Accepted Manuscript
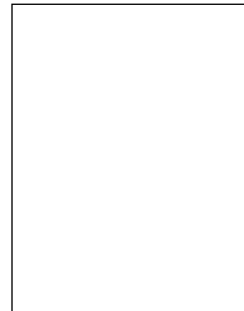
Title: N availability, soil microbial biomass and β-glucosidase activity as influenced by the decomposition of nine plant residues during soil fertility improvement in Ghana

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N availability, soil microbial biomass and β-glucosidase activity as influenced by the decomposition of nine plant residues during soil fertility improvement in Ghana

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ABSTRACT

This study wasconducted to determine how the litter quality and decomposition of nine species (*Acacia auriculiformis, Albizia zygia, Azadiractha indica, Baphia nitida, Gliricidia sepium, Leucaena leucocephala, Tithonia diversifolia, Senna spectabilis and Zea mays*) influence soil N availability, microbial biomass and β-glucosidase activity during soil fertility improvement. The results on plant residue chemistry showed significant differences among species with N concentration ranging from 12.2 g kg^{-1} in *Z. mays* to 39.2 g kg^{-1} in *B. nitida.*C/N ratio was greatest in *Z. mays* (34.4) while lignin and polyphenol concentrations were greatest in *A. auriculiformis.* The highest decomposition rate (0.251% day^{-1}) occurred in *T. diversifolia* and least in *A. auriculiformis*, *A. zygia*, *B. nitida* and *Z. mays* with half-lives of between 28 – 56 days. Similar to the results on decomposition, between 80 to 89% of N, P, K, Ca and Mg were released from *T. diversifolia* within 7 days compared with more than 70% retention in *A. auriculiformis*, *B. nitida* and *Z. mays.* Moreover, the half-lives of decomposition and nutrient release of *G. sepium*, *L. leucocephala*, *A. indica* and *S. spectabilis*were within 14 days. Mineral N, soil microbial biomass and β-glucosidase activities increased in all treatments with *T. diversifolia* recording the greatest effect. While N mineralization occurred in all species throughout the experiment, an initial N immobilization was recorded in *A. zygia*, *B. nitida*, *A. auriculiformis* and *Z. mays* treatments for up to 14 days. Further, the results showed the decomposition, nutrient release rates, mineral N, soil microbial biomass and β-glucosidase activities were dependent on litter quality. Phosphorus, lignin, lignin/N ratio and (lignin + polyphenol)/N ratio were most influential based on significant (p ≤ 0.05) results.

Key Words: leguminous species; litter quality; soil fertility;organic matter

INTRODUCTION

Like most parts of sub-Saharan Africa, soil fertility remains a major constraint to improving crop productivity in Ghana.For several decades, efforts to mitigate soil fertility challenges have sought several cost-effective agricultural interventions such as agroforestry and conservation agriculture which encourages the use of organic resources (including crop residues, tree/shrub

prunings and green manure).The use of organic resources on farmlands improves soil fertility and remainscrucial for many areas of the humid and sub-humid tropics dominated by soils of low cation exchange capacity (Partey and Thevathasan, 2013). Whilst there is significant evidence to substantiate the agronomic importance of organic resources, the major challenge for most farmers is how to choose the most appropriate plant residue for soil improvement practices.

Research conducted by Palm *et al*. (2001) and Mafongoya *et al*. (1998) provided a selection criterion and decision support system for organic resource use and management based on their chemistry (mainly N, P, C/N, lignin and polyphenol compositions) and decomposition patterns.High quality organic residues (generally high in N with low C/N ratio, lignin and polyphenols contents) decompose relatively faster and can be solely incorporated into soils for increased net N mineralization. Conversely, the incorporation of low quality organic resources with low N concentration and wide C-to-N ratio could result in initial net N immobilization unless supplementary N is provided through the application of N fertilizers (Bhupinderpal-Singh and Rengel, 2007; Troeh and Thompson, 2005). While the recommendations of Palm *et al*. (2001) and Mafongoya *et al*. (1998) remain useful in predicting decomposition and nutrient release of plant residues the influence varies among species, residue management and environmental conditions.With several indices proposed for predicting decomposition and nutrient release from plant litter (Finn *et al*., 2015; Partey *et al*., 2014), it is necessary to identify litter chemical characteristics that allow for a quantitative prediction of the time course of nutrient release from the leaf biomass of specific species (Schroth, 2003). With such information, we should be able to tailor residue management practices that positively affect soil biological properties and maintains high nutrient status and organic matter in smallholder agroecosystems.

In several parts of sub-Saharan Africa, wide ranges of experiments have confirmed the fertilizer equivalency values and high nutrient supply capabilities of the leaf biomass sources of *Acacia auriculiformis, Albizia zygia, Azadiractha indica,Baphia nitida, Gliricidia sepium, Leucaena leucocephala, Tithonia diversifolia, Senna spectabilis and Zea mays* (Beedy *et al*., 2010; Partey *et al*., 2011; Vanhie *et al*., 2015). However, only few studies quantifying decomposition and nutrient release from the leaf biomass of the species have related nutrient release from biomass to soil fertility indicators such as N availability, soil microbial biomass and β-glucosidase activities. N mineralization, β-glucosidase and the microbial biomass have been cited in the literature as useful indicators of organic matter decomposition and soil fertility (Pal and Panwar, 2013; Stott *et al*., 2010). Information on the influence of plant residue decomposition on such soil parameters should be relevant in suggesting how plant residues could be managed for improved nutrient synchronization and utilization efficiency within cropping systems (Hobbie, 2015). It was therefore the objective of this studyto determine how thelitter quality and decomposition of *A. auriculiformis, A. zygia, A. indica,B. nitida, G. sepium, L. leucocephala, T. diversifolia, S. spectabilis and Z. may* influencesoil N availability, microbial biomass and β-glucosidase activity.

MATERIALS AND METHODS

Study site

The study was conducted at the agroforestry demonstration field of the Faculty of Renewable Natural Resources (FRNR), Kwame Nkrumah University of Science and Technology, Kumasi (KNUST), Ghana, located at latitude 01 43° N and longitude 01 36° W. The

research area had lied fallow for five years prior to the execution of this study. The area falls within the moist semi-deciduous forest zone of Ghana, characterized by a bimodal rainfall pattern, with the major wet season between May and July. This area also experiences a short dry season in August and a long one between December and March. The annual rainfall of the area ranges between 1, 250 and 1, 500 mm. The area is characterized by a mean annual temperature of 26.6 ^{o}C and a mean annual humidity of 67.6%. Climatic data recorded during the research period are shown in Figure 1. Soil type at study site is a ferric acrisol(Partey *et al*., 2011).

Initial soil characterization

Prior to setting up the experiment, soil samples were randomly collected at the surface 0 – 20 cm from 16 locations at the experimental site for baseline characterization using a stainless steel soil auger (10 inches in diameter). The samples were composited and homogenized into one sample from the 16 sub-samples. They were then air-dried and sieved to 2-mm size before being analyzed using four replicated sub-samples from the composited sample. Soil pH was measured with a glass electrode (1: 1 H_2O), particle size using the hydrometer method, total nitrogen was determined by dry combustion using LECO TruSpec^{TM} CN autoanalyzer (LECO Corporation), organic carbon by the dichromate oxidation method (Motsara and Roy 2008), cation exchange capacity by flame photometry using ammonium acetate extract, available P by ammonium phosphomolybdate method and available K by flame photometry (Toth and Prince 1949). The physicochemical properties of the soil at the beginning of the experiment were: pH (4.6), total N (0.42 g kg^{-1}), available P (2.1 mg kg^{-1}), available K (224.0 mg kg^{-1}), organic C (13.8 g kg^{-1}), CEC (5.8 cmol$_c$ kg^{-1}), sand (67.6%), silt (28.4%) and clay (4.0%).

