Decomposition and Fertilizing Effects of Maize Stover and *Chromolaena odorata* on Maize Yield

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Resumé

Tetteh, F. M., Safo, E. Y. & Quansah, C. *Les effets de la décomposition et la fécondation du maïs et 'Chromolaena odorata' sur le rendement du maïs.* La qualité, le niveau de la décomposition et l'effet fertilisant de *Chromolaena odorata* et le maïs étaient déterminés dans l'expériment du terrain comme l'application de la superficie ou enterrés dans les sacs litières. Des études sur l'effet du matériau des plantes avec les qualités variantes (Maïs et *C. odorata*) appliquées uniquement (10 mg ha^{-1}) et mélangées sur le graine du maïs et le rendement de la biomasse étaient également entamées sur la série du sol "Asuansi" (ferric Acrisol).

Le contenu total de l' azote des résidus est entre 0.85% en maïs et 3.50% en *C. odorata*. Dans le cas de la carbon organique, c'est entre 34.90% en *C. odorata* et 48.50% en maïs. Dans le cas du phosphore, c'est entre 0.10% en maïs et 0.76% en *C. odorata*. Dans la saison sèche, le niveau de la décomposition (K) était 0.0319 $ĵour^{-1}$ pour *C. odorata* et 0.0081 pour le maïs. Dans la saison sèche c'était 0.0083 pour *C. odorata* et 0.0072 $ĵour^{-1}$ pour le maïs. L'enterrement du matériau des plantes a réduit la période de la vie moitié (t_{50}) de 18 à 10 ĵours pour *C. odorata* et 45 à 20 ĵours pour le maïs. Dans le cas de *C. odorata* unique, (10 mg ha^{-1}) on a obtenu 2556 kg ha^{-1} de rendement de la graine par rapport à 2167 kg ha^{-1} pour le maïs. Le mélange des résidus du maïs et les résidus de *C. odorata* ont amélioré le contenu nutritif ainsi que les nutriments relâchés par le mélange aboutissant en rendement plus élevé dans le mélange que le traitement unique. Il est recommandé qu'on utitise *C. odorata* comme l'engrais végétal, le paillis ou le matériau compostage pour augmenter la fertilisation du sol.

Mots clés: La décomposition, la synchronie, la vie-moitié, le résidu de la qualité élevée, N immobilisation.

Abstract

The quality, rates of decomposition and the fertilizing effect of *Chromolaena odorata*, and maize stover were determined in field experiments as surface application or buried in litter bags. Studies on the effect of plant materials of contrasting qualities (maize stover and *C. odorata*) applied sole (10 Mg ha^{-1}) and mixed, on maize grain and biomass yield were also conducted on the Asuansi (Ferric Acrisol) soil series. Total nitrogen content of the residues ranged from 0.85% in maize stover to 3.50% in *C. odorata*. Organic carbon ranged from

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34.90% in *C. odorata* to 48.50% in maize stover. Phosphorus ranged from 0.10% in maize stover to 0.76% in *C. odorata.* In the wet season, the decomposition rate constants (k) were 0.0319 day^{-1} for *C. odorata*, and 0.0081 for maize stover. In the dry season, the k values were 0.0083 for *C. odorata*, and 0.0072 day^{-1} for maize stover. Burying of the plant materials reduced the half-life (t_{50}) periods from 18 to10 days for *C. odorata*, and 45 to 20 days for maize stover. Maize grain yield of 2556 kg ha^{-1} was obtained in sole *C. odorata* (10 Mg ha^{-1}) compared with 2167 kg ha^{-1} for maize stover. Mixing of maize stover and *C. odorata* residues improved the nutrient content as well as nutrient release by the mixtures resulting in greater maize grain yields in the mixtures than the sole maize stover treatment. It is recommended that *C. odorata* be used as green manure, mulching or composting material to improve soil fertility.

Keywords: Decomposition, synchrony, half-life, high quality residue, N immobilization.

Introduction

In tropical ecologies, crops obtain most of their nutrients from decomposing organic residues (Constantinides and Fownes, 1993). The productivity of tropical fallow systems is sustained through a controlled nutrient cycling, accumulation and breakdown of organic matter. It is estimated that, globally, about 130 million tons of plant residues are available in organic form, although the quantity usable is much smaller (FAO, 1984). In most cropping systems, the efficiency with which nutrients in plant residues are taken up depends on the rate at which they are mineralized and the time they are required by the plant. Most cropping systems in Ghana are characterized by low level of synchrony (Tetteh, 2004). With the inability of most resource-poor farmers to afford mineral fertilizers, the use of N-rich plant residues as source of nutrients has proven to be a viable alternative source of soil fertility replenishment in low input smallholder farming systems (Thonnisen *et al.*, 2000; Makumba *et al.*, 2007 and Akinnifesi *et al.*, 2007).

