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Plant Leaf Residue Decomposition, Nutrient Release and Soil Enzyme Activity

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Abstract

We studied the impact of plant leaf residue decomposition and nutrient release of nitrogen and phosphorus of two weed species - *Imperata cylindrica* and *Chromolaena odorata* - and one native forest species - *Phyllanthus discoideus* - on soil enzyme activities in a pot experiment in the humid tropics of central Cameroon. We tested the impact of plant leaf residue types on decomposition rate, nutrient release and enzyme activities in soil. We measured mass loss, nutrient release of nitrogen (N) and phosphorus (P) from decomposing residues, and soil enzymes of the carbon cycle (ß-glucosidase), N cycle (protease) and P cycle (acid and alkaline phosphatase) over 120 days.
Mass loss from both chromolaena and phyllanthus residues started immediately and was rapid, whereas mass loss from decomposing imperata leaves was only 24% after 90 days. Nitrogen and P release was greater from decomposing chromolaena and phyllanthus leaves than from imperata residues. After 120 days, chromolaena and phyllanthus plant leaf residues had released nearly three times as much of its initial pools of N and P than had imperata plant leaf residue. Beta-glucosidase activity was strongly affected by plant leaf residue types and mass loss. Knowledge on resource-use efficiency of invading weeds might help understand the processes affecting nutrient availability in soils through their return of plant leaf residues differing in quality.

Key words: weed infestation, residue decomposition, nutrient release, soil enzyme activity

Introduction

In central Cameroon weeds are becoming more and more of a problem due to soil degradation caused by intensive agriculture (Degrande, 2001; Norgrove, submitted). *Chromolaena odorata* (L.) King & Robinson and *Imperata cylindrica* (L.) Raeusch, are major invasive weeds in both tree and food crop systems in Cameroon (Norgrove et al., 2000). Both species are perceived by farmers as troublesome weeds, increasing labor requirements for weeding and decreasing crop yield and crop quality (Chikoye et al., 2000). However plant biomass and other organic resources play a dominant role in soil fertility management of smallholder farming systems in the tropics (Palm et al., 2001). The turnover and mineralization of residues largely depends on soil biological processes, and its decomposition by soil microorganisms ensures the recycling of nutrients that can be then reused by plants and microbes. The majority of the plant biomass is comprised of

insoluble compounds that require enzymatic activity to decompose (e.g. Carreiro et al., 2000; Sinsabaugh and Moorhead, 1994; Sinsabaugh et al., 2002).
We studied the impact of plant leaf residue decomposition and nutrient release of two weed species - *Imperata cylindrica* and *Chromolaena odorata* - and one native forest species - *Phyllanthus discoideus* - on soil enzyme activities in a pot experiment in the humid tropics of central Cameroon. We tested the impact of plant leaf residue types on decomposition rate, nutrient release and enzyme activities in soil. We measured mass loss, nutrient release of N and P from decomposing residues, and soil enzymes of the C cycle (ß-glucosidase), N cycle (protease) and P cycle (acid and alkaline phosphatase) over 120 days. The results will show if differences in plant leaf residues influence the decomposition rate, nutrient release and soil enzyme activity.

Materials and methods
The study site was located at IITA (International Institute of Tropical Agriculture) in near Yaoundé, Cameroon at 3°51` N and 11°31` E. Mean annual temperature is between 24 and 27^{o}C. Rainfall distribution is bimodal, averaging 1600 mm per year with long rains from March to July and a short rainy season from September to November. Soils of the study area were ferric Acrisols and Ferralsols (FAO, 2001).
We conducted a pot experiment outdoors under ambient conditions in which native *Phyllanthus discoideus* (phy) and weedy plant leaf residues of *Imperata cylindrica* (imp) and *Chromolaena odorata* (chr) were crosswise incubated on soils originating from under different vegetations. The soils were similar in chemical and physical properties however they had been under either *Imperata, Chromolaena* or natural forest vegetation for several years (Norgrove, submitted). Soils were taken with a shovel from the 0 to 5 cm depth, sieved, filled into bottom-punched plastic pots and the three plant leaf residue types were incubated on the surface of the pots. Each combination was replicated 4 times. Non-amended soils served as reference (nil). The amendment of the plant leaf residue per pot corresponded to 15 t ha $^{-1}$ dry mass, and match realistic production rates for natural or managed systems (Ibewiro et al., 2000; Tian et al., 2000). Soils and plant residues samples were taken at 0, 20, 40, 60, 90 and 120 days after incubation (DAI). Soil samples for enzyme analyses were kept field moist, sieved to pass a 4 mm sieve and stored in sealed plastic bags at 4°C until analyses. Beta-glucosidase activity in the soil was measured according to Eivazi and Tabatabai (1988). Results of enzyme activity are expressed as micrograms p-nitrophenol (pNP) released per g of dry soil per hour. The plant leaf residues were oven dried at 60°C to constant mass and ground to 0.5 mm. The ash-free dry weight (DW) was recorded. Total N was determined with an ammonium sensitive electrode (Powers et al., 1981), and total P content was determined by the malachite green colorimetry procedure (Motomizu et al., 1983).
Statistical analysis was performed with SYSTAT Program version 10.2 (SYSTAT, 2002). Soil chemical and biochemical characteristics were statistically analyzed by ANOVA using soil, plant leaf residue and time as main factors. Treatment differences were determined by using Tukey's Honestly Significant Difference test (HSD) at the 95% confidence level.
Pearson's correlation coefficient r was used to describe the degree of linear association between soil enzyme activity, DM loss and release of N and P from decomposing plant leaf residues.

