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Decomposition and nutrient release patterns of the leaf biomass of the wild sunflower (*Tithonia diversifolia*): a comparative study with four leguminous agroforestry species

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Abstract The selection and use of appropriate plant materials to maintain a sufficiently high nutrient supply to meet crop needs remains a major challenge of nutrient management under low input systems. Therefore, research on plant biomass quality as it relates to decomposition and nutrient release has become imperative. This research was conducted at the Agroforestry Research Station of the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana to determine the decomposition and nutrient release patterns of *Tithonia diversifolia*, a rarely used non-traditional species but of research interest in soil fertility improvement practices in Ghana. The decomposition and nutrient release patterns of *T. diversifolia* was compared with *Senna spectabilis*, *Gliricidia sepium*, *Leucaena leucocephala* and *Acacia auriculiformis* which are commonly used in biomass transfer systems. Results of the study confirmed significantly high N, P, K concentrations in *T. diversifolia* comparable to levels recorded for the four leguminous species. In addition, *T. diversifolia* recorded the highest percent decomposition and nutrient release rates which differed significantly ($P < 0.05$) from rates of the four leguminous species. It was apparent from the study that decomposition and nutrient release rates of species are related to quality of leaf material. Phosphorus and Mg concentration in particular were most influential in decomposition and nutrient release based on significant results. For this reason, it would be imperative to consider the concentrations of P and Mg among other factors in selecting high quality plant materials for green manuring.

Keywords Biomass quality · Nutrient concentrations · *T. diversifolia* · Decomposition

Introduction

In Africa, land productivity and food production have for several decades depended on a system of shifting cultivation characterized by a long period of fallow with a relatively short cropping period (Nye and Stephens 1962). This traditional practice of shifting cultivation and related bush fallow systems have for generations provided resource-poor farmers with an efficient and stable food production system with no purchased inputs (Sanchez and Salinas 1981). Nair

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(1984) attributed the effectiveness of this system to the constant cycle and transfer of nutrients from one compartment of the system to another, which operates through the physical and biological processes of canopy wash, litter-fall, root decomposition and plant uptake. Although shifting cultivation with long fallow periods was an accepted soil fertility improvement system (Nair 1984), the increased population pressure on cropping land, and the concomitant shortening of fallow periods, limits soil fertility regeneration under this system (Getahun and Wilson 1982). Although fertilizers have been beneficial in improving soil fertility at places where shifting cultivation has been limited, it is increasingly difficult for smallholder farmers who earn less than one dollar a day to afford the fertilizer requirements in many developing countries. This makes alternative means of improving soil fertility highly imperative.

According to George et al. (2001), the incorporation of woody perennials into cropping systems via agroforestry can help sustain agricultural production. This is because, the addition of plant residues from the tree component to the soil plays a critical role by contributing to recycling of plant nutrients, improvements in soil structure, microbial activities and maintenance of high soil nutrient status (Wu et al. 2000; Vanlauwe et al. 2001). Although biomass transfer systems involving leguminous species such as *Leucaena leucocephala*, *Gliricidia sepium*, *Senna spectabilis* and *Acacia auriculiformis* have made substantial contributions to the development of low input soil fertility improvement practices in the tropics, the selection and use of appropriate plant materials to maintain a sufficiently high nutrient supply to meet crop needs, still remains a major challenge of nutrient management under these low input systems (Kwabiah et al. 2001). Since the extent to which plant residues influences soil fertility and crop growth is in part determined by their biochemical qualities, decomposition and the concurrent timing of nutrient release and crop nutrient demand (Koenig and Cochran 1994), understanding the decomposition and nutrient release patterns of plant biomass will be crucial in manipulating their incorporation into cropping systems to improve nutrient synchronization.

Recently, the potential of the green biomass of the Mexican sunflower (*Tithonia diversifolia*) for soil fertility improvement and crop production has gained tremendous research interest in many parts of Africa (Niang et al. 1996; Gachengo et al. 1999). A member of the asteraceae family, *T. diversifolia* is briefly a succulent and soft shrub plant that grows to a height of 1–3 m; and bears alternately positioned leaves along most of the stem (ICRAF 1997). It originates from Mexico and its now wildly distributed in Africa, Asia and South America (Jama et al. 2000). In Kenya and many parts of Africa, foliar analysis of *T. diversifolia* green biomass revealed relatively high nutrient (N, P, K, Ca and Mg) concentrations comparable to most leguminous species used in biomass transfers (Jama et al. 2000). Although the mechanisms by which *T. diversifolia* acquires and accumulates nutrients in its leaf tissues are largely unknown, several researchers have confirmed that *T. diversifolia* biomass used as green manure rapidly releases accumulated nutrients into the soil, making them available to crops (George et al. 2001; Jama et al. 2000; Cobo et al. 2002). In addition, field experiment conducted on a chromic acrisol in Morogoro, Tanzania, showed that the application of *T. diversifolia* green manure enhances P availability and improves maize yields through modification of soil properties, such as soil pH, exchangeable Al and exchangeable Ca, which are associated with P transformation and availability (Ikerra et al. 2006). Although research confirms *T. diversifolia* leaf nutrient concentrations and its implications on biomass transfers (George et al. 2001), less is reported on the decomposition and nutrient release patterns of *T. diversifolia* leaf biomass. Using the chemical characteristics of *T. diversifolia* leaf biomass and its decomposition and nutrient release patterns (Swift et al. 1979), we conducted a field research to evaluate the suitability of *T. diversifolia* green biomass for soil fertility improvement in Ghana. This was conducted in comparison with *S. spectabilis*, *L. leucocephala*, *A. auriculiformis* and *G. sepium* which are commonly used in biomass transfer systems in Ghana.