Plant residue characterization

The species used in the experiment were: *Albizia zygia, Azadirachta indica, Acacia auriculiformis, Baphia nitida, Gliricidia sepium, Leucaena leucocephala, Senna spectabilis, Tithonia diversifolia* and *Zea mays*.The selection of these species was based on their relative abundance at the study area and their confirmed fertilizer equivalency values and nutrient supply capabilities. Except for dried maize stover collected from an adjacent cropping field, the fresh leaf biomass of the species including petioles, rachis and soft stemswere collected from already established fields at the study site. To determine the chemical composition of the plant residues they were oven dried at 65 ^{o}C for 72 hours, grounded with a grinder and sieved to 0.5 mm size. The sieved plant materials were analyzed for total N, P, K, Ca, Mg, C, lignin and polyphenolic compositions in four replicates. For all analyses, total N and C were determined simultaneously by dry combustion using LECO TruSpec^{TM} CN autoanalyzer (LECO Corporation) while total K, Ca, and Mg were determined by the dry ashing and atomic absorption spectrophotometery method as described by Eneji *et al*. (2005). Phosphorus was also determined in an ash solution by the ammonium phosphomolybdate method (Motsara and Roy, 2008) whilst lignin was determined according to the acid detergent fiber method. Polyphenols were determined by the method described by Gachengo *et al*. (1999). The general chemical characteristics of all plant materials used are reported in Table 1.

Decomposition studies

The decomposition and nutrient release patterns of the selected species were studied on the field using the litterbag technique. Fresh leaf biomass of the species equivalent to 20 g on a dry weight basis were collected from the study location and placed in a 30 x 30 cm rigid nylon litterbag of 1.5 mm mesh size. The litterbags were placed horizontally at 15 cm depth with 0.5 m spacing between them. Using plant species as treatments, litter bags were arranged in a randomized complete block design with four replications. At 7, 14, 28, 56 and 84 days of decomposition, four litterbags (representing four replicates) for each species were randomly selected to monitor dry matter and nutrient losses. Plant materials remaining in the litterbags at each sampling time were separated from soil and organic debris by hand and oven dried at 65 ^{o}C to constant weight. The oven-dried samples were separately weighed to determine dry matter losses and thereafter grounded to pass a 0.5 mm sieve for chemical analysis. The chemical analysis was done separately for each replicate. In order to correct for contamination by the mineral soil, samples were ashed at 450 ^{o}C for four hours. The difference between the dry weight of the decomposed leaves and their ash contents were taken as the ash-free dry weight. The amount of nutrients remaining in the litterbags at each sampling time was determined by multiplying the ash-free dry weight of the mass of leaves remaining by their nutrient concentrations.

Quantification of N mineralization and microbial activities

Incubation experiment was performed under laboratory-controlled conditions to determine N mineralization from the selected plant residues and their effects on soil microbial biomass and β-glucosidase activity. Briefly, 125 mg (equivalent to 5 t ha^{-1}) of 0.5 mm sieved dried and ground leaf biomass of the species were mixed with 50 g of 2 mm sieved sandy-loam soil in 250 ml beakers and incubated in the dark at 28 ^{o}C for 84 days. Unamended soil was used as a control. There were 24 beakers for every treatment. Prior to amending soil, the soil was preconditioned by moistening to 50% water holding capacity for five days. This was done to stabilize microbial activities (Xiang *et al*., 2008). The beakers were covered to prevent rapid loss of water due to evaporation. Soil moisture content was checked by weighing every other day and the weight loss was replaced by addition of distilled water. The moisture content was kept constant at 50% water holding capacity of the soil throughout the experiment. Nitrogen mineralization was determined by measuring the production of mineral N ($NH_4^+ + NO_3^-$) at 7, 14, 28, 56, and 84 days of incubation. Ammonium and nitrate were determined by extracting 25 g of moist soil with 2 M KCl at a 1:4 soil and extractant ratio. Ammonium and nitrate in the KCl extract were determined by the indophenol blue and phenoldisulphonic acid methods respectively (Motsara and Roy, 2008). All measurements were done by sampling four beakers per treatment on every sampling period. Analysis was done separately for each soil sample in a beaker. Net cumulative N mineralized from the different treatments was calculated by subtracting the inorganic N of the unamended control from amended soils at each sampling time (Abbasi and Khizar, 2012; Sistani *et al*., 2008). On the last sampling day of the N mineralization studies, soil microbial activities were estimated using the soil microbial biomass carbon and β-glucosidase activity as indicators. β-glucosidaseactivity was assayed by the method described by Eivazi and Tabatabai (1990). Soil microbial biomass carbon was determined using the chloroform fumigation and extraction method (Ladd and Amato, 1989). Soluble carbon in the 0.5 M K_2SO_4 extract of fumigated and

unfumigated soils was determined colorimetrically as described by Motsara and Roy (2008). The following equation according to Sparling and West (1998) was used to estimate the microbial C using k factor of 0.35 (Sparling *et al*., 1990):

$$MBC = E_C / k \tag{1}$$

Where E_C = the extracted C after fumigation − extracted C before fumigation, k = the fraction of the killed biomass extracted as carbon under standardized conditions.

Mathematical calculations and statistical analysis

Data collected on N mineralization, soil microbial biomass carbon, β-glucosidase activity and the decomposition and nutrient release rates of the species were analyzed using analysis of variance (ANOVA) test. Least significant difference at 5%probability level was used to make treatment comparisons. For the decomposition study, percent dry weight and nutrient remaining (on ash- free basis) were regressed on time using nonlinear regression models. Nonlinear regression models were produced using standard curve procedures in GENSTAT 11 (VSN International Ltd, 2008). The single three-parameter exponential model (Wieder and Lang, 1982) was used to determine the decomposition and nutrient release rate constant (*k*). The general form of the model was:

$$Y = D_o + D_i e^{-kt} + error \tag{2}$$

Where *Y* is the percent of initial material or nutrient remaining at sampling time *t*, D_o is the recalcitrant pool fraction and D_i is the difference 100 - D_o. Correlation and regression analyses were used to establish relationships among measured parameters.