Results
Mass loss from both chromolaena and phyllanthus plant leaf residues started immediately after the beginning of the incubation study (Figure 1). After 3 weeks (20 DAI), 40% of both plant leaf residues was decomposed. Thereafter, loss of decomposing phyllanthus leaves was faster than of chromolaena plant leaf residue and after 60 days, 40% of the initial chromolaena leaves remained but only 20% of the initial phyllanthus leaves. At the end of the decomposition study after 120 days, 4% of the initial phyllanthus biomass remained whereas, on average, 24% of initial chromolaena leaf plant leaf residue remained undecomposed. By contrast, imperata decomposed

slowly with only 24% of its dry matter lost in 90 days. After 90 days, however, mass loss increased greatly, losing more than 60% of its dry weight within 30 days (Figure 1). At the end of our decomposition experiment (120 days) about 20% of the initial biomass remained, similarly to chromolaena.

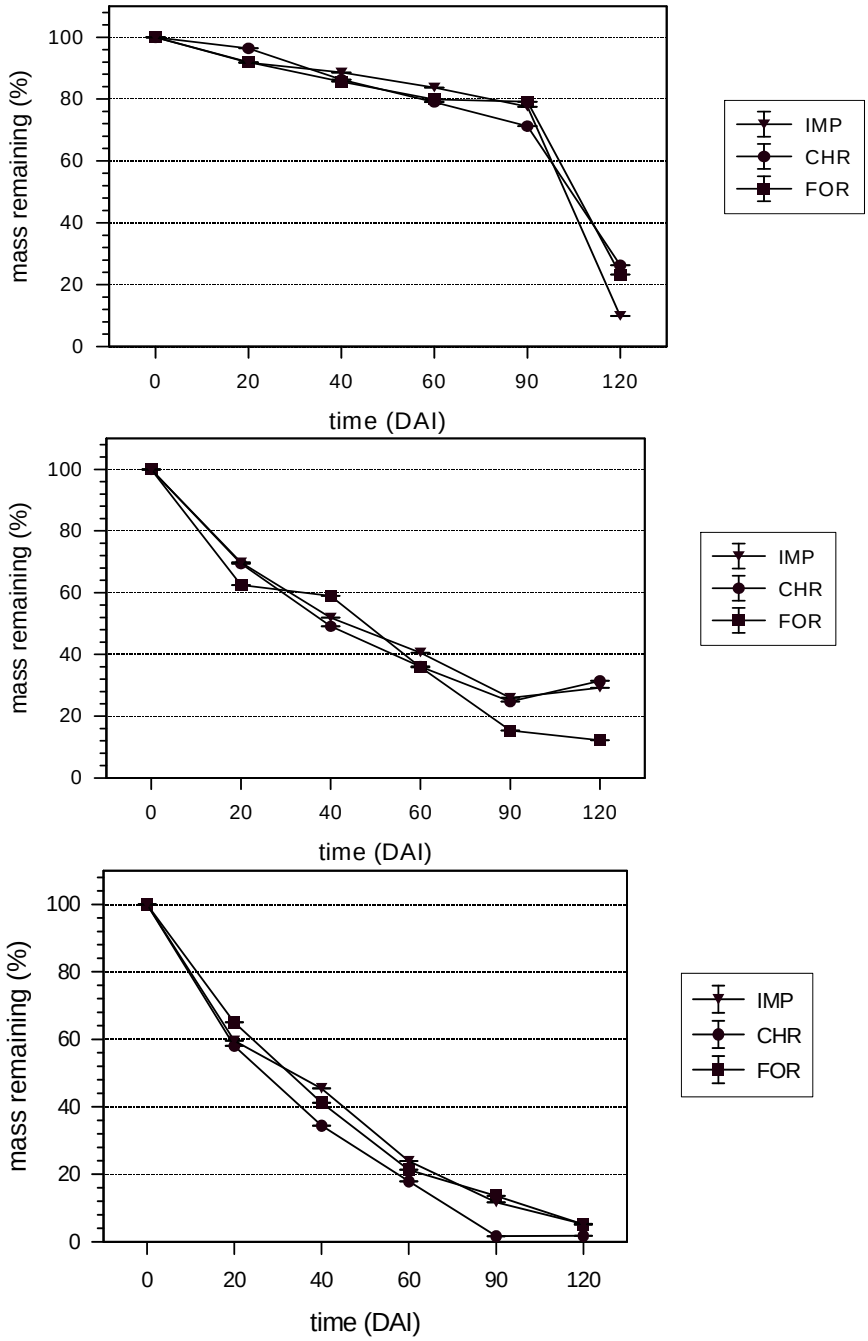

Figure 1. Decomposition of leaves of *Imperata cylindrica* (top), *Chromolaena odorata* (middle) and *Phyllanthus discoideus* (bottom), on soils sampled under imperata (Imp), chromolaena (Chr) and forest (For) vegetation over 120 days at Yaoundé, Cameroon in 2004.

Nitrogen release (g N pot^{-1}) from decomposing plant leaf residues was highest during the first 60 days. It was, on average, 3 g per pot for both phyllanthus and chromolaena leaves, and 0.54 g for imperata leaves. At the end of our decomposition