Chromolaena odorata is one of the most dominant weeds in a typical traditional fallow in the semi deciduous forest and forest-savanna transition zones of Ghana. According to Obatolu and Agboola (1993), it is a luxuriant growing weed in the humid tropics. When land is cleared for farming as well as ĵust after harvest, *C. odorata* debris often mix with other crop residues (especially maize stover) of contrasting chemical composition (quality) before decomposition commences. Plant residues of higher C:N ratios are usually considered to decompose more slowly than those with low C:N ratios (Parr and Papendick, 1978; Patra, *et al.*, 1992). Crop residues are an important resource of nutrients on the farm. There are several competing interests for this resource, including the use as animal feed or as a fuel resource (Gupta *et al.*, 1987). Most often, in the northern regions of Ghana maize stover is totally removed from the soil surface for use as fuel or burnt completely to reduce the incidence of pest and diseases infestation in subsequent crops. Litter-feeding organisms such as termites and earthworms influence organic matter dynamics as well as carbon and nutrient mineralization in the soil (Martin, 1991). Being the commonest organic residues in most cropping systems in Ghana, and to develop effective techniques for using plant residues acceptable by small scale farmers, *C. odorata* and maize plant debris decomposition, nutrient release pattern and the contributions from these residues to the nutrient budget need to be known.

The investigations were aimed at determining the decomposition and the fertilizing effect of *C. odorata* debris and maize stover on maize in the semi-deciduous forest zone of Ghana.

Materials and methods

The study was carried out in Kumasi, Ghana, on soils of Asuansi series classified by Adu (1992) as Ferric Acrisol according to FAO (1990) and Typic Haplustult according to USDA (1998). This soil occurs at the upper to middle slope sites of the Kumasi Asuansi/Nta-Ofin Compound Asssociation. The area lies between latitudes 06°. 39' and 01°.43' North and longitudes 01°.39' and 01°.42' West of the Greenwich meridian in the semi-deciduous forest zone of Ghana.

Residue characterization

Plant materials of *C. odorata* and maize stover were collected from fallows and fields at the Kwadaso Central Agricultural Station experimental fields. These plant materials were dried in the oven at 70 °C for 72 hours and milled to pass through a 2 mm sieve. Organic matter in residues was derived from the difference between dry matter and ash content; carbon content was obtained by dividing organic matter values by 2 (Bebwa and Leĵoly, 1993). Total nitrogen was determined by the Kĵeldahl method using the Tecator Kĵeltec distillation apparatus. For phosphorus, potassium, calcium and magnesium determinations, a 0.5 g sample of the sieved organic materials was ashed in a muffle furnace. The ash was dissolved in 0.1 M HCl, filtered and made to 100 ml volume with distilled water. Phosphorus in the ashed samples was determined by the yellow vanado-molybdate method and potassium determined by flame photometry. Calcium and magnesium were determined by EDTA titration. Total soluble polyphenols were analysed by Folin-Denis method. Polyphenols were extracted in 50% methanol heated to 80 °C and determined colorimetrically using the Folin-Denis reagent with tannic acid as the standard (Anderson and Ingram, 1993).

Soil characterization

The physical and chemical properties of

the topsoil (0 - 15 cm) and subsoil (15 - 30 cm) are presented in Table 1. Soil pH was determined in a 1:2.5 (w:v) suspension of soil and water using HI 9017 Micro-processor pH meter. Organic carbon was determined by a modified Walkley and Black procedure as described by Nelson and Sommers (1982). Total nitrogen was determined by the Kĵeldahl digestion and distillation procedure as described in Soils Laboratory Staff (1984). Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0 M ammonium acetate (NH_4OAc) extract (Black, 1965) and the exchangeable acidity (H^+ and Al^{3+}) was determined in 1.0 M KCl extract as described by Page *et al.*, 1982. The readily acid-soluble forms of P were extracted with a $HCl:NH_4F$ mixture called the Bray's No. 1 method as described by Bray and Kurtz (1945) and Olsen and Sommers (1982).

Field residue decomposition studies

Litter bags (20 x 30 cm) were made from uv-stabilized nylon mosquito nets. A 15 g sample each of maize and *C. odorata* was put in each litter bag, corresponding to a loading rate of 2.5 Mg ha^{-1} (Nĵunie *et al.*, 2004). Larger samples put in litter bags do not have good contact with the soil and therefore affect the rate of decomposition. Three factors were studied: surface application of plant residues, burying of plant residues and applying plant residues on soil surface without using litter bags (unconfined). These were carried out in the wet and dry seasons. A triplicate sample of each plant material was sampled at 1, 2, 4, 6, and 10 weeks (for maize stover). The samples were dried at 60°C for 72 hours and weighed. The rate of decomposition was expressed in a negative exponential function using the relation:

$W_t/W_o = W_o e^{-kt}$ (Anderson and Ingram, 1993),

where:

W_t = mass of plant residue in a particular day (or time).

W_o = initial mass of plant residue.

k = amount of organic material which is lost per unit time.