RESULTS AND DISCUSSION

Chemical characteristics of plant residues

There were signifcant differences in the chemical composition of the species(Table 1). Nitrogen ranged from 12.2 g kg^{-1} in *Z. mays* stover to 39.2 g kg^{-1} in the leaf biomass of *B. nitida*. In addition, P (4.1 g kg^{-1}), K (41 g kg^{-1}) and Mg (9.1 g kg^{-1}) were greatest in *T. diversifolia.* Moreover, Ca (18.2 g kg^{-1}) and C (490 g kg^{-1}) were greatest in *A. indica.*. Although non-leguminous, the N concentration (32.6 g kg^{-1}) of *T. diversifolia* leaf biomass was significantly greater than that recorded for most of the leguminous species (*A. zygia*, *L. leucocephala*, *G. sepium* and *S. spectabilis*). Reports of high nutrient composition in the biomass of *T. diversifolia* has been attributed to the extensive rooting system of the plant which enables it to scavenge nutrients from soil depths and deposit in the biomass (Garrity and Mercado, 1994). Garrity and Mercado (1994) cited the scavening ability of *T. diversifolia* to be typical of the asteraceae family that the species belongs. Unlike the rest of the species studied, the C/N ratioof *Z. mays* stover was above the critical maximum of 30: 1 beyond which intial net N immobilization could be expected (Troeh and Thompson, 2005). Further, lignin and polyphenol concentrations of *A. auriculiformis*, *A. zygia* and *B. nitida*leaf biomass were significantly greater than the threshold

6

beyond which slow decomposition and an intial net N immobilization could be expected. Brady and Weil (2004) set a critical maximum of 200 g kg^{-1} and 30 g kg^{-1} for lignin and polyphenol respectively if plant residues are to be used for soil fertility improvement. Similar recommendations have been made by several authors (Mafongoya *et al*., 1998; Palm *et al*., 2001; Tian *et al*., 1995). Considering the above results, farmers who wish to apply the leaf biomass of *A. auriculiformis*, *A. zygia*, *B. nitida* and *Z. mays* may consider application with supplementary N fertilizers (Bhupinderpal-Singh and Rengel, 2007; Troeh and Thompson, 2005).

Plant residue decomposition and nutrient release patterns

The decomposition and nutrient release of the species followed an exponential pattern with significant non-linear relationship between nutrient release or weight loss and time (Tables 2 and 3). The applicability of the model is evident in the high R^2 values obtained. Generally, the highest weight loss occurred in *T. diversifolia* recording about 80% weight loss within 7 days of burial. This result is consistent with the findings of Gachengo *et al*. (1999) who reported a half-life of about one week for the disappearance of *T. diversifolia* dry matter in the rainy season in western Kenya. In constrast with *T. diversifolia*, relatively slow decomposition rates were observed with *A. auriculiformis*, *A. zygia*, *B. nitida* and *Z. mays* stover where only about 30% of leaf material decomposed within a week (Figure 2). Whilst similar studies with *B. nitida* and *A. zygia* are rare for comparison, slow decomposition in *A. auriculiformis* and *Z. mays* stover have been similarly reported (Partey *et al*., 2011). Meanwhile, the decomposition patterns of *A. indica*, *S. spectabilis*, *L. leucocephala* and *G. sepium* were closely related, each recording a half-life between 7 and 14 days. At the end of the sampling period, decomposition rate increased in the order: *A. auriculiformis* = *A. zygia* = *B. nitida* = *Z. mays* < *A. indica* < *G. sepium* = *L. leucocephala* = *S. spectabilis* < *T. diversifolia*.

There were clear indications that a high decomposition rate may result in a fast nutrient release as *T. diversifolia* consistently recorded the greatest N, P, K, Ca and Mg release rates. Nitrogen release rate (k_N % day^{-1}) ranged from 0.058 in *A. auriculiformis* to 0.325 in *T. diversifolia*. Similar to the results on decomposition, about 89% of N was released from *T. diversifolia* within 7 days compared with more than 70% retention in *A. auriculiformis*, *B. nitida* and *Z. mays* (Figure 3). Generally, the half-life of N was about a week for *G. sepium*, *L. leucocephala*, *S. spectabilis* and *A. indica*. In addition, phosphorus release rate (k_P day^{-1}) was comparable to that of nitrogen with *T. diversifolia* recording significantly (p < 0.001) greatest (about 90%) release of P within a week. The results of *G. sepium*, *L. leucocephala*, *S. spectabilis* and *A. indica* were similarly related recording between 42 to 56% of N after two weeks. In addition, the half-life of P was between 14 and 28 days for *A. auriculiformis*, *A. zygia*, *B. nitida* and *Z. mays*. The above observations have been similarly reported (Hossain *et al*., 2011) and confirm that green manures from *T. diversifolia*, *G. sepium*, *S. spectabilis*, *L. leucocephala* and *A. nitida* may be suitable for improving soil fertility at least in the short-term (Primo *et al*., 2014). This notwithstanding, the accelerated decomposition in the species (particularly *T. diversifolia*), may restrict long term build up of organic matter (Palm *et al*., 2001). The implication is that farmers may have to apply these organic resources every season which may incur high economic costs and eventually constrain large-scale landscape adoption by smallholder farmers (Partey and Thevathasan, 2013). Unlike *T. diversifolia*, *G. sepium*, *L. leucocoephala*, *A. indica* and *S. spectabilis* biomass applications from *A. auriculiformis*, *B. nitida*, *A. zygia* and *Z. mays* may limit N availablity in the short term but can be controlled when

7

applied together with N fertilizers or highly decomposable organic matter (Bhupinderpal *et al*., 2007; Partey *et al*., 2013). The application of such relatively low quality plant residues may provide certain mulching benefits such as conservation of soil moisture, sheet erosion control and weed suppression (Nair, 1984). Among the cations (Ca, Mg and K), all the plant residues recorded relatively high fast release of K through time with a half-life of about 7 days for all species. The fastest release rate of potassium is in support of the hypothesis that leaching is the primary process influencing K losses (Partey *et al*., 2013).Calcium release rate (k_{Ca} day^{-1}) and Mg release rate (k_{Mg} day^{-1}) were generally comparable with similar pattern recorded for *G. sepium*, *L. leucocephala*, *S. spectabilis* and *A. indica*.

Meanwhile, the role of residue chemistry in plant biomass decomposition and nutrient release, was evident (Table 4). The control of substrate quality in decomposition and nutrient release is highly documented in the tropics (Abera *et al*., 2014;Guendehou*et al*., 2014). In this study, neither N concentration nor C/N ratio was useful in predicting decomposition and nutrient release rates of the species. The assertion by Palm *et al*. (2001) that initial N concentration and C: N ratio influences the degradability of organic residues added to the soil was not confirmed by the results of this experiment. Results may be related to different decomposer communities which may have developed on plant materials based on their intrinsic qualities (Partey*et al*., 2012). However, only lignin, lignin/N ratio and (ligin + polyphenol)/N ratio were influential in predicting the N release rate and decomposition of the speccies. These results are in agreement with the findings of Tian *et al*. (1995) and Mafongoya *et al*. (1998). Further, P, K, Mg and Ca release rates were influenced by the composition of P in the plant residues which has been similarly reported by Partey *et al*. (2011). In relation to the residue chemical characteristics, decomposition and nutrient release, the hierarchical cluster analysis in Figure 4 showed that *L. leucocephala*, *G. sepium* and *S. spectabilis* were most similar with a similarity index of 0.98. The similarity index was formed using data on all the chemical characteristics, decomposition rates and nutrient release rates of the species. In addition, *A. auriculiformis* and *A. zygia* were classified similar which makes it reasonalble to assume that the application of such species may produce similar effects on soil properties.

