b) roots of ◆ *Ageratum conyzoides* and ■ *Spilanthes paniculata*.

Similar to the decay rate coefficient, the element release rate coefficients (k_N, k_P, k_K) also followed a biphasic release pattern and were best fitted by a polynomial model in all residues (Table 6). In the case of the three fast decomposing residues, rapid N release in the first phase was continued up to 60 d of decomposition (1.15-1.47% day^{-1}), and this was followed by a slower phase (0.66-0.99% day^{-1}). However, there was an opposite trend in *Ageratum conyzoides* roots. Phosphorus release followed a similar trend in all decomposing litters with rapid nutrient release (1.08-1.47% day^{-1}) in the initial 60 d, followed by a comparatively slower rate (0.68-0.90% day^{-1}) in the later stage. Rapid K release in all residues only lasted for the initial 30 d (1.84-2.86% day^{-1}); afterwards the rate slowed (0.63-0.75% day^{-1}).

The release rate coefficient of N, P and K in the weed residues varied from 3.65 to 8.03, 4.75 to 8.40 and 7.3 to 9.86, respectively (Table 4). The rate of nutrient release from decomposing plant materials depends on whether they are combined in the components such as the cell lumen (N and P), with structural materials (C) or are largely present in ionic form (K) in cell vacuoles (Khalid et al., 2000). The early increase in N concentration *in situ* root incubation may be due to their anatomical structure as well as fungal translocation and microbial immobilization (Blair et al., 1990). The initial decline in foliage N concentration may be due to mineralization and leaching (Christensen, 1985). Generally, plant foliage has a higher percentage of parenchyma tissue. It is possible that this resulted in faster weight loss and mineral nutrients loss. About 10-25% of N was liable to mechanical leaching from soft tissues (Gosz et al., 1973). Loss of P was slightly faster than mass loss, as 64-88% of total P content of the fresh material released within 60 d of incubation (Table 3). However, at the end of the study in the three fast decomposing materials i.e., foliage and root of *Spilanthes paniculata* and foliage of *Ageratum conyzoides*, the P concentration increased slightly indicating that below a certain concentration the rate of P immobilization exceeds the mineralization rate. This may be due to C:element ratios of plant residues, below the level at which it becomes limiting to decomposition organisms (Swift et al., 1979). This was also evident from the decreased microbial population isolated from decomposing materials after 60-120 d of field incubation. Potassium, a non-structural plant component (Arunachalam and Singh, 2004), is highly mobile and subjected to loss by leaching (Deka and Mishra, 1984; Christensen, 1985). Maximum (55-90%) K release occurred during the initial 30 d of decomposition. Larcher (1995) reported that K leaching from decomposing litter was influenced by environmental factors rather than microbial activity. However, in this work the nutrient release rate did not show a significant relationship with the amount of rain (Table 6). This may be due to adequate rainfall (220.9-786.4 mm month^{-1}) throughout the study period. Despite these variations, K and other elements concentration in the decaying materials were positively correlated with its dry mass ($P < 0.001$). A similar trend was observed for tree leaf litter (Prescott et al., 1993), for fine root, and leaf litter in regenerating forest stands (Arunachalam et al., 1998).

Based on the report that good quality residues with C:N of < 25 decompose and release nutrients faster (Myers et al., 1993), residues of *Spilanthes paniculata* and foliage of *Ageratum conyzoides* are of good quality. The initial N concentration and fungal population showed a significant positive relationship with the rate of decomposition. However, the lignin and cellulose concentration and the C:N and lignin:N ratios showed a significantly negative correlation with decomposition rate. Thus, initial N, lignin and the C:N ratio are intrinsic factors that regulate the microbial colonization, and diversity eventually determines the decomposition rate of weed residues under shifting cultivation. It is well established that the environmental factors of rainfall and temperature influence decay rate, nutrient release and the microbial population of decomposing litter. However, no relationship of decay, nutrient release and microbial population with environmental variables was found in this study. This may be due to favorable conditions throughout the experimental period. Thus, high resource quality, faster decay and favorable environmental conditions as well as suitable fungal flora for fast decomposition suggest that the weed residues could be recycled in the input systems

to compensate for nutrient loss due to crop harvest for better soil nutrient management. After one crop about 2,915 kg ha^{-1} of plant biomass was taken from the field. This removed about 35 kg N, 8 kg P and 54 kg K ha^{-1}. As the life span of the selected weed residues was 4–8 months and they decomposed in 5 months, they alone could recycle about 21 kg N, 3 kg P and 21 kg K ha^{-1} in a year. Further, these plants grow abundantly in any degraded land in this region, so incorporation of these residues in the form of compost in agricultural field can rapidly recycle soil nutrients.

Table 3. Decay rate and elements (N, P, K) release rate coefficient (mg day^{-1} and % day^{-1}) during different phases of decomposition (Phase 1 = 0-60 d (summer); Phase II = 61-150 d (rainy season).