The rate constant was estimated as the slope of the graph,

$\log_n (W_t/W_o) = -kt + \log_n W_o$ (Anderson and Ingram, 1993).

Table 1. Chemical properties of Asuansi soil series (Ferric Acrisol).

Soil depth (cm)	*pH*	*Total N*	*Organic Matter*	*ECEC*	*Exch. K*	*Bray-1 P*
		%	%	cmol kg^{-1}	cmol kg^{-1}	mg kg^{-1}
0-15	5.80	0.145	2.50	8.07	0.23	5.00
15-30	5.00	0.050	1.10	6.51	0.11	1.50

Soil fauna

Five 25 cm x 25 cm by 30 cm deep, soil monoliths of the Asuansi series (Ferric Acrisol) were sampled and hand sorted for macro-invertebrates. Sampling was done on plots with decomposing *C. odorata* and maize plant material 4 weeks after application (peak of plant residue decomposition observed in this experiment). Litter was removed from the 25 cm quadrant to be sampled. The monolith was isolated by digging a 20 cm wide by 30 cm deep trench round it to facilitate cutting of the sample into horizontal strata and collecting living organisms (earthworms, ants, termites, etc) escaping from the block.

Maize fertilization experiment

At Kwadaso Agricultural Research Station, maize (variety *Obatanpa)* was planted to the Asuansi soil series (Ferric Acrisol, FAO) with plot size 4.0 x 6.0 m with a planting distance of 70 x 35 cm. The treatments were: 1. Control (no residue applied), 2. Maize stover (10 Mg ha^{-1}), 3. Maize stover (5 Mg ha^{-1}) + *C. Odorata* 5 Mg ha^{-1}), 4. Maize stover (3 Mg ha^{-1}) + *C. odorata* (7 Mg ha^{-1}) and 5. *C. odorata* (10 Mg ha^{-1}). A total of 10 Mg ha^{-1} of organic residue with different proportions of maize and *C. odorata* was applied where there is organic amendment. There were 4 replications arranged in a randomized complete block design. Soil samples were taken before imposing the treatments and after harvest. Stover weight and grain weights were taken. Recovery of residue nitrogen by maize was estimated by the difference method:

$$\text{Apparent N recovery (\% ANR)} = \frac{(\text{total maize N})r - (\text{total maize N})c}{\text{Residue N added}} \text{x}100$$

where:
r = residue treatment, and
c = control (no added residue N).

Statistical analysis

All data were subjected to analysis of variance (ANOVA) using the software package Statistix 7 (Analytical Software, 2000). Means were separated with the least significant difference at p = 0.05. Student's *t*- test was also used to analyze data on quality of plant material.

Results

The chemical properties of the soil used are in Table 1. The results of chemical analysis carried out on maize stover and *C. odorata* plant material are in Table 2. Total nitrogen, phosphorus, calcium, magnesium, polyphenols and ash content of *C. odorata* plant material were greater than maize stover. Maize stover however had a higher carbon and potassium contents as well as higher C:N and polyphenol: N ratios.

Residue decomposition

The mass of residue remaining was significantly affected by the initial quality of the two residues. Results of decomposition of *C. odorata* and maize stover are in Figures 1a, b, c and d. Decomposition of *C. odorata* and maize stover materials were more pronounced from the fourth week of application. *Chromolaena odorata* decomposed

Table 2. Chemical composition of *Chromolaena odorata* and maize stover materials.

Parameter	*Maize stover*	*C. odorata*
Carbon (%)	48.60	42.30
Total N (%)	0.85	2.52
Phosphorus (%)	0.13	0.76
Potassium (%)	1.10	1.57
Calcium (%)	0.64	3.53
Magnesium (%)	0.19	1.89
Polyphenols (%)	7.30	12.50
Ash (%)	10.00	14.00
C:N	57.20	16.79
Polyphenol:N	15.86	4.96

faster than maize stover material. *Chromolaena odorata* lost 50% of its mass (i.e t_{50}) at 18 days following surface application. Maize stover lost about 50% of their biomass only after 45 days of surface application. These half-life values were estimated from the decomposition curves.

Figures 1a and 1c compare the rates of decomposition of surface applied and buried *C. odorata* and maize stover materials in the wet season. Burying reduced the half-life of the plant materials by about 50% i.e. from 18 to 10 days for *C. odorata* and from 45 to 20 days for maize stover in the wet season. Decomposition of buried plant materials was faster than those applied on the soil surface. Surface applied *C. odorata* and maize stover materials followed zero-order and a first order kinetics (exponential) respectively. The decomposition rate constant, *k*, as derived from a single exponential function, and the t_{50} as well as the R^2 values are in Table 3. The t_{50} values determined from the graphs were different from the calculated values.