N mineralization

Analysis of variance test showed significant (p = 0.001) effect of the plant residues on available N on all sampling periods. Nitrogen mineralization occurred in all species except in *Z. mays*, *A. zygia*, *B. nitida* and *A. auriculiformis* where N was immobilized for up to 14 days (Figure 5). At the end of the incubation period, cumulative N mineralized ranged from 34 mg N kg^{-1} in *Z. mays*to 182 in *T. diversifolia* mg N kg^{-1} (Figure 5). *A. indica*, *G. sepium*,*L. leucocephala* and *S. spectabilis* showed comparable effects on mineral N. Although, the application of organic residues with relatively low C/N (< 30: 1) will generally result in increased net N mineralization (Ostrowska and Porebska, 2015; Partey *et al*., 2012) it was not so in all species. As demonstrated in Figure 5, N immobilization occurred in *A. auriculiformis*, *A. zygia*, and *B. nitida* up to 14 days despite a C/N ratio lower than the critical minimum (30:1). From a correlation and regression analysis, it was found that N mineralization of the plant materials used could not be predicted by their initial N concentrations nor their C/N ratios. However, lignin, lignin/N ratio and (lignin + polyphenol)/N were found to be most influential based on significant (p ≤ 0.05) results (Table 5). The initial chemical analysis of *A. zygia, A. auriculiformis* and *B. nitida* showed relatively high lignin and polyphenol contents (Table 1) and may therefore account for the initial N immobilization observed. While the observations do not

8

undermine the applicability of N concentration and C/N ratio as plant quality indices, it was consistent with the results of the litterbag experiment and the findings of other studies in the same zone (Palm and Sanchez, 1990; Partey *et al*., 2011).

Soil microbial biomass

Soil microbial biomass increased with the plant residue inputs (Figure 6a). Generally, microbial biomass carbon ranged from 24.9 mg C kg^{-1} in the control (no inputs) to 298.2 mg C kg^{-1} in *T. diversifolia*. Among the plant residue treatments, the least effect was recorded for *A. auriculiformis* whereas comparable effects were observed between the following: *B. nitida* and *Z. mays*; and *S. spectabilis* and *L. leucocephala*. Increased microbial biomass by organic C inputs is well documented (Chowdhury *et al*., 2000; García-Gil *et al*., 2000; Peacock *et al*., 2001). The varying effects of the different organic substrates on soil microbial biomass could be due to their differences in chemical composition. Consistent with the results on decomposition, lignin; lignin/N ratio; (ligin + polyphenol)/N ratio;and P were most influential determinants of the effect of the plant residues on soil microbial biomass (Table 5). This observation supports soil ecological claims that substrate composition has profound influences on microbial utilization of C and nutrients in the substrate (Tu *et al*., 2006). In addition, the significant positive correlation observed between the soil microbial biomass carbon and mineral N (r^2 = 0.96, p = 0.001) (Table 5) confirmed soil microbial biomass as a significant indicator of soil fertility. It is reported that soil microbial biomass under different organic amendments may have implications for nutrient availability to crops (Partey and Thevathasan, 2013). This is because high microbial biomass often leads to high nutrient availability to crops through enhancing both the microbial biomass turnover and the degradation of non-microbial organic materials (Tu *et al*., 2006; Wang *et al*., 2004).

β-glucosidase activity

Similar to the results on mineral N and microbial biomass, β-glucosidase activity increased with the addition of the plant residues (Figure 6b). Among the plant residues, β-glucosidase activity was significantly (p ≤ 0.05) greatest with *T. diversifolia*(519.8 mg PNP kg^{-1} soil h^{-1}) and least with *Z. mays* stover (84.5 mg PNP kg^{-1} soil h^{-1}) application. Significant differences among the plant residues could be due to differences in their intrinsic chemical composition. Consistent with the results on decomposition and soil microbial biomass, β-glucosidase activity was influenced by P, lignin composition, lignin/N ratio and (lignin + polyphenol)/N ratio. Considering both decomposition and β-glucosidase activity were influenced by the same chemical parameters, it is possible that β-glucosidase played a key role in the degradation of the plant residues. According to Stott *et al*. (2010), β-glucosidase is sensitive to changes in soil and residue management and reflects a soil's ability to break down plant residues and improve the availability of nutrients. This assertion is further supported by the significant positive correlation observed between β-glucosidase, mineral N and the soil microbial biomass which confirms β-glucosidaseas a viable indicator for soil fertility assessment (Green *et al*., 2007; Stott *et al*., 2010).

CONCLUSIONS

The general objective of this study was to determine how the litter quality and decomposition of *A. auriculiformis, A. zygia, A. indica,B. nitida, G. sepium, L. leucocephala, T. diversifolia, S. spectabilis and Z. may* influence soil N availability, microbial biomass and β-glucosidase activity. The results on plant residue chemistry showed significant differences among species with N concentration ranging from 12.2 g kg^{-1} in *Z. mays* to 39.2 g kg^{-1} in *B. nitida.*C/N ratio was greatest in *Z. mays* (34.4) while lignin and polyphenol concentrations were greatest in *A. auriculiformis.* The highest decomposition rate (0.251% day^{-1}) occurred in *T. diversifolia* and least in *A. auriculiformis*, *A. zygia*, *B. nitida* and *Z. mays* with half-lives of between 28 – 56 days. Similar to the results on decomposition, between 80 to 89% of N, P, K, Ca and Mg were released from *T. diversifolia* within 7 days compared with more than 70% retention in *A. auriculiformis*, *B. nitida* and *Z. mays.* Moreover, the half-lives of decomposition and nutrient release of *G. sepium*, *L. leucocephala*, *A. indica* and *S. spectabilis* were within 14 days. Mineral N, soil microbial biomass and β-glucosidase activities increased in all treatments with *T. diversifolia* recording the greatest effect. While N mineralization occurred in all species throughout the experiment, an initial N immobilization was recorded in *A. zygia*, *B. nitida*, *A. auriculiformis* and *Z. mays* treatments for up to 14 days. Further, the results showed the decomposition, nutrient release rates, mineral N, soil microbial biomass and β-glucosidase activities were dependent on litter quality. Phosphorus, lignin, lignin/N ratio and (lignin + polyphenol)/N ratio were most influential based on significant ($p \leq 0.05$) results. The study confirmed that the application of *T. diversifolia*, *G. sepium*, *L. leucocephala*, *S. spectabilis* and *A. indica* leaf biomass may improve soil fertility but long-term build-up of organic matter may be restricted due to accelerated decomposition.

ACKNOWLEDGEMENT

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Table 1 Chemical characteristics of the leaf biomass of species used in the experiment

Plant materials	N	P	K	Ca	Mg	C	Lignin	Polyphenol	C/N
					----(g kg^{-1})----				
A. auriculiformis	20.5 ± 1.2	1.4 ± 0.1	19.0 ± 1.3	14.6 ± 1.2	3.3 ± 0.1	453.2 ± 3.7	462.1 ± 2.1	86.2 ± 1.1	22.1 ± 0.1
A. indica	21.2 ± 1.3	1.1 ± 0.0	13.3 ± 1.1	18.2 ± 1.4	4.7 ± 0.2	490.0 ± 4.3	90.1 ± 1.2	13.8 ± 0.9	23.1 ± 1.3
A. zygia	24.3 ± 2.0	2.2 ± 0.1	21.0 ± 2.1	15.4 ± 1.1	2.7 ± 0.1	479.0 ± 4.1	338.1 ± 4.8	68.2 ± 3.4	19.7 ± 1.2
B. nitida	39.2 ± 1.8	2.2 ± 0.1	23.0 ± 2.3	14.1 ± 1.4	2.3 ± 0.2	475.0 ± 5.0	320.0 ± 2.8	54.3 ± 1.4	12.1 ± 0.8
G. sepium	27.7 ± 1.1	2.9 ± 0.2	18.0 ± 1.5	7.9 ± 1.2	6.6 ± 0.2	455.3 ± 2.1	131.1 ± 2.1	20.7 ± 1.6	16.4 ± 1.2
L. leucocephala	24.6 ± 1.4	1.9 ± 0.1	19.0 ± 1.3	12.7 ± 1.1	6.3 ± 0.1	460.2 ± 2.3	141.8 ± 4.2	30.1 ± 2.4	18.7 ± 1.1
Z. mays	12.2 ± 1.3	1.2 ± 0.1	20.6 ± 1.7	4.2 ± 0.2	2.9 ± 0.1	420.0 ± 3.1	58.1 ± 1.0	6.2 ± 0.7	34.4 ± 1.1
S. Spectabilis	28.9 ± 1.6	2.5 ± 0.1	23.0 ± 1.4	6.4 ± 0.1	5.3 ± 0.1	451.2 ± 1.3	89.1 ± 1.7	14.9 ± 0.6	15.6 ± 1.0
T. diversifolia	32.6 ± 1.7	4.1 ± 0.2	41.0 ± 2.4	13.5 ± 1.3	9.1 ± 0.3	450.2 ± 1.2	50.2 ± 1.8	17.4 ± 1.1	13.8 ± 0.6