Species	k (mg)	%	k_N (mg)	%	k_P (mg)	%	k_K (mg)	%
Ageratum conyzoides (foliage)								
Phase I	24	1.27	0.029	1.38	0.025	1.30	0.065	2.86
Phase II	9	0.60	0.010	0.66	0.014	0.79	0.012	0.63
Ageratum.conyzoides (roots)								
Phase I	11	0.80	0.007	0.54	0.017	1.08	0.027	1.84
Phase II	5	0.43	0.013	0.79	0.010	0.68	0.019	0.74
Spilanthes paniculata (foliage)								
Phase I	28	1.36	0.036	1.47	0.036	1.47	0.063	2.83
Phase II	12	1.08	0.012	0.74	0.014	0.79	0.018	0.74
Spilanthes paniculata (roots)								
Phase I	23	1.23	0.019	1.15	0.031	1.41	0.031	2.03
Phase II	14	0.80	0.024	0.99	0.018	0.90	0.019	0.75

Table 4. Daily decay rate and elements release rate coefficient of decomposing weed residues (k decay rate coefficient; t_{50} half life period and t_{99} time required for 99% decomposition).

	Ageratum conyzoides		*Spilanthes paniculata*	
	Foliage	roots	Foliage	roots
Mass loss				
k	6.57	2.92	7.67	7.30
t_{50} (d)	38.50	86.23	33.00	34.65
t_{99} (d)	277.78	625.00	238.10	250.00
Nitrogen				
k_N	6.57	3.65	8.03	8.03
t_{50} (d)	38.50	69.30	31.50	31.50
t_{99} (d)	277.78	500.00	227.27	227.27
Phosphorus				
k_P	6.57	4.75	8.40	8.40
t_{50} (d)	38.50	53.31	30.13	30.13
t_{99} (d)	277.78	384.62	217.39	271.39
Potassium				
k_K	8.03	7.3	9.86	8.03
t_{50} (d)	31.5	34.65	25.67	31.5
t_{99} (d)	227.27	250.00	185.19	227.27

Table 5. Population of fungal species (g^{-1} dry litter x 10^3) associated with decomposing residue.

Fungal species	Days					
	0	30	60	90	120	150
***Ageratum conyzoides* (Foliage)**						
Acrimonium butyri	–	–	–	10.59	–	–
Arthoderma tuberculatum	–	–	1.28	–	–	–
Aspergillus flavus	–	–	–	1.06	4.04	1.18
Aspergillus fumigatus	–	–	1.28	–	–	–
Cercospora sp.	–	–	6.28	–	–	–
Cladorrhinum foecundissimum	–	–	–	2.12	2.36	–
Cladosporium cladosporioides	–	–	–	2.12	2.36	–
Cladosporium herbarum	–	–	21.03	–	–	–
Cladosporium macrocarpum	1.6	5.16	11.28	12.71	–	–
Chrysosporium merdarium	1.73	8.55	–	–	–	–
Geotrichum candidum	–	3.39	2.56	–	1.8	–
Humicola fuscoatra	–	–	8.72	–	–	–
Metarrhizium sp.	5.07	–	–	–	–	–
Monilia sp.	–	–	–	1.06	–	–
Mortierella elongata	3.33	6.77	–	–	–	–
Mortierella gamsii	–	–	–	–	–	2.26
Mucor racemosus	–	–	–	–	–	2.26
Penicillium canescens	–	1.61	12.56	–	–	–
Penicillium frequentans	–	–	2.56	1.18	–	–
Penicillium brevicompactum	–	–	3.72	9.53	7.08	4.62
Trichoderma koningii	–	–	1.28	–	–	–
Verticillium albo-atrum	–	–	–	–	4.61	2.26
Verticillium nigrescens	–	–	–	–	5.84	2.26
Sterile form	–	–	–	7.41	8.09	5.81
Total	**11.73**	**25.48**	**72.55**	**47.78**	**36.18**	**20.65**
***Ageratum conyzoides* (Roots)**						
Aspergillus niger	–	–	–	–	–	1.21
Cladosporium cladosporioides	–	–	–	–	1.52	–
Cladosporium sp.	–	–	–	–	–	2.31
Geotrichum candidum	1.22	3.21	2.59	6.67	9.87	–
Monilia sp.	–	1.54	–	–	–	–
Mortierella elongata	2.44	–	2.47	6.67	–	–
Nigrospora sphaerica	1.46	–	10.62	17.86	–	–
Penicillium brevicompactum	–	–	1.23	2.38	15.57	10.44
Penicillium chrysogenum	–	–	–	–	2.78	–
Verticillium sp.	–	4.74	1.60	–	–	2.31
Sterile form	–	–	–	–	11.27	3.52
Total	**5.12**	**9.49**	**18.52**	**33.57**	**41.01**	**19.78**

Continued...