Materials and methods

Study site

The study was conducted at the Agroforestry Research Station of the Faculty of Renewable Natural Resources (FRNR), Kwame Nkrumah University of

Science and Technology (KNUST), Kumasi, Ghana, located at Lat 01 43° N and Long 01 36° W. The research area had lied fallow for 1½ years after 2 years of maize cultivation with no external inputs. The area falls within the moist semi-deciduous forest zone of Ghana and it is 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°C and a mean annual humidity of 67.6%. Climatic data collected during the research period is shown in Fig. 1. Soil type at study site is a ferric acrisol with extreme acidic condition according to the soil reaction rating by Motsara and Roy (2008). In addition, the soil has moderate levels of N and organic matter (Table 1).

Experimental design and sampling procedure

Plant species used in the study were: *T. diversifolia*, *G. sepium*, *L. leucocephala*, *S. spectabilis* and *A. auriculiformis*. The selection of these species was based on their relative abundance at the study area and their use as organic amendments for soil fertility improvement. Fresh leaves of these species including petioles (in the case of *T. diversifolia*, *G. sepium* and *A. auriculiformis*) and rachis in the case of *L. leucocephala* and *S. spectabilis* (since they have compound leaves) were collected from already established fields at study site and characterized for quality parameters. Samples of fresh leaves collected were air-dried and ground to pass through a 0.5 mm sieve and analyzed for total N, P, K, Ca, Mg and organic C. Nitrogen was determined by the Kjeldahl method, potassium was determined in an ash solution using a Gallenkamp flame analyzer, phosphorus by the ammonium phosphomolybdate method (Motsara and Roy 2008), carbon by the gravimetric ash method and calcium and magnesium by the EDTA titration method (Motsara and Roy 2008).

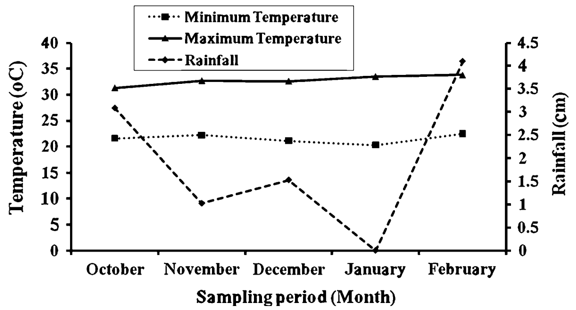

Fig. 1 Mean monthly rainfall and temperature recordings during the experimental period at the agroforestry research station. Minimum and maximum temperatures represent monthly means

Table 1 Physico-chemical properties of the top-soil (0–15 cm) of the experimental site at the Agroforestry Research Station, Kumasi, Ghana

Parameter	Value
pH (H_20) (1:1)	4.05
Organic C (g/kg)	22.9
Organic matter (g/kg)	39.5
Total N (g/kg)	2.2
Available Bray-1 P (mg/kg)	5.64
Available Bray-1 K (mg/kg)	251
Exchangeable cations ($cmol_c$/kg)	
Ca	3.7
Mg	2.4
K	0.4
Na	0.1
Exchangeable acidity (Al + H) ($cmol_c$/kg)	0.6
ECEC ($cmol_c$/kg)	7.1
Base saturation (%)	92
Texture (g/kg)	
Sand	604
Silt	355
Clay	41

The decomposition and nutrient release patterns of the selected species were studied using the littler-bag technique. Fresh leaves of *T. diversifolia*, *G. sepium*, *L. leucocephala*, *S. spectabilis* and *A. auriculiformis* equivalent to 40 g on a dry weight basis were collected from the agroforestry research station and placed in a 22 × 50 cm rigid nylon litter-bag of 1.5 mm mesh size. The litter-bags were placed within plough depth (0–15 cm) with 0.5 m spacing between them. Using plant species as treatments, litter bags were arranged in a randomized complete block design with five replications. At 1, 2, 4, 8 and 12 weeks of decomposition, five litter-bags (representing five replicates) for each species were randomly selected to follow dry matter and nutrient losses. Plant materials remaining in the litter-bags at each sampling time were separated from soil and organic debris by hand and oven dried at 65°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 biochemical analysis. The biochemical analysis was done separately for each replicate. In order to correct for contamination by the mineral soil, samples were ashed at 450°C for 4 h. 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. The percent dry weight and nutrient remaining (on ash-free basis) at each sampling time was calculated using the relation:

$$A_R = \frac{At}{Ao} \times 100\% \tag{1}$$

Where A_R is the percent nutrient or quantity of plant material remaining, At is the amount of plant material or nutrient remaining at each sampling time and Ao is the initial weight of plant material or nutrient concentration.