Values are the means of four replicates ± standard error

Table 2 Nonlinear equation fitted for weight loss of plant materials over 84 days of burial in soil

Species	Non-linear equation	Standard error	R^2	P value
A. auriculiformis	$Y = 31.4 + 65.7\ e{-0.042}^{t}$	4.68	0.98	0.003
A. indica	$Y = 14.5 + 83.5\ e{-0.076}^{t}$	4.95	0.99	0.002
A. zygia	$Y = 30.1 + 68.3\ e{-0.060}^{t}$	2.79	0.99	<0.001
B. nitida	$Y = 27.3 + 70.2\ e{-0.044}^{t}$	3.87	0.99	0.001
G. sepium	$Y = 14.5 + 85.5\ e{-0.117}^{t}$	5.6	0.80	0.003
L. leucocephala	$Y = 23.2 + 76.4\ e{-0.102}^{t}$	1.68	1.00	<0.001
S. spectabilis	$Y = 14.0 + 84.5\ e{-0.102}^{t}$	4.06	0.99	<0.001
T. diversifolia	$Y = 6.2 + 93.6\ e{-0.251}^{t}$	5.53	0.99	0.002
Z. mays	$Y = 10.5 + 86.5\ e{-0.031}^{t}$	4.31	0.99	0.001

N = 4

Table 3 Nonlinear equation fitted for N, P, K, Ca and Mg release from decomposing plant materials over 84 days of burial in soil

Nutrients	Species	Non-linear equation	Standard error	R^2	P value
Nitrogen	*A. auriculiformis*	$Y = 25.8 + 73.2\ e^{-0.058t}$	2.02	0.99	<0.001
	A. indica	$Y = 16.3 + 83.2\ e^{-0.108t}$	2.97	0.99	<0.001
	A. zygia	$Y = 23.2 + 76.1\ e^{-0.070t}$	2.22	0.99	<0.001
	B. nitida	$Y = 21.5 + 77.9\ e^{-0.861t}$	2.19	0.99	<0.001
	G. sepium	$Y = 12.5 + 87.5\ e^{-0.190t}$	2.07	0.99	<0.001
	L. leucocephala	$Y = 19.5 + 80.5\ e^{-0.131t}$	5.96	0.98	0.003
	S. spectabilis	$Y = 15.8 + 84.0\ e^{-0.109t}$	1.40	0.90	<0.001
	T. diversifolia	$Y = 2.4 + 97.6\ e^{-0.325t}$	2.67	0.99	<0.001
	Z. mays	$Y = 28.3 + 70.8\ e^{-0.059t}$	1.90	1.00	<0.001
Phosphorus	*A. auriculiformis*	$Y = 22.8 + 76.3\ e^{-0.059t}$	3.71	0.99	<0.001
	A. indica	$Y = 10.3 + 88.6\ e^{-0.085t}$	3.44	0.99	<0.001
	A. zygia	$Y = 22.8 + 77.2\ e^{-0.076t}$	1.39	0.99	<0.001
	B. nitida	$Y = 22.7 + 76.2\ e^{-0.064t}$	4.22	0.99	<0.001
	G. sepium	$Y = 11.7 + 87.6\ e^{-0.135t}$	5.17	0.99	0.002
	L. leucocephala	$Y = 16.5 + 83.6\ e^{-0.111t}$	0.56	1.00	<0.001
	S. spectabilis	$Y = 10.4 + 88.6\ e^{-0.085t}$	2.96	0.99	<0.001
	T. diversifolia	$Y = 2.5 + 97.5\ e^{-0.333t}$	2.69	0.99	<0.001
	Z. mays	$Y = 10.5 + 87.5\ e^{-0.048t}$	4.54	0.99	<0.001
Potassium	*A. auriculiformis*	$Y = 5.0 + 93.1\ e^{-0.082t}$	4.74	0.99	<0.001
	A. indica	$Y = 1.7 + 98.0\ e^{-0.099t}$	1.74	0.99	<0.001
	A. zygia	$Y = 4.0 + 94.8\ e^{-0.088t}$	4.68	0.99	<0.001

15

	B. nitida	$Y = 5.6 + 92.9\ e^{-0.088t}$	4.08	0.99	<0.001
	G. sepium	$Y = 2.8 + 96.6\ e^{-0.128t}$	2.84	0.99	<0.001
	L. leucocephala	$Y = 2.7 + 96.2\ e^{-0.099t}$	5.05	0.99	0.001
	S. spectabilis	$Y = 1.5 + 98.3\ e^{-0.102t}$	1.11	1.00	<0.001
	T. diversifolia	$Y = 1.9 + 97.9\ e^{-0.261t}$	4.07	0.99	<0.001
	Z. mays	$Y = 4.7 + 92.8\ e^{-0.085t}$	6.21	0.98	0.002

N = 4

Table 3 (continued)

Nutrients	Species	Non-linear equation	Standard error	R^2	P value
Calcium	*A. auriculiformis*	$Y = 37.7 + 61.7\ e^{-0.138t}$	3.88	0.98	0.002
	A. indica	$Y = 25.5 + 74.0\ e^{-0.131t}$	2.61	0.99	<0.001
	A. zygia	$Y = 36.0 + 63.6\ e^{-0.148t}$	5.43	0.97	0.005
	B. nitida	$Y = 35.7 + 63.0\ e^{-0.106t}$	4.31	0.98	0.002
	G. sepium	$Y = 26.0 + 73.6\ e^{-0.202t}$	9.61	0.94	0.015
	L. leucocephala	$Y = 32.3 + 67.4\ e^{-0.191t}$	9.80	0.92	0.021
	S. spectabilis	$Y = 23.4 + 76.0\ e^{-0.124t}$	2.92	0.99	<0.001
	T. diversifolia	$Y = 4.4 + 95.5\ e^{-0.267t}$	3.97	0.99	<0.001
	Z. mays	$Y = 24.1 + 74.7\ e^{-0.091t}$	5.32	0.98	0.003
Magnesium	*A. auriculiformis*	$Y = 26.8 + 69.5\ e^{-0.063t}$	8.55	0.94	0.013
	A. indica	$Y = 5.6 + 92.5\ e^{-0.089t}$	6.08	0.98	0.002
	A. zygia	$Y = 24.0 + 71.1\ e^{-0.068t}$	9.75	0.93	0.018
	B. nitida	$Y = 23.8 + 72.1\ e^{-0.058t}$	8.16	0.95	0.011
	G. sepium	$Y = 4.32 + 94.0\ e^{-0.106t}$	5.96	0.98	0.002
	L. leucocephala	$Y = 11.8 + 85.9\ e^{-0.088t}$	6.20	0.98	0.003
	S. spectabilis	$Y = 7.1 + 91.6\ e^{-0.093t}$	5.15	0.99	0.001
	T. diversifolia	$Y = 2.5 + 97.3\ e^{-0.239t}$	4.43	0.99	<0.001
	Z. mays	$Y = 23.5 + 75.1\ e^{-0.074t}$	4.27	0.99	0.001