experiment at 120 days, twice as much (80%) of the initial N content remained in the imperata plant leaf residue compared to both chromolaena phyllanthus leaves which retained about 40% of the initial N content in their plant leaf residue. The release of P from imperata leaf residues amounted to about 70 mg per pot (60%), half the amount released from phyllanthus leaves, 130 mg or 80%. After 120 days, total amount of P released from decomposing chromolaena and phyllanthus leaves (150 mg) was twice the amount mobilized from imperata leaves (70 mg per pot).

During the first 40 days of leaf decomposition, the activity of ß-glucosidase remained rather stable at about 40 to 50 µg pNP g^{-1} h^{-1}, and no significant differences between the plant leaf residues were found (Figure 2). After 60 days, the activity of ß-glucosidase had increased about 4 to 5 fold in soils amended with chromolaena and phyllanthus leaves but only 2 fold in soils under imperata plant leaf residues. At the end of our decomposition experiment at 120 days, the activity of ß-glucosidase was significantly higher under chromolaena (323 µg pNP g^{-1} h^{-1}) than under phyllanthus (141 µg pNP g^{-1} h^{-1}) and imperata (49 µg pNP g^{-1} h^{-1}).

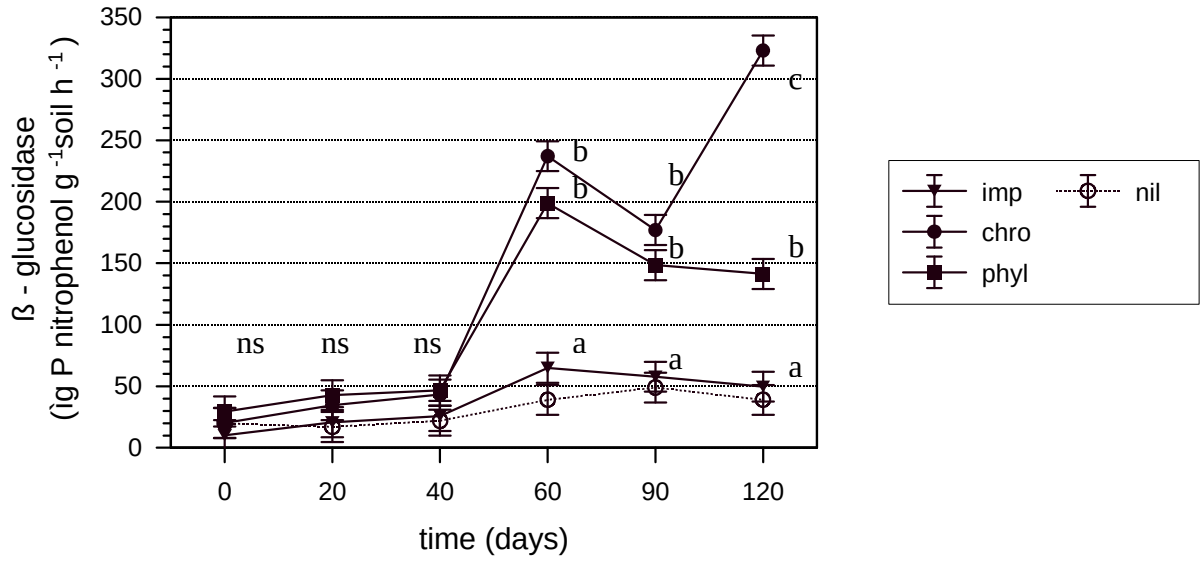

Figure 2. Temporal variability of ß - glucosidase activity in topsoil (0 - 3 cm) amended with imperata (imp), chromolaena (chr) and phyllanthus (phy) leaves during 120 days at IITA, Yaoundé, Cameroon in 2004. Data are averaged over soils.