Dry season decomposition

Decomposition of plant materials buried in the soil in the dry season was reduced considerably. The half-life (t_{50}) extended from 22 (in the wet season) to 83 days (in the dry season) for *C. odorata* and 45 to 96 for maize stover (Table 3). During the dry season, about 50-70% of all the buried organic residues remained in the soil after three months (Figure 1d), whereas in the wet season, after 35 days, about 10% of maize stover and no *C. odorata* plant material remained in the soil (Figure 1c). Regression equations relating the rate of decomposition ($k\mathrm{day}^{-1}$) to the polyphenol, Polyphenol/N, and C/N ratios for *C. odorata,* maize stover and other plant residues (*Panicum maximum*, *Glirisidia sepium* and *Leucaena leucocephala*) show inverse relationships as:

$k\mathrm{day}^{-1} = 0.034 - 0.088$ (Polyphenol);
$R^2 = 0.3436$.

$k\mathrm{day}^{-1} = 0.033 - 0.166$ (Polyphenol/N);
$R^2 = 0.6926$.

$k\mathrm{day}^{-1} = 0.028 - 0.036$ (C/N);
$R^2 = 0.3391$.

The high R^2 value (0.6926) meant that the rate of decomposition ($k\mathrm{day}^{-1}$)

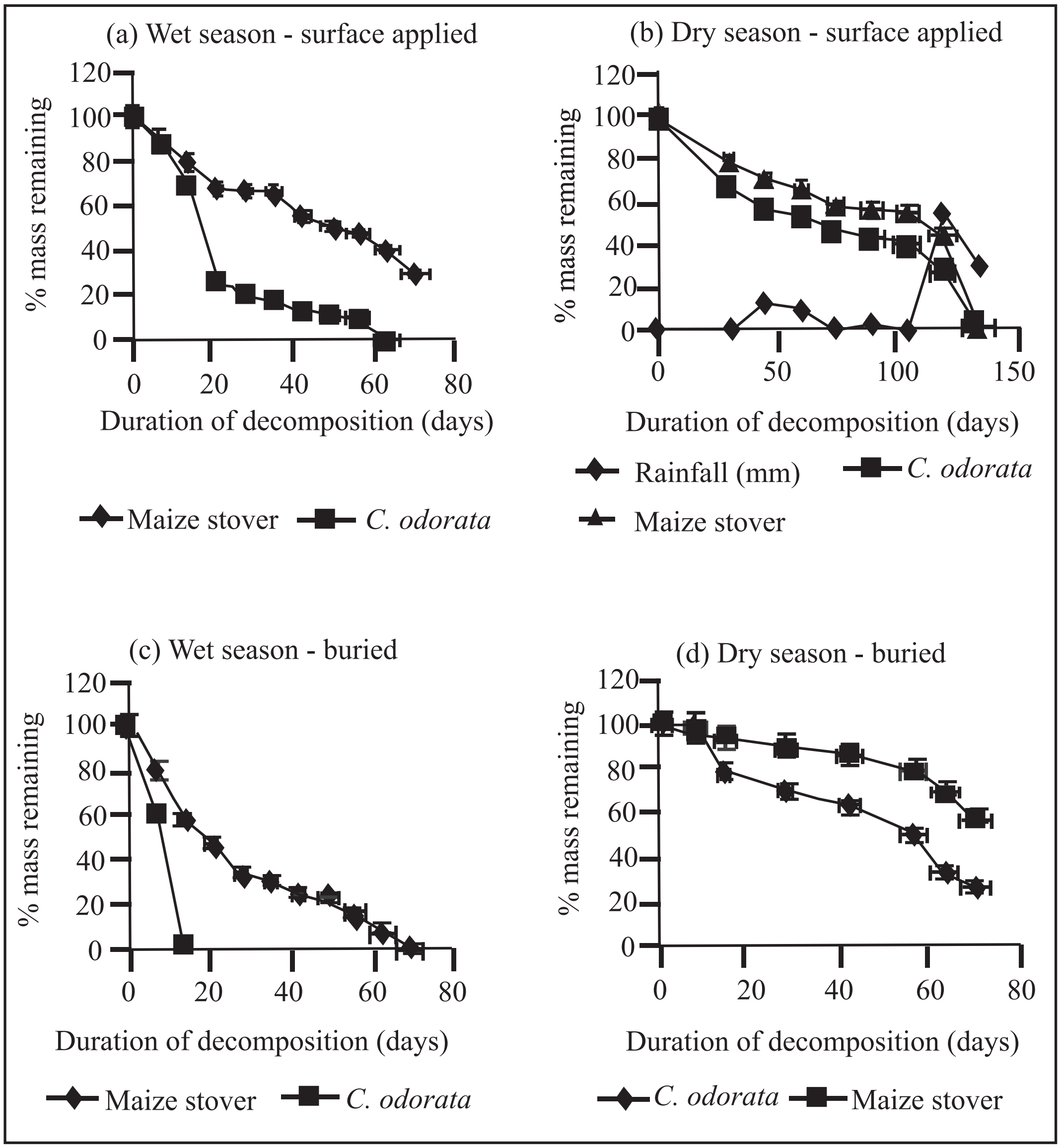

Figure 1. Decomposition of maize stover and *Chromolaena odorata* plant materials in buried and surface applied liter bags in the wet and dry seasons in the semi-deciduous forest zone of Ghana. (a) Wet season surface applied. (b) Dry season surface applied. (c) Wet season buried. (d) Dry season buried.

depended more on polyphenol/N ratio than polyphenol content and the C/N ratio. Thus Polyphenol/N ratio was a better indicator of decomposability than C/N ratio and polyphenol content of residues.