Spilanthes paniculata (Foliage)						
Aspergillus niger	–	–	–	–	2.33	1.17
Botrytis cinera	–	–	–	–	–	0.53
Cladosporium cladosporioides	1.67	–	–	–	1.16	–
Fusarium sporotrichioides	–	–	–	–	–	0.53
Geotrichum candidum	–	–	9.47	12.08	2.33	–
Humicola fuscoatra	–	–	–	–	2.33	–
Monilia sp.	–	–	–	–	1.16	–
Mortierella elongata	2.78	1.49	4.08	5.14	–	–
Oidiodendron griseum	–	–	–	–	–	0.53
Penicillium brevicompactum	–	–	–	–	–	3.94
Penicillium canescens	1.67	–	–	–	–	–
Penicillium coccosporum	–	1.49	–	–	–	–
Penicillium fellutanum	–	–	2.76	3.47	–	–
Staphylotrichum coccosporiodes	–	4.46	–	–	–	–
Verticillium sp.	–	–	–	–	–	1.70
Sterile form	–	5.95	–	1.67	3.49	0.53
Total	**6.11**	**13.38**	**16.32**	**22.36**	**10.47**	**7.23**
Spilanthes paniculata (Roots)						
Acremonium butyri	–	–	–	–	–	1.89
Aspergillus fumigatus	–	–	8.64	17.38	–	–
Aspergillus niger	–	–	–	–	4.70	–
Cercospora sp.	–	–	–	1.19	–	–
Chalaropsis sp.	–	–	–	3.45	–	–
Cladosporium cladosporioides	–	–	–	1.19	2.29	–
Chrysosporium sp.	–	–	–	2.26	–	–
Humicola grisea	–	–	3.70	1.19	4.70	–
Monilia sp.	–	–	–	1.19	2.29	–
Mortierella bisporalis	–	–	–	–	–	1.89
Mortierella verticillata	–	–	6.17	2.26	–	–
Mortierella wolfii	–	–	–	2.26	–	–
Nectria ventricosa	–	–	–	–	–	0.63
Nigrospora sphaerica	1.28	4.61	1.23	2.26	–	–
Oidiodendron griseum	–	–	–	–	–	2.63
Oidiodendron sp.	–	1.58	–	–	–	–
Penicillium brevicompactum	–	–	–	–	–	1.37
Penicillium canescens	2.56	3.03	–	2.26	–	–
Verticillium sp.	3.85	7.63	–	–	–	–
Sterile form	–	–	–	1.19	6.99	1.89
Total	**7.69**	**16.84**	**19.75**	**38.10**	**20.96**	**10.32**

Table 6. Relationship between weight loss (% day^{-1}) with initial litter chemistry and nutrient release (% day^{-1}) as well as microbial population with different element concentrations and environmental condition.

Interactions	Regression equation	*df*	*r*	*P*
Weight loss (% day^{-1}) vs. initial element concentrations				
N	$y = 0.1279 + 0.1221x$	19	0.549	0.005
P	$y = 0.613 - 1.2829x$	19	–0.431	ns
K	$y = 0.4066 - 0.0864x$	19	–0.263	ns
C	$y = 0.801 - 0.0149x$	19	–0.392	ns
Lignin	$y = 0.6411 - 0.0235x$	19	–0.894	0.001
Cellulose	$y = 0.03x - 0.4187$	19	–0.644	0.005
C/N	$y = 0.4669 - 0.215x$	19	–0.557	0.005
Lignin/N	$y = 0.4397 - 0.0118x$	19	–0.799	0.001
Days of incubation vs. weight remaining (g)				
Ageratum conyzoides (foliage)	$y = 0.0003x^2 - 0.0753x + 4.5614$	29	–0.959	0.001
A. conyzoides (roots)	$y = 0.0002x^2 - 0.0466x + 4.8824$	29	–0.991	0.001
Spilanthes paniculata (foliage)	$y = 0.0004x^2 - 0.0832x + 4.6535$	29	–0.976	0.001
S. paniculata (roots)	$y = 0.0003x^2 - 0.0735x + 4.8276$	29	–0.990	0.001
Weight loss (% day^{-1}) vs. element release (% day^{-1}), rainfall (mm) and temperature (°C)				
N	$y = 0.0022 + 1.0915x$	19	0.815	0.001
P	$y = 0.0123 + 0.5289x$	19	0.558	0.005
K	$y = 0.0111 + 0.9043x$	19	0.516	0.005
Rainfall	$y = 0.0155x - 2.593$	19	0.644	0.005
Temperature	$y = 1.1342x - 22.521$	19	0.641	0.005
Rainfall vs. bacterial population	$y = -0.0008x^2 + 0.7088x - 60.598$	23	0.528	0.005
Weight loss vs. bacterial population	$y = -0.1187x^2 + 5.1574x + 49.948$	23	0.268	ns
Rainfall vs. fungal population	$y = -0.0003x^2 + 0.2226x - 12.352$	23	0.538	0.005
Weight loss vs. fungal population	$y = -0.1232x^2 + 2.1353x + 21.024$	23	0.197	ns
N vs. fungal population	$y = -41.566x^2 + 93.582x - 26.489$	23	0.562	0.005
N vs. bacterial population	$y = -93.768x^2 + 193.96x - 32.544$	23	0.468	ns
P vs. fungal population	$y = 43.365e^{-5.0193x}$	23	0.422	ns
P vs. bacterial population	$y = 171.11e^{-8.7687x}$	23	0.504	0.005
K vs. fungal population	$y = 30.121e^{-0.8906x}$	23	0.489	0.005
K vs. bacterial population	$y = 79.429e^{-1.3292x}$	23	0.499	0.005

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