Discussion

Whereas mass loss from both chromolaena and phyllanthus residues started immediately and was rapid, mass loss from decomposing imperata leaves was only 24% during the first 90 days of decomposition. Our results confirm studies with litter bags conducted under similar conditions (Ibewiro et al., 2000; Norgrove et al., 2000; Tian et al., 2000). Throughout the decomposition study, mass loss (Figure 1) from decomposing phyllanthus and chromolaena leaves always exceeded N and P loss. Mass loss from decomposing residues is regulated by plant leaf residue quality (e.g. Allison and Vitousek, 2004a; Palm and Sanchez, 1991). Initial plant leaf residue C:N ratios of 25 (or N contents of 2.5%) have been suggested as the threshold controlling immobilization (C:N > 25) versus mineralization (C:N < 25) (e.g. Hendrickson, 1985; Wagger et al., 1998). Although the initial C:N ratio was 60 for imperata residues (N content was 1%) and 10

for both chromolaena and phyllanthus leaves (> 4% N) we did not find N immobilization in decomposing plant leaf residues throughout our decomposition study . Other studies reported that structural plant compounds such as lignin (L) and polyphenols (PP) regulated mass loss and nutrient release from decomposing plant leaf residues. Thresholds were 15% for L, 3% for PP or 10 for the ratio L and PP over N (Oglesby and Fownes, 1992; Palm and Sanchez, 1991). Plant materials above these thresholds are expected to decompose slowly and to immobilize N due to the formation of stable polymers between polyphenolics and amino groups and/or binding of lignin to cellulose. We did not determine L and PP contents of the leaf tissues but other studies conducted near our site in Cameroon (Norgrove et al., 2000) and under similar soil and climatic conditions in Nigeria (Ibewiro et al., 2000; Tian et al., 2000) reported higher L and PP contents and a higher (L+PP)/N ratio for imperata leaf material of 18%, 4.6% and 33, respectively, and low values for chromolaena plant leaf residue averaging at 10%, 2.3% and 3.1, respectively.

Beta-glucosidase activity was positively correlated with mass loss. Relative to the non-amended soils, the activity of ß-glucosidase started to increase rapidly with time (Figure 2). In the initial decomposition process, easily decomposable plant components such as low molecular weight cellulolytic substances are released rapidly. They act as substrate for ß-glucosidase and other cellulolytic enzymes (Sagar, 1988). Therefore, their activity increased with time which later may decrease as cellulose is being decomposed and used by microorganisms, and more recalcitrant plant leaf residue remains (Sall et al., 2003). Because the quantity of the leaf biomass applied to each soil was alike, differences in activity of ß-glucosidase likely resulted from quality differences of the amended plant leaf residues. Chromolaena and phyllanthus plant leaf residues had comparatively lower L and PP contents and thus induced higher ß-glucosidase activities than imperata leaf residues. Polyphenols may inhibit ß-glucosidase activity (Benoit and Starkey, 1968; Swain, 1979) while L may impede the growth of cellulolytic bacteria and fungi (Roper and Gupta, 1995), leading to lower mass loss rates and lower decomposition of carbohydrates from the recalcitrant imperata leaf residues. In addition, the physical characteristics of the plant leaves and their placement as surface mulch on top of the soils may have affected ß-glucosidase activity. Imperata leaf material is very bulky and rigid compared to chromolaena and phyllanthus leaves. Therefore, the poor imperata residue-soil contact and the high toughness of the imperata leaf stalks may have delayed colonization by microorganisms and limited enzyme diffusion (Cornelissen et al., 1999; Henriksen and Breland, 2002).

Conclusion

In conclusion, plant leaf residue type had a strong impact on mass loss and nutrient release of N and P from decomposing phyllanthus, chromolaena and imperata residues. After 120 days, chromolaena and phyllanthus plant leaf residues had released nearly three times as much of its initial pools of N and P than had imperata plant leaf residue. Beta-glucosidase was greatly affected by plant leaf residue type and mass loss. Low input farming in the humid tropical regions is affected by weed infestation and land degradation. Knowledge on resource-use efficiency of invading weeds might help understand the processes affecting nutrient availability in soils through their return of plant leaf residues differing in quality.

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