Decomposition of unconfined litter

The rates of decomposition of fresh mulches applied at the rate of 20 Mg ha^{-1} are in Figure 2. By the seventh day following the application of the mulches, about 40-50% of fresh weight of the initial mass was lost. From the seventh to the 28^{th} day the decomposition rates reduced abruptly. The rate of decomposition of the confined (Figure 1a) and unconfined (Figure 2) litter followed the same trend. The initial rapid decay followed zero-order kinetics, i.e., could be represented by a linear equation. This is followed by a slower phase of decomposition.

Soil fauna

At the time of sampling, the invertebrates observed in the soils with the decomposing plant residues were termites. The population counts of invertebrates under decomposing maize stover and *C. odorata* residues are in Table 4.

The results show that termite population in the topsoil under decomposing maize stover was more than twice the number under *C. odorata*. Termite population also decreased with depth. There is no significant difference between the population of termites in the top and sub-soils under *C. odorata*. Similarly, there is no significant difference between termite populations in the subsoils under *C. odorata* and maize stover. The decrease in termite population with depth under maize was about 65%.

Maize field trial

Results of the field experiment comparing the fertilizing effect of maize stover and *C. odorata* applied to maize grown continuously in three cycles (seasons) at Kwadaso are in Table 5. Generally, maize grain yield declined with time when successively cropped on the same plot. Application of 10 Mg ha^{-1} of plant materials (sole and mixed) of *C. odorata*, and maize stover increased maize grain yield relative to the control in the first year of cropping from 1911 to 2556 kg ha^{-1} on a Ferric Acrisol at Kwadaso. Apart from the sole maize stover (10 Mg ha^{-1}) treatment, the rest of the treatments gave yields that were significantly greater than the control in the first cropping season (Table 5). In the second season, it was only the sole maize stover (10 Mg ha^{-1}) treatment that gave significantly smaller yields than the control, sole *C. odorata* and mixed *C. odorata* (7 Mg ha^{-1}+3 Mg ha^{-1} maize stover) treatments. In all the treatments, irrespective of the type of residue applied, there was a decline in maize grain yield by about 38% from the first to the second cropping cycle. From the second to the third cropping cycle, the decline in maize grain yield was about

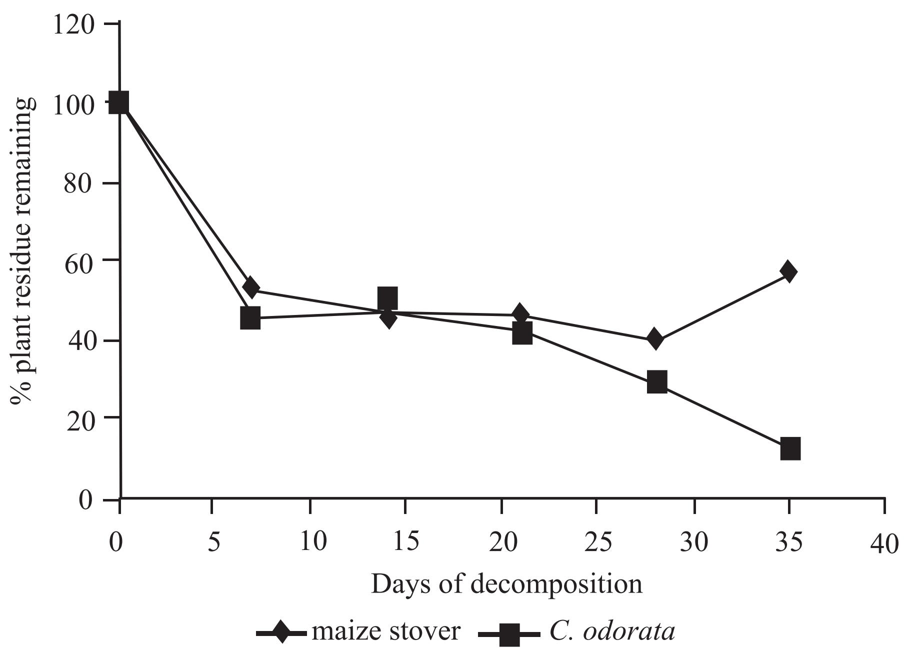

Figure 2. Decomposition of unconfined surface applied maize stover and *C. odorata* materials in the wet season on a Ferric Acrisol at Kwadaso.