Statistical analysis

Data collected on the dry weight and nutrient remaining (on ash-free basis) in decomposing leaves at each sampling time were analyzed using analysis of variance (ANOVA). Least significant difference at $P \leq 0.05$ was used to make treatment comparisons. 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). Root mean square error values were used to assess fit of the models. The best fit model was determined based on lowest root mean square error values. The general form of the model was:

$$Y = \beta_o + \beta_i e^{-kt} + \text{error} \tag{2}$$

Where Y is the percent of initial material or nutrient remaining at sampling time t, β_o is the recalcitrant pool fraction and β_i *is* the difference $100 - \beta_o$. Correlation and regression analysis were also carried out between chemical parameters of the plant materials used in the litterbags and their decomposition and nutrient release rates.

Results

Quality of plant materials

With the exception of C, ANOVA test on the initial foliar analysis showed significant differences ($P < 0.05$) in N, P, K, Ca and Mg concentrations measured for the different leaf materials. All plant materials had C: N ratios narrower than 32:1 beyond which soil N immobilization can be expected (Troeh and Thompson 2005). Carbon to nitrogen ratios varied from 16 in *T. diversifolia* to 22 in *A. auriculiformis*. Among the different plant materials analyzed, *A. auriculiformis* and *L. leucocephala* recorded C: P ratios greater than 200:1 which represent threshold value for initial net mineralization of P (Schroth 2003). Nitrogen concentration in *T. diversifolia* was highest and significantly different from levels recorded for the other four species. However, recorded N concentrations for all tested species were above the critical level of 20–25 g/kg, below which net immobilization of N would be expected (Palm et al. 1997). Nitrogen levels ranged from 21.5 g/kg in *A. auriculiformis* to 33.6 g/kg in *T. diversifolia*. Phosphorus concentration in *A. auriculiformis*, and *L. leucocephala* were below the critical level of 25 g/kg, below which net P immobilization would occur (Palm et al. 1997). However, P levels in all species were high compared to levels in other tropical species (Vitousek 1984). Potassium level was highest in *G. sepium* and the same for *T. diversifolia* and *L. leucocephala*. Calcium and magnesium levels recorded for the five species, followed the increasing order of *S. spectabilis* < *G. sepium* < *L. leucocephala* < *T. diversifolia* < *A. auriculiformis* and *A. auriculiformis* < *S. spectabilis* < *L. leucocephala* < *G. sepium* < *T. diversifolia*, respectively (Table 2).

Table 2 Chemical characteristics of species used in decomposition experiment g/kg

Treatment	N	P	K	Ca	Mg	C	C:N	C:P
Aa	21.5	1.5	5.0	14.7	3.4	479.2	22.29	320.6
Ss	29.9	2.6	5.4	6.5	5.1	466.2	15.61	179.7
Ll	25.6	2.0	6.2	12.8	6.1	478.7	18.70	240.7
Td	33.6	4.2	6.2	13.6	9.2	457.3	13.61	108.9
Gs	28.7	3.0	6.4	8.0	6.7	471.0	16.41	157.4
$LSD_{0.05}$	0.6	0.2	0.5	0.6	0.2	20.0	0.9	19.9

(Aa *Acacia auriculiformis*, Ss *Senna spectabilis*, Ll *Leucaena leucocephala*, Td *Tithonia diversifolia*, Gs *Gliricidia sepium*; *LSD* least square difference

Decomposition patterns

The highest dry weight loss occurred in *T. diversifolia* during the first week of the experiment and lowest in *A. auriculiformis* (Fig. 2). Percent dry weight remaining after the first week of decomposition ranged from 20% in *T. diversifolia* to 82% in *A. auriculiformis*. During the same period, 49% of *G. sepium* leaves had decomposed which increased rapidly to 77% after the second week. After 8 weeks, the amount of *T. diversifolia* leaf material remaining was insignificant (and inseparable from mineral soil) compared with all species, especially with *A. auriculiformis* recording about 31% of decomposing leaf material remaining on the 12th week of the experiment. With the exception of *L. leucocephala* which had a biphasic decomposition pattern, all plant materials generally showed steady and uniform increase in decomposition through time.

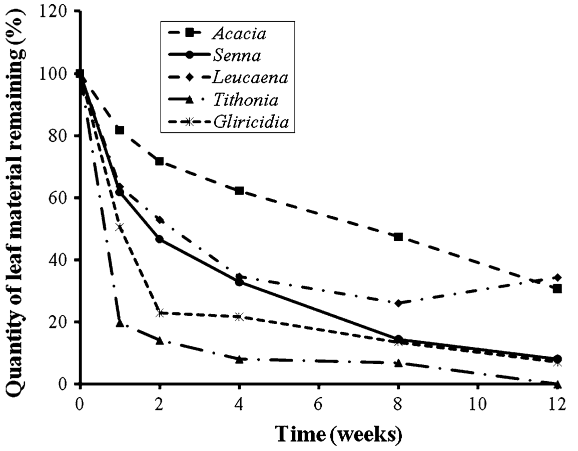

Fig. 2 Quantity of initial leaf material remaining from decomposing leaves over 12 weeks

Analysis of variance test confirmed significant ($P < 0.05$) effect of species type on decomposition rates at all sampling periods. As revealed by the statistical comparison, decomposition rates in both *S. spectabilis* and *L. leucocephala* were similar during the first 28 days of decomposition (Table 3). Generally, percent decomposition rate was highest in *T. diversifolia* and lowest in *A. auriculiformis*. With the exception of *A. auriculiformis*, decomposition rate decreased with increasing period of decomposition. The decomposition rate of *T. diversifolia* differed significantly ($P < 0.05$) from all species. In addition, statistics revealed a significant ($P < 0.01$) nonlinear relationship between percent decomposing rate and time (Table 4).