Table 4

Pearson correlation coefficient (r) values for the linear relationship between plant residue chemistry and decomposition or nutrient release rates

Nutrient release rate	Chemical characteristic			
	P	Lignin	Ligin/N	(Lignin + Polyphenol)N
k_D	0.87^{***}	-0.52^{*}	-0.59^{**}	-0.56^{*}
k_N		-0.80^{***}	-0.55^{*}	
k_P	0.69^{**}			
k_K	0.85^{***}		-0.52^{*}	-0.49^{*}
k_{Ca}	0.80^{***}			
k_{Mg}	0.82^{***}	-0.53^{*}	-0.57^{**}	-0.54^{*}

N = 18. *, ** and *** refers to significance at 5%, 1% and 0.1% probability levels respectively. All empty spaces were not significant ($p > 0.05$). k_D= decomposition rate, k_N = nitrogen release rate, k_P = phosphorus release rate, k_K = potassium release rate, k_{Ca} = calcium release rate, k_{Mg} = magnesium release rate,

Table 5 A correlation matrix of the linear relationship between mineral N, β-glucosidase activity, soil microbial biomass carbon and plant residue characterisitcs

	β-glucosidase	Soil microbial biomass C	Mineral N
β-glucosidase	1.00		
Soil microbial biomass C	0.93^{***}	1.00	
Mineral N	0.85^{***}	0.98^{***}	1.00
Lignin	-0.52^{*}	-0.64^{**}	-0.67^{**}
Polyphenol		-0.52^{*}	-0.55^{*}
Lignin/N	-0.57^{**}	-0.69^{**}	-0.72^{***}
Polyphenol/N		-0.53^{*}	-0.55^{*}
(Ligin + Polyphenol)/N	-0.54^{*}	-0.66^{**}	-0.69^{**}
Phosphorus	0.81^{***}	0.80^{**}	0.73^{***}