Table 3. Plant residue decomposition rate constants (*k*) and half-life (t_{50}) values in the wet and dry seasons in the semi-deciduous forest zone, Kwadaso, Ghana.

Plant residue	*k* *Wet season*	*k* *Dry season*	t_{50} *Wet season*	t_{50} *Dry season*	R^2
C. odorata	0.0319	0.0083	21.80	83.30	0.855
Maize stover	0.0081	0.0072	45.50	96.20	0.930

Values are the means of duplicate samples calculated from $t_{50} = 0.693k^{-1}$.

Table 4. Population count of termites in soil (Ferric Acrisol) treated with *C. odorata* and maize stover in semi-deciduous forest zone, Kwadaso, Ghana.

Soil depth	*C. odorata*	*Maize stover*
Top soil (0-20 cm)	1,365,480	2,968,037
Sub soil (20-40 cm)	978,256	1,056,378
$LSD_{0.05}$ = 854,589		SEM = 370,593

Table 5. Maize grain yield as affected by the application of maize stover, *C. odorata* material and their combinations on a Ferric Acrisol, Kwadaso, Ghana.

Treatments	*Yield (kg ha^{-1})*		
	2000	*2001*	*2001(minor)*
10 T *C.odorata* ha^{-1}	2555.7	2142.8	616.3
3 T Maize ha^{-1}+7T *C.odorata* ha^{-1}	2488.9	2051.5	582.3
5 T Maize ha^{-1}+5 T *C.odorata* ha^{-1}	2411.1	1382.7	420.7
10 T Maize stover ha^{-1}	2166.7	1032.4	314.0
Control	1911.1	1516.7	241.6
$LSD_{0.05}$	304.9	446.9	116.3

Means followed by different letters indicate significance at p <0.05.

70% for the *C. odorata* treatment and 70% for the control.

Effect of plant residues and their combinations on maize grain yield

In all the three seasons the largest maize grain and biomass yields were obtained in the *C. odorata* (10 Mg ha^{-1}) treatment. The maize stover (10 Mg ha^{-1}) treatments in all the three cropping seasons were significantly smaller than the *C. odorata* treatment. *Chromolaena odorata* plant materials in different proportions also affected yields differently. With increasing proportion of *C. odorata* plant material in the applied mixtures, maize grain yield increased proportionately (Table 5). Statistically, treatments with 50:50 *C. odorata*:maize stover and 100% maize stover (10 Mg ha^{-1}) were not different. However, the 50:50 *C. odorata*+maize stover treatment reduced maize grain yield by about 15, 53, and 49% respectively for the first, second and third seasons as compared to the 100%

C. odorata treatments.

Recovery of N by maize from decomposing maize and *C. odorata* residues

The percent nitrogen recovered by maize from *C. odorata* and maize residues increased from 3.1 to 4.9% of the initial N added with increasing proportion of *C. odorata* in the mixture. With increasing proportion of maize stover in the mixture (M30:C70), (M50:C50) and (M100:C0), the amount of N recovery by maize in the field decreased from 4.9% in the 100% *C. odorata* treatment to 3.1% in the 100% maize residue treatment in the first season (Table 6).

In the second season the % N recovered values were smaller and ranged from 7% in the sole maize stover material treatment to 2.3% in the sole *C. odorata* treatment.

From Table 7, the largest amount of nutrients applied was in the *C. odorata* treatment followed by the Maize 3 Mg ha^{-1}+*C. odorata* 7 Mg ha^{-1} treatment. The total quantity of nutrients applied in 10 Mg ha^{-1} *C. odorata* residue was about three times the nutrient input from maize stover alone. The other two combinations also added nutrient levels of 269.0 and 306.3 kg ha^{-1} respectively for 50% Maize+50% *C. odorata* and 30% maize stover+70% *C. odorata* treatments.

Table 6. Recovery of plant material N by maize on a Ferric Acrisol in the semi-deciduous forest zone of Ghana (estimated by the difference method).

	% N recovery by maize	
Plant material	*1st cropping season*	*2nd cropping season*
10 Mg Maize stover ha^{-1}	3.10	-7.00
5 Mg Maize stover+5 Mg *C.odorata* ha^{-1}	3.10	-2.10
3 Mg Maize stover + 7 Mg *C.odorata* ha^{-1}	4.10	2.10
10 Mg *C.odorata*	4.90	2.30
$LSD_{0.05}$	0.54	0.47

Table 7. Amount of Nutrients added in plant materials in the various treatments.