Nutrient release patterns

Data collected showed marked differences in N, P, K, Ca and Mg release patterns in the decomposing leaf materials of *A. auriculiformis*, *S. spectabilis*, *L. leucocephala*, *T. diversifolia* and *G. sepium*. With the exception of K in *L. leucocephala* and Mg in *T. diversifolia*, nutrient release rates were generally higher than decomposition rates among species. The highest percent N, P, K, Ca and Mg released was recorded for *T. diversifolia* during the first week and even afterwards. Between 4 and 8 weeks of decomposition, N immobilization apparently occurred in *A. auriculiformis*, *S. spectabilis*, *L. leucocephala* and *G. sepium* whilst *T. diversifolia* mineralized its leaf N at a relative faster rate. Nitrogen retention in decomposing leaves at the end of the study period were less than 32% and followed the increasing order of *T. diversifolia* (undeterminable level) < *S. spectabilis* < *G. sepium* < *A. auriculiformis* < *L. leucocephala* (Fig. 3). Even though N release pattern differed from patterns observed for decomposition, percent N release rate (k_N day^{-1}) was also highest in *T. diversifolia* (0.328 day^{-1}) and lowest in *A. auriculiformis* (0.056 day^{-1}). Percent N release rate followed the increasing order of *A. auriculiformis* < *S. spectabilis* < *L. leucocephala* < *G. sepium* < *T. diversifolia* (Table 5). Correlation and regression analysis confirmed a significant positive correlation between k_N day^{-1} and P ($P < 0.05$, $r = 0.93$); and Mg concentrations ($P < 0.01$, $r = 0.96$;

Table 3 Decomposition rates (k_D day^{-1}) of different leaf materials as influenced by species type under field conditions

Decomposition rates[a]/species	Sampling period (days)				
	7	14	28	56	84
A. auriculiformis	0.029	0.024	0.017	0.013	0.014
S. spectabilis	0.069	0.055	0.040	0.035	0.030
L. leucocephala	0.065	0.045	0.038	0.024	0.013
T. diversifolia	0.231	0.136	0.088	0.048	0*
G. sepium	0.097	0.109	0.055	0.036	0.032
$\text{LSD}_{0.05}$	0.005	0.016	0.016	0.002	0.002

* Zero because leaf materials remaining could not be quantified. Leaf material was inseparable from soil mineral particles

[a] Decomposition rates are in percentages

Table 4 Nonlinear regression models for weight loss of leaf material

Species	Equation	R^2	$S_{yx\dagger}$	P value‡
Acacia auriculiformis	$Y = 24.8 + 71.5\ e^{-0.025t}$	0.98	4.90	0.004
Senna spectabilis	$Y = 10.82 + 86.29\ e^{-0.061t}$	0.98	5.46	0.002
Leucaena leucocephala	$Y = 30.24 + 69.13\ e^{-0.092t}$	0.98	4.48	0.002
Tithonia diversifolia	$Y = 6.21 + 93.64\ e^{-0.258t}$	0.99	4.97	0.001
Gliricidia sepium	$Y = 12.16 + 88.0\ e^{-0.125t}$	0.98	5.74	0.002

† Standard error of estimate

‡ Significance of fit

R^2 = coefficient of determination

Table 6). Analysis of variance test also confirmed significant ($P < 0.05$) effect of species type on k_N day^{-1}. Significant differences in k_N day^{-1} among species was observed during the second, fourth and eighth weeks of decomposition. At weeks 1 and 12, there were no significant differences in k_N day^{-1} among the following pairs: *S. spectabilis* and *L. leucocephala;* and *A. auriculiformis* and *L. leucocephala* respectively. Meanwhile, k_N day^{-1} in *T. diversifolia* differed significantly from all species (Table 7).

Phosphorus released increased steadily among species through time. However, P immobilization occurred in *L. leucocephala* between the 8th and 12th week of decomposition. As observed for N, phosphorus release rates (k_P day^{-1}) were highest in *T. diversifolia* and lowest in *A. auriculiformis*. Phosphorus release rate had a significant positive correlation with P ($P < 0.05$) and Mg ($P < 0.01$) concentrations. In addition, ANOVA test confirmed significant ($P < 0.05$) effect of species type on k_P day^{-1} with no significant differences ($P > 0.05$) in k_P day^{-1} between *S. spectabilis* and *Leucocephala* at weeks 1, 2 and 4 of decomposition. In addition, differences in k_P day^{-1} at weeks 4 and 8 were not significant between *L. leucocephala* and *G. sepium;* and *S. spectabilis* and *G. sepium* respectively.