N = 18. *, ** and *** refers to significance at 5%, 1% and 0.1% probability levels respectively. All empty spaces were not significant ($p > 0.05$).
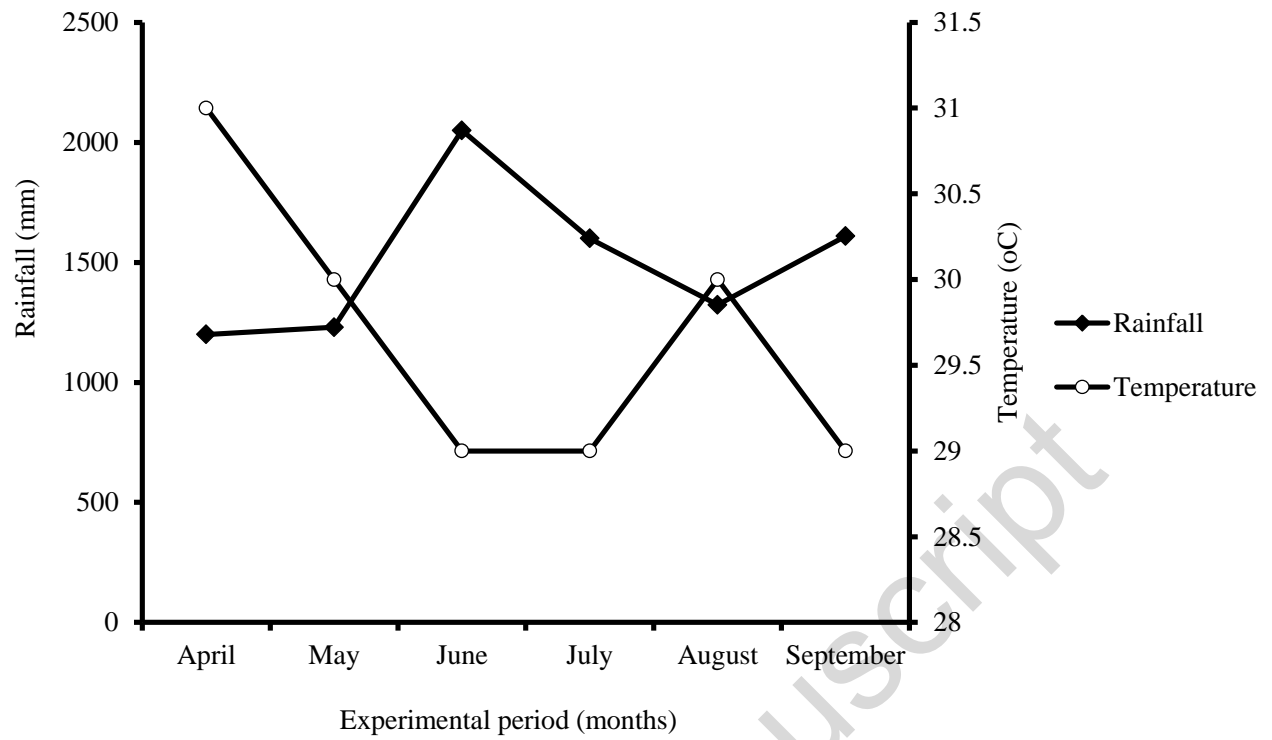
Figure 1: Mean monthly temeperature and rainfall at the experiemental station in 2014. Values are the means of 3 replciates.
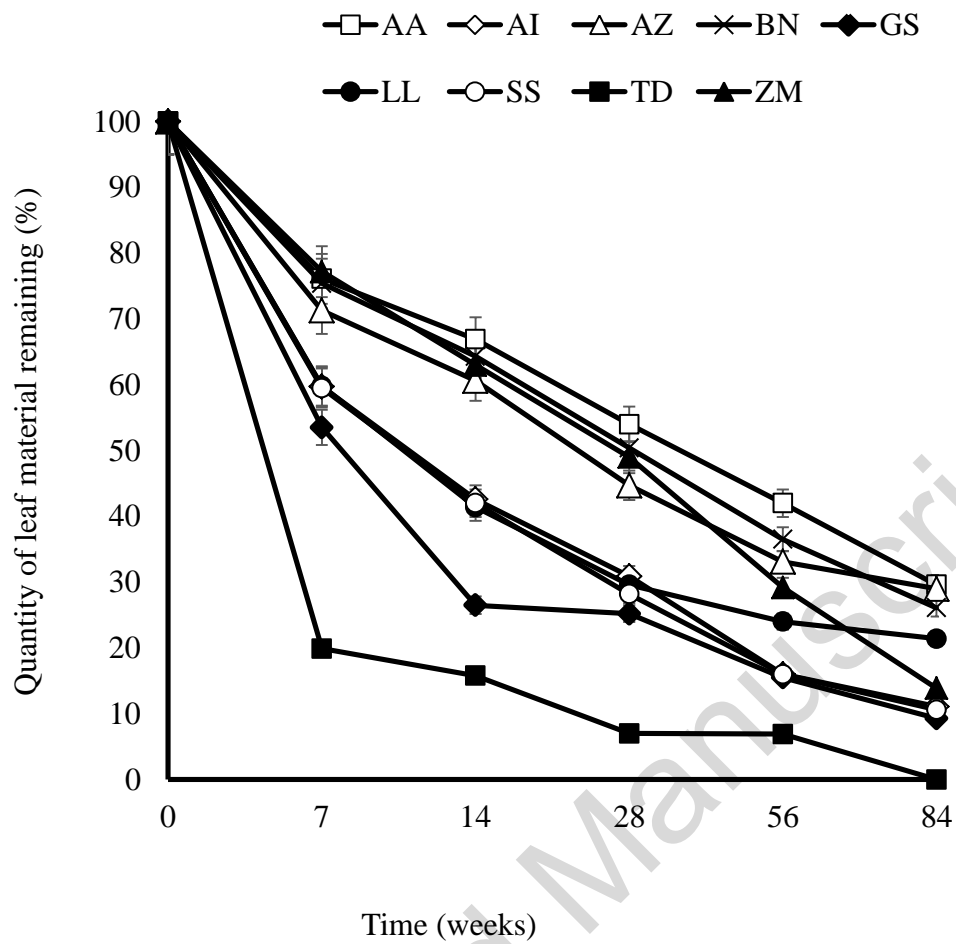
Figure 2: Quantity of initial leaf material remaining over 84 days of burial in soil. Data points are the means of 4 replicates. Error bars are the standard error of means. AA = *A. auriculiformis*, AI = *A. indica*, AZ = *A. zygia*, BN = *B. nitida*, GS = *G. sepium*, LL = *L. leucocephala*, SS = *S. spectabilis*, TD = *T. diversifolia*, ZM = *Z. mays*
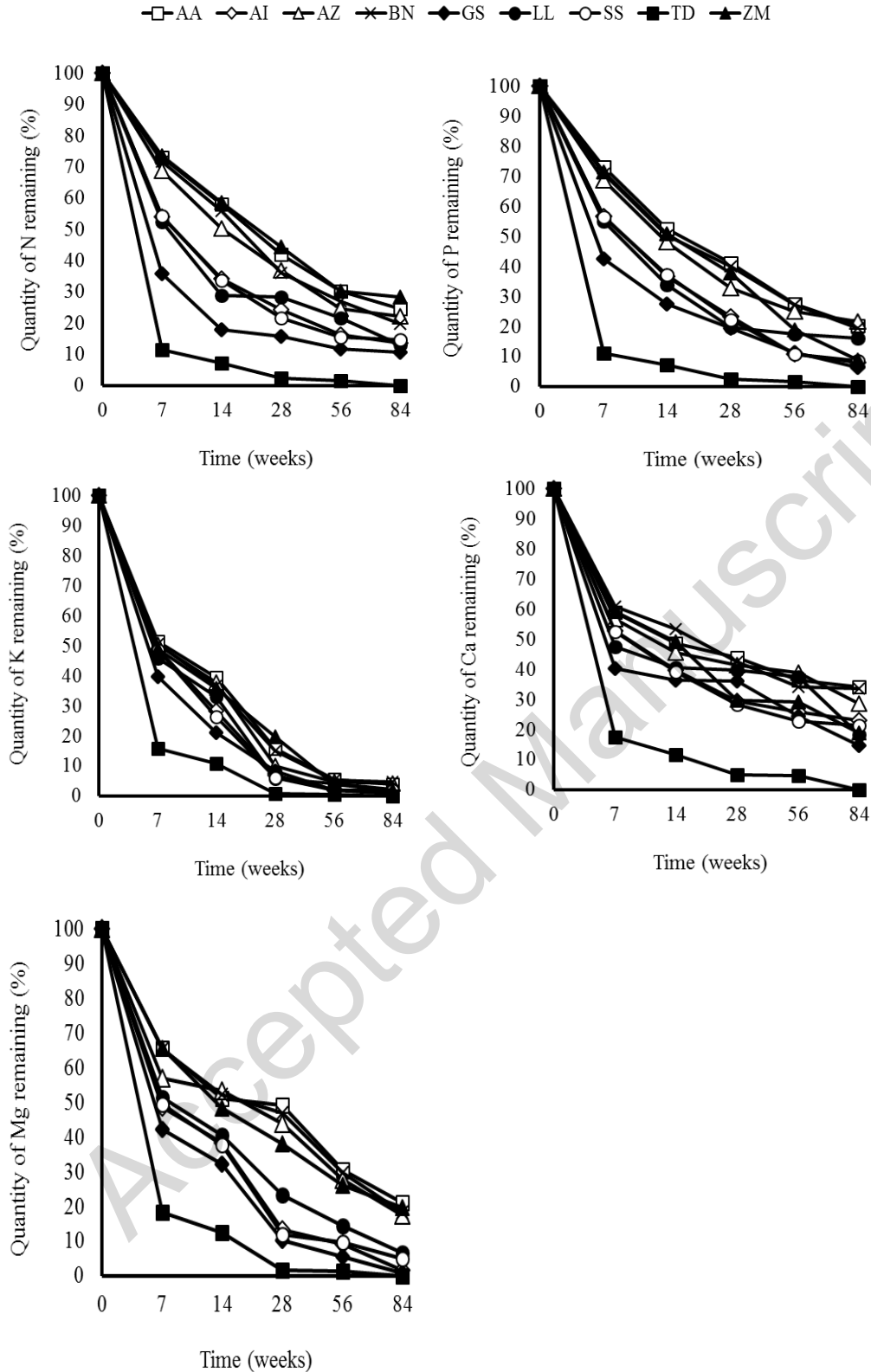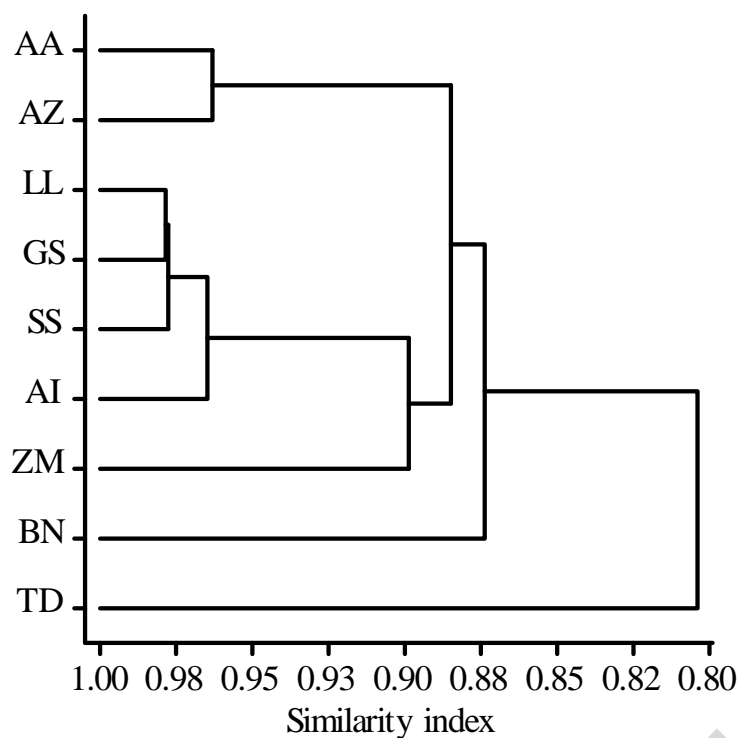
Figure 3: Nutrient (N, P, K, Ca, Mg) release patterns of decomposing plant materials over 84 days of burial in soil under field conditions. Data points are the means of 4 replicates. AA = *A. auriculiformis*, AI = *A. indica*, AZ = *A. zygia*, BN = *B. nitida*, GS = *G. sepium*, LL = *L. leucocephala*, SS = *S. spectabilis*, TD = *T. diversifolia*, ZM = *Z. mays*