Treatment	*N*	*P*	*K*	*Total (N+P+K)*
	---------------------	*kg ha^{-1}*	---------------------	
C. odorata (10 Mg ha^{-1}).	252.0	76.0	50.0	378.0
Maize stover (10 Mg ha^{-1})	85.0	20.0	56.0	161.0
Maize5Mg ha^{-1}+*C. odorata* 5Mg ha^{-1}	168.5	48.0	53.0	269.5
Maize3Mg ha^{-1}+*C. odorata* 7Mg ha^{-1}	196.3	59.0	51.0	306.3
$LSD_{0.05}$	52.5	15.8	10.0	78.6

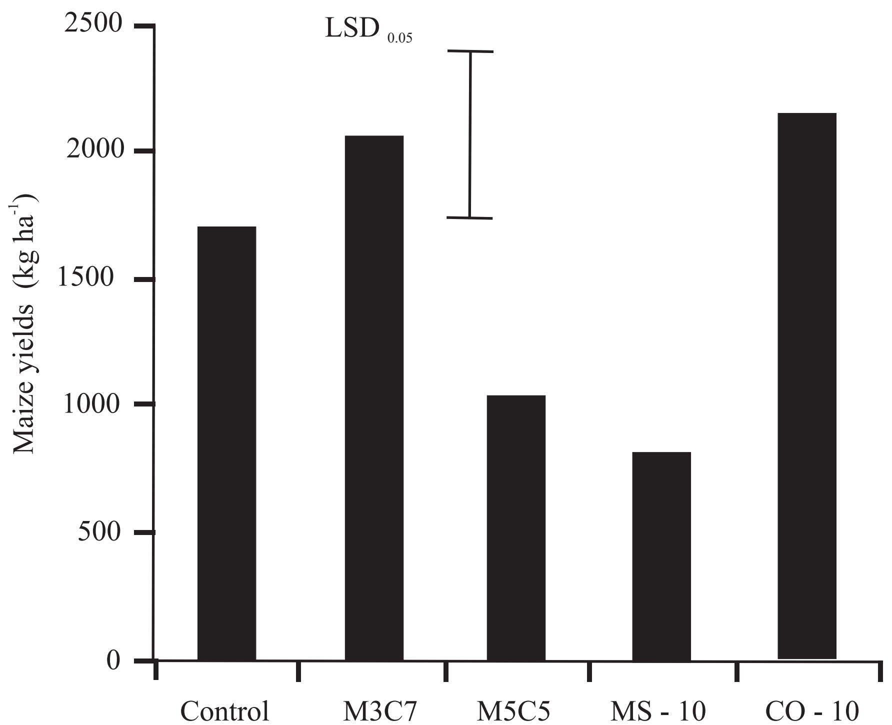

Figure 3. Application of 10 Mg ha^{-1} of maize stover (MS-10) and *C. odorata* (CO-10) biomass and their combinations (maize stover 3Mg ha^{-1}+*C. odorata* 7Mg ha^{-1} M3C7; maize stover 5Mg ha^{-1}+ *C. odorata* 5Mg ha^{-1}-M5C5) and their effect on second season maize grain yield at Kwadaso.

Discussion

Residue quality, N immobilization and continuous cultivation of maize

According to Swift *et al.* (1979), the three main factors, which control the decomposition of organic materials, are the quality of the decomposing organic material, the decomposer organisms and the environmental condition. Materials with smaller rates of decomposition (e.g. maize stover) are considered to be of low quality. The differences in the chemical composition and rate of decomposition of maize stover and *C. odorata* closely reflected in maize grain yield obtained in the different treatments. *Chromolaena odorata*, contained more nutrients (NPK) and decomposed faster than maize stover material. It was therefore a better fertilizing material than maize stover. The reduction in maize grain yield in the maize stover treatments could be attributed to N immobilization by maize stover hence, reduction in N availability in the soil.

Decomposition of confined residues in litter bags

The decomposition process was observed to be in two main states: an initial phase of rapid decay followed by a slower phase. Between the initial rapid and slower phases there is a sharp bend in the decay curve. The reason for the sharp bend is that products of decomposition of the initial rapid phase have been synthesized into humic substances, which are very resistant and more stable to microbial decomposition than the components themselves (Jenkinson, 1981). The initial rapid phase of decomposition is similar for *C. odorata* and maize stover materials. The initial stages of decomposition in the confined and unconfined residues were rapid. However within this rapid phase, the confined and unconfined organic materials, applied on soil surface, lost about 30 and 50% of their initial weight respectively. This was most probably because compaction of plant residue within the litter bag (confined) could create different microclimates in the interior of the bag, compared to conditions in the unconfined litter. This condition could result in reduced rate of decomposition in the confined plant materials in the litter bag. Confining the plant materials in litter bags however enabled monitoring of the decomposition of plant materials especially beyond the point where the original form of the plant material was lost beyond recognition. The more contact the material had with favourable environmental conditions (moisture, microbial population, uniform temperature, etc), the faster the decomposition. Experiments conducted by Fuhr and Sauerbeck (1968) showed that most crop residues lost about two-thirds of their carbon in the initial rapid phase of decomposition.