Potassium happened to be the element with the fastest release rate among species with its dynamic pattern differing among species. With the exception of weeks 2 and 4, potassium release rate (k_K day^{-1}) differed significantly among all species. At week 2, k_K day^{-1} did not differ significantly ($P > 0.05$) between *A. auriculiformis* and *L. leucocephala.* This observation also occurred at week 4 together with the following pairs: *A. auriculiformis* and *S. spectabilis; S. spectabilis and L. leucocephala; L. leucocephala* and *T. diversifolia; L. leucocephala* and *G. sepium; and T. diversifolia and G. sepium.* Potassium release rate followed the order: *T. diversifolia* > *G. sepium* > *S. spectabilis* > *L. leucocephala* > *A. auriculiformis.*

Between 4 and 8 weeks of decomposition, Mg immobilization was recorded for *A. auriculiformis*, *L. leucocephala*, and *G. sepium* which were later mineralized at a relatively faster rate especially in *A. auriculiformis*. Calcium release rate (k_{Ca} day^{-1}) was

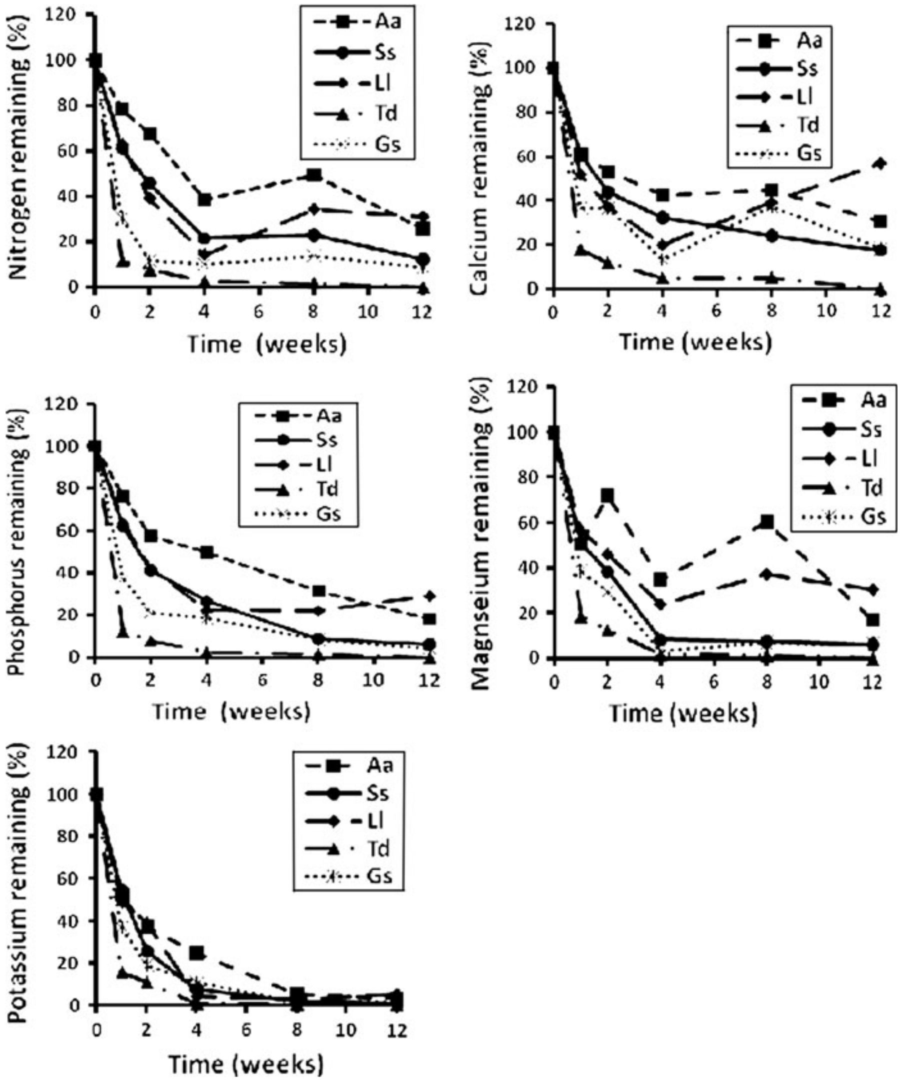

Fig. 3 N, P, K, Ca and Mg release patterns in decomposing leaf materials of *Tithonia diversifolia* (*Td*), *Acacia auriculiformis* (*Aa*), *Senna spectabilis* (*Ss*), *Leucaena leucocephala* (*Ll*) and *Gliricidia sepium* (*Gs*) over 12 weeks of placement in soil

fastest in *T. diversifolia* and slowest in *S. spectabilis* during the first week of decomposition. Meanwhile, an increase in decomposition generally resulted in an increase in nutrient release rates with the exception of Ca.