Figure 4: A dendrogram of a hierarchical cluster analysis showing similarities among species in relation to their overall chemical composition, decomposition and nutrient release patterns. AA = *Acacia auriculiformis*, AZ = *Albiziazygia*, AI = *Azadirachtaindica*, BN = *Baphianitida*, GS = *Gliricidiasepium*, LL = *Leucaenaleucocephala*, ZM = *Zea mays*stover, SS = *Senna spectabilis*, TD = *Tithoniadiversifolia*. Similarity index was formed using data on all the chemical characteristics, decomposition rates and nutrient release rates.
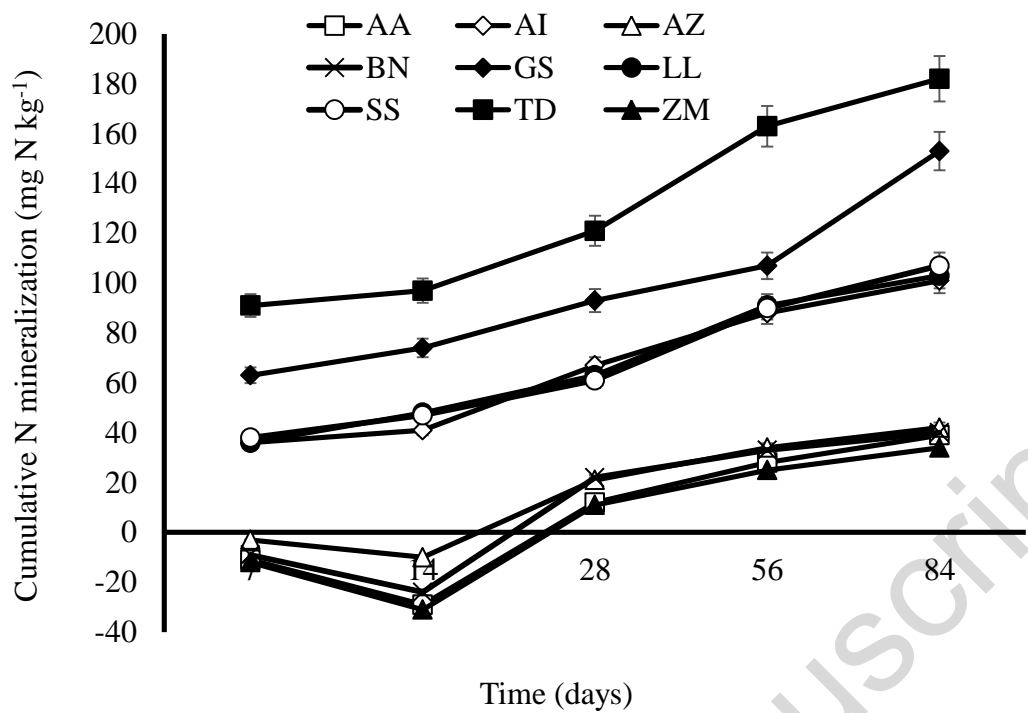
Figure 5: Cumulative net N mineralization following the application of plant residues over 84 days. Data points are the means of four replicates. Error bars are standard error of means. AA = *Acacia auriculiformis*, AZ = *Albiziazygia*, AI = *Azadirachtaindica*, BN = *Baphianitida*, GS = *Gliricidiasepium*, LL = *Leucaenaleucocephala*, ZM = *Zea mays*, SS = *Senna spectabilis*, TD = *Tithoniadiversifolia*.
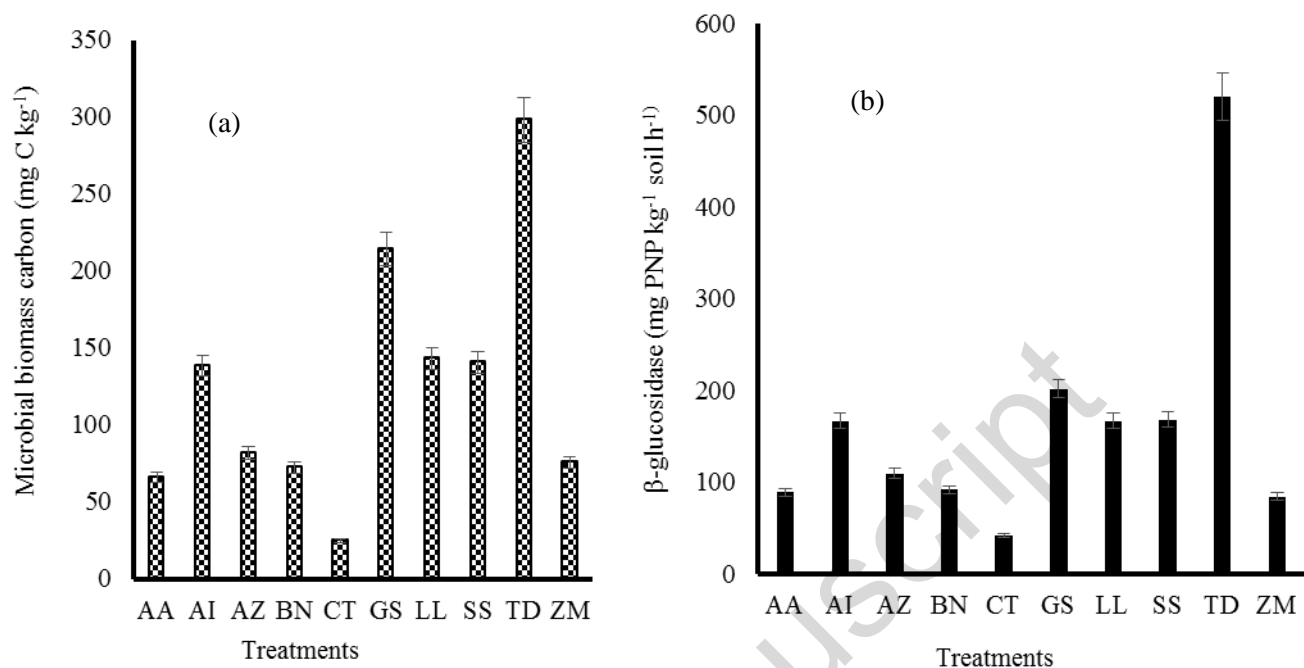
Figure 6 Effects of plant residue application on soil microbial biomass (a) and β-glucosidase activity (b). Data points are the means of four replicates. Error bars are standard error of means. AA = *Acacia auriculiformis*, AZ = *Albiziazygia*, AI = *Azadirachtaindica*, BN = *Baphianitida*, GS = *Gliricidiasepium*, LL = *Leucaenaleucocephala*, ZM = *Zea mays*, SS = *Senna spectabilis*, TD = *Tithoniadiversifolia*, CT = control (no inputs).