Discussions and conclusion

As expected, differences in biochemical composition were apparent among the species. Although *T. diversifolia* is non-leguminous, its N concentration was comparable and significantly higher than levels recorded for the four leguminous species. The N, P and K levels of *T. diversifolia* recorded in this study were comparable to the observations of Jama et al. (2000) who confirmed high nutrient composition values of *T. diversifolia* green manure in comparison with six different agroforestry species used in soil fertility improvement practices (Table 8). Although the mechanism by which *T. diversifolia* is able to build nutrients in its biomass is unclear, it is evident to have a tremendous scavenging ability in pumping these nutrients from large volumes of soil and accumulating them in the leaves: an attribute of the Asteraceae family of *T. diversifolia* (Garrity and Mercado 1994). This scavenging characteristic of *T. diversifolia* might restrict its establishment in association with annual crops. In addition, *T. diversifolia* roots are confirmed to be associated with

Table 5 Nonlinear regression models for nutrient loss in leaf materials

Nutrient/species	Equation	S_{yx}	R^2	P value
Nitrogen				
Acacia auriculiformis	$Y = 33.16 + 67.2\ e^{-0.056t}$	10.6	0.91	0.027
Senna spectabilis	$Y = 16.43 + 83.14\ e^{-0.083t}$	5.0	0.99	0.002
Leucaena leucocephala	$Y = 26.54 + 74.9\ e^{-0.124t}$	10.3	0.93	0.018
Tithonia diversifolia	$Y = 2.51 + 97.45\ e^{-0.328t}$	2.87	1.0	<0.001
Gliricidia sepium	$Y = 10.21 + 89.90\ e^{-0.222t}$	2.79	1.0	<0.001
Phosphorus				
Acacia auriculiformis	$Y = 19.96 + 77.22\ e^{-0.041t}$	5.97	0.98	0.004
Senna spectabilis	$Y = 7.53 + 90.98\ e^{-0.067t}$	3.72	0.99	<0.001
Leucaena leucocephala	$Y = 23.68 + 77.21\ e^{-0.103t}$	4.85	0.98	0.002
Tithonia diversifolia	$Y = 2.63 + 97.32\ e^{-0.317t}$	2.98	1.0	<0.001
Gliricidia sepium	$Y = 10.16 + 89.41\ e^{-0.160t}$	5.88	0.98	0.002
Potassium				
Acacia auriculiformis	$Y = 6.56 + 90.71\ e^{-0.079t}$	4.81	0.98	0.003
Senna spectabilis	$Y = 0.84 + 99.73\ e^{-0.093t}$	1.75	1.0	<0.001
Leucaena leucocephala	$Y = 2.80 + 96.31\ e^{-0.089t}$	7.11	0.98	0.003
Tithonia diversifolia	$Y = 1.94 + 97.90\ e^{-0.261t}$	4.19	0.99	<0.001
Gliricidia sepium	$Y = 3.95 + 95.48\ e^{-0.141t}$	4.01	0.99	<0.001
Calcium				
Acacia auriculiformis	$Y = 38.8 + 60.36\ e^{-0.123t}$	6.54	0.96	0.009
Senna spectabilis	$Y = 21.77 + 77.21\ e^{-0.089t}$	3.93	0.99	0.001
Leucaena leucocephala	$Y = 38.13 + 62.1\ e^{-0.237t}$	15.3	0.81	0.081
Tithonia diversifolia	$Y = 4.45 + 95.43\ e^{-0.266t}$	3.92	0.99	<0.001
Gliricidia sepium	$Y = 24.83 + 74.9\ e^{-0.230t}$	11.8	0.91	0.026
Magnesium				
Acacia auriculiformis	$Y = 38.0 + 58.0\ e^{-0.097t}$	23.2	0.61	0.240
Senna spectabilis	$Y = 5.78 + 93.44\ e^{-0.091t}$	5.34	0.99	0.001
Leucaena leucocephala	$Y = 30.99 + 68.91\ e^{-0.135t}$	6.77	0.96	0.007
Tithonia diversifolia	$Y = 2.43 + 97.33\ e^{-0.236t}$	4.37	0.99	<0.001
Gliricidia sepium	$Y = 5.83 + 93.24\ e^{-0.129t}$	6.36	0.98	0.002

arbuscular mycorrhizal fungi particularly of the *Glomaceae* family (Sharrock et al. 2004) which might have tremendous influence on its nutrient uptake abilities even on nutrient depleted soils. Besides differences in intrinsic characteristics of the various leaf materials studied, the concentrations of nutrients (particularly N, P and K) confirm their suitability for soil fertility improvement practices in smallholder agriculture. Most of the nutrients were above critical and optimal levels reported in leaf materials by Motsara and Roy (2008). Like the other organic materials, the application of *T. diversifolia* biomass to the soil can be very advantageous and serve a better alternative in affecting many chemical and microbiological indicators associated with nutrient cycling (Nziguheba et al. 2000) and soil fertility especially in places where mineral fertilizer applications are limited.

The applicability of using rates constants obtained from the single exponential model in describing best fitted decomposition and nutrient release patterns of plant materials have been contested (Wieder and Lang 1982; Ezcurra and Becerra 1987). However, the high R^2 values obtained from this study makes the single exponential model seem applicable. Statistical comparison of the decomposition constant of the species confirmed the fastest decomposition and nutrient release in *T. diversifolia*. This rapid decomposition and nutrient release rates of *T. diversifolia* leaf biomass is in agreement with the findings of

Table 6 Pearson's correlation coefficient (r) of the linear relationship between nutrient release rate and initial chemical characteristics of leaf materials

Nutrient	Nutrient release rate				
	k_N	k_P	k_K	k_{Ca}	k_{Mg}
C	–0.74	–0.79	–0.85	–0.26	–0.69
N	0.78	0.80	0.79	0.41	0.68
P	0.93*	0.93*	0.94*	0.57	0.83
K	0.75	0.66	0.53	0.89*	0.60
Ca	0.09	0.19	0.19	0.33	0.40
Mg	0.96**	0.96**	0.91*	0.81	0.92*
C:N	–0.75	–0.75	–0.74	–0.40	–0.62
C:P	–0.83	–0.81	–0.79	–0.50	–0.66

* and ** means significant at 5% and 1% probability levels, respectively

Gachengo et al. (1999) who reported a half-life of about 1 week for the disappearance of *T. diversifolia* dry matter in the rainy season in western Kenya. From the results, it was evident that substrate quality influences decomposition and nutrient release patterns of plant materials. The control of substrate quality in decomposition is highly documented and has been shown to be more influential than climatic factors in the tropics (Meentemeyer 1978; Palm and Sanchez 1990). In this study, neither N concentration nor C/N ratio was useful in predicting decomposition and nutrient release rates. The assertion by Melillo and Aber (1983) 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 (Cobo et al. 2002). Among the plant chemical characteristics studied, only P and Mg concentrations served as useful indicators of degradability of plant materials based on significant results (Tables 6 and 9). The nutrient release patterns followed by the species studied demonstrate the importance of substrate quality in nutrient dynamics. Potassium happened to be the fastest release cation. The order of release of the cations (Ca < Mg < K) are similarly reported by Palm and Sanchez (1990). The fastest release rate of potassium is in support of the hypothesis that leaching is the primary process influencing K losses (Swift et al. 1981). Net N immobilization occurred in all leguminous species (*A. auriculiformis*, *S. spectabilis*, *L. leucocephala* and *G. sepium*) which agrees with results from temperate regions (Berg and Staaf 1981; Melillo and Aber 1984). The lack of net N immobilization in non-leguminous species such as *T. diversifolia* is also reported (Swift et al. 1981; Anderson et al. 1983) in the tropics which is consistent with the observation made here. Phosphorus immobilization occurred only in *L. leucocephala*. Phosphorus immobilization during decomposition is reported at both tropical and temperate regions (Anderson et al. 1983; Melillo and Aber 1984; Palm and Sanchez 1990). This observation is said to occur when P is limiting to microbial activities (Melillo and Aber 1984; Schlesinger and Hasey 1981). It was evident from the study that N dynamics influenced P dynamics. All plant materials generally had a moderate to high P concentration in their tissues before decomposition but showed an increased P concentration at week 4 (Fig. 4) resulting in N/P ratios near ten, the ideal ratio for decomposer organisms (Vogt et al. 1986). N/P ratios generally increased to 23, 30 and 19 at week 8 in *A. auriculiformis, S. spectabilis*, *L. leucocephala* and *G. sepium* respectively but dropped drastically thereafter. Lack of available N (toward the end of the experiment) should be more influential in this circumstance than phosphorus limitation (Palm and Sanchez 1990). This is evident in the independent P mineralization at week 12. Further explanation is supported by the trend followed by *T. diversifolia* which maintained a N/P ratio near ten throughout the course of the study suggestion that N was controlling P dynamics.

From the results obtained, there are clear indications that biomass quality affects the decomposition and nutrient release patterns of the selected plant leaf biomass. Based on the above results, the fresh leaves of *T. diversifolia, S. spectabilis* and *G. sepium* were rated as high quality litter and may be applied as green manure to short duration crops such as vegetables as well as most annual crops, due to their high N (>2.5%) and P (>0.25%) concentrations (Palm et al. 2001). Meanwhile, the accelerated decomposition and nutrient release of *T. diversifolia* may limit its potential for long term build-up of soil fertility. *L. leucocephala* leaves were rated as intermediate high quality litter due to the relatively low P concentration (<0.25%) which might lead to

Table 7 Nutrient release rates of different leaf materials as influenced by species type under field conditions

Nutrient release rate[a]/species	Sampling period (days)				
	7	14	28	56	84
N release rate (k_N day^{-1})					
A. auriculiformis	0.035	0.028	0.034	0.013	0.016
S. spectabilis	0.071	0.056	0.055	0.026	0.025
L. leucocephala	0.067	0.067	0.070	0.019	0.014
T. diversifolia	0.309	0.184	0.132	0.072	0*
G. sepium	0.170	0.153	0.082	0.035	0.029
$LSD_{0.05}$	0.008	0.006	0.003	0.005	0.003
P release rate (k_P day^{-1})					
A. auriculiformis	0.039	0.040	0.025	0.021	0.020
S. spectabilis	0.069	0.063	0.047	0.044	0.033
L. leucocephala	0.065	0.061	0.053	0.027	0.015
T. diversifolia	0.3	0.180	0.129	0.072	0*
G. sepium	0.142	0.110	0.060	0.044	0.038
$LSD_{0.05}$	0.019	0.019	0.010	0.002	0.002
K release rate (k_K day^{-1})					
A. auriculiformis	0.093	0.070	0.050	0.051	0.039
S. spectabilis	0.086	0.097	0.091	0.071	0.054
L. leucocephala	0.101	0.067	0.111	0.063	0.034
T. diversifolia	0.265	0.158	0.173	0.093	0*
G. sepium	0.141	0.118	0.173	0.075	0.051
$LSD_{0.05}$	0.004	0.011	0.079	0.005	0.003
Ca release rate (k_{Ca} day^{-1})					
A. auriculiformis	0.072	0.045	0.031	0.014	0.014
S. spectabilis	0.071	0.059	0.004	0.025	0.021
L. leucocephala	0.094	0.071	0.057	0.017	0.007
T. diversifolia	0.247	0.154	0.107	0.053	0*
G. sepium	0.143	0.072	0.072	0.018	0.02
$LSD_{0.05}$	0.003	0.002	0.006	0.002	0.002
Mg release rate (k_{Mg} day^{-1})					
A. auriculiformis	0.098	0.024	0.038	0.009	0.021
S. spectabilis	0.097	0.068	0.089	0.044	0.033
L. leucocephala	0.082	0.056	0.051	0.018	0.014
T. diversifolia	0.241	0.148	0.146	0.076	0*
G. sepium	0.136	0.088	0.123	0.047	0.033
$LSD_{0.05}$	0.017	0.004	0.004	0.003	0.002

* Zero because leaf materials remaining could not be quantified. Leaf material was inseparable from soil mineral particles

[a] Nutrient release rates are in percentages

immobilization of P or reduce the rate of mineralization despite the high levels of N in the leaves. Therefore, such materials may be composted to start the breakdown before application to crops (Palm et al. 2001). On the other hand, the fresh leaves of *A. auriculiformis* were rated as low quality litter due to the low levels of N (<2.5%) and P (<0.25%). The leaves may be unsuitable for use as a fertilizer technology. Meanwhile, *A. auriculiformis* fresh leaves may be used as surface mulch to protect soil against evaporative losses or to control surface water flow. Alternatively, the fresh leaves of *A. auriculiformis* may be mixed with very high grade organic matter or N and P fertilizers to compensate for the low N, P or both N and P levels (Palm et al. 2001). Furthermore, organic residues such as *L. leucocephala*

Table 8 N, P, K concentration of green leaves of *T. diversifolia* as compared to other shrubs and trees (Jama et al. 2000)

Species	Nitrogen (%)		Phosphorus (%)		Potassium (%)	
	Mean	Range	Mean	Range	Mean	Range
Tithonia diversifolia	3.5	3.1–4.0	0.37	0.24–0.56	4.1	2.7–4.8
Calliandra calothyrsus	3.4	1.1–4.5	0.15	0.04–0.23	1.1	0.6–1.9
Crotalaria grahamiana	3.2	3.0–3.6	0.13	0.13–0.14	1.3	0.9–1.6
Lantana camara	2.8	2.3–4.0	0.25	0.18–0.30	2.1	1.8–2.4
Leucaena leucocephala	3.8	2.8–6.1	0.2	0.12–0.33	1.9	1.3–3.4
Sesbania sesban	3.7	1.4–4.8	0.23	0.11–0.43	1.7	1.1–2.5
Tephrosia vogelii	3.0	2.2–3.6	0.19	0.11–0.27	1.0	0.5–1.3

and A. auriculiformis, which decompose and release nutrients slowly, can be considered for long-term build up of soil fertility.

Table 9 Relationship between percent rate of decomposition (k_D day^{-1}) and chemical composition of leaf materials of the various species used in the experiment

Element	Equation	R^2	SE*	*P* value‡
N	$k_D = 0.016\ (N) - 0.34$	0.68	0.06	0.088
P	$k_D = 0.081\ (P) - 0.1$	0.88	0.04	0.019
K	$k_D = 0.1007\ (K) - 0.48$	0.47	0.08	0.205
Ca	$k_D = 0.004\ (Ca) + 0.07$	0.03	0.10	0.793
Mg	$k_D = 0.041\ (Mg) - 0.14$	0.95	0.02	0.005
C	$k_D = -0.008\ (C) + 3.79$	0.64	0.06	0.105
C:N	$k_D = -0.021(C{:}N) - 0.48$	0.61	0.06	0.121
C:P	$k_D = -0.001\ (C{:}P) - 0.29$	0.68	0.06	0.086

R^2 = coefficient of determination, * = standard error, ‡ = significance of fit

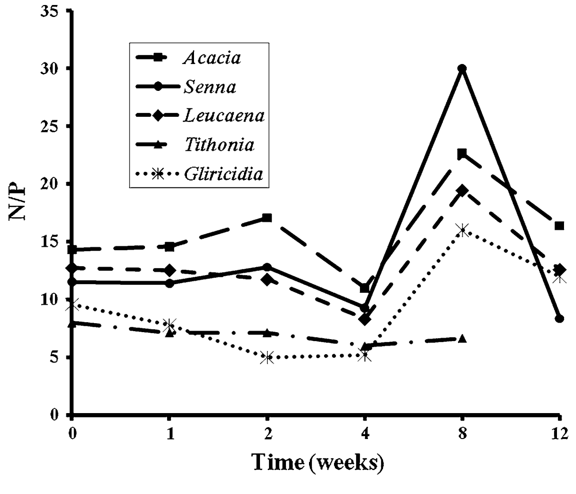

Fig. 4 Nitrogen-to-phosphorus ratios with time in the decomposing leaves of *Tithonia diversifolia, Acacia auriculiformis, Senna spectabilis, Leucaena leucocephala* and *Gliricidia sepium*

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