Decomposition of unconfined litter

The use of unconfined litter (litter spread on the surface of the soil) in decomposition comes close to what happens naturally. Results obtained in the treatment with unconfined plant materials were erratic because daily weather changes such as rainfall, drought, heat, humidity, etc., affected their decomposition. On the soil surface most of the litter became dry when the weather was hot and sunny, and gained moisture during rains. These alternating dry and wet periods affected the rate of decomposition. Under moisture limiting conditions, microbial decomposition appeared slower and more constant while frequent rainfall events resulted in more rapid decomposition and N release from rye (*Secale cereale* L), and crimson clover (*Trifolium incarnatum* L) (Nĵunie *et al.*, 2004). Decomposition studies of unconfined *C. odorata* materials did not go beyond five weeks because of the difficulty in picking organic materials at the advanced stage of decomposition. Decomposition of litter on the soil surface is more affected by extremes of temperature and humidity than materials mixed with the soil.

Decomposition of buried and surface-applied plant materials

Plant materials decompose faster when buried than when placed on the soil surface. Sugahara and Katoh (1992) observed that, after corn, soybean, grain sorghum, wheat and cotton plant materials were buried for one year, the mass loss was more than double that of the same plant material placed on the soil surface. Brown and Dickey (1970) also reported weight loss of 40% after 18 months, for wheat straw exposed on the soil surface, whereas buried plant samples had losses up to 98%, despite the soil being frozen for 5 months.

Similar trends in decomposition of plant material were observed at Kwadaso for maize stover, and *C. odorata*. However, the rates obtained in the semi-deciduous environment especially in the rainy season, were greater than those reported in the literature. Whereas it took 18 months to lose 40% of the initial weight of wheat straw exposed on the surface as reported by Brown and Dickey (1970), it took 45 days to lose 50% of maize stover. This may be attributed to more favourable environmental conditions (warm temperature, moist conditions, high microbial activity, etc.) in the semi-deciduous forest zone at Kwadaso. Dry season decomposition rates were however, similar to rates obtained in temperate climates.

Dry season decomposition

The reduced rate of decomposition of plant materials in the dry season is very important in the conservation of plant nutrients in tropical environment. This study has demonstrated that plant materials can remain in the soil with reduced rate of decomposition throughout the dry season, until the first rains when conditions become favourable for decomposition. This dry weather condition could delay nutrient release from organic materials. However, during the rainy season, nutrients could be released faster when conditions favourable to decomposition and crop growth occur.

The decomposition of *C. odorata* in the rainy season followed a linear function (in both buried and surface application) whereas maize stover, followed an exponential function. In the dry season, all the plant materials also followed a linear function but with lower decomposition rates as shown by graphs with gentle gradient. This underscores the importance of moisture in decomposition (Wagger, 1989; Nĵunie *et al*., 2004). Moisture is of central importance in the soil, controlling the overall level of microbial activity and hence the rate of decomposition. According to Clement and Williams (1982), there is optimal water content at which the mineralization of both nitrogen and carbon was maximal.

Residue quality, residual effect and continuous cultivation of maize

The differences in the chemical composition and decomposition of the plant residues (maize stover and *C. odorata*) closely reflected in maize yield obtained. *Chromolaena odorata* was a better fertilizing material than maize stover because it contained more nutrients than maize stover.

It has been proposed that manipulation of residues of low and high quality may improve synchrony of nutrient release with subsequent crop requirement. It is conceptualized that for low quality slow decomposing plant material the succeeding crop will use small proportion of the applied plant N in the soil. From the results obtained so far succeeding crops do not benefit significantly from the slow release of nutrients from decomposing plant residues. According to the synchrony hypothesis (Myers *et al.*, 1994), low quality (low N and P, high lignin or polyphenol contents) organic materials extended the time period of availability of nutrients to the plant. Results obtained mean that *C. odorata* (as compared to maize stover) had greater nutrient content, and greater rate of decomposition and therefore greater amount of nutrients were released for the uptake of the maize crop. This was manifested in the greater yield of treatments with greater proportions of *C. odorata* material.

The natural way of enhancing synchrony is the influence of the dry season (harmattan period) on the decomposing plant residues. During the dry season, activities of microbial, fungal and other decomposing organisms are significantly reduced. The reduction in moisture content results in a decreased rate of decomposition. The plant residues are therefore preserved until the onset of favourable conditions when nutrients will be released to coincide with time of crop nutrient demand in the cropping season.

Effect of plant materials and their combinations on yield of maize

This work has confirmed results of similar works that it was possible to reduce the rate of decomposition by mixing high and low quality plant materials (Mulongoy *et al*., 1993; Handayanto *et al.,* 1997). It was expected that the slower rate of decomposition could also increase the residual effects of the residues in subsequent cropping seasons. Results of field experiments of this study however indicated that reducing residue quality by mixing contrasting quality residues rather reduced the total amount of N (and other nutrients) released from the organic materials. Total NPK content of sole *C. odorata* and sole maize stover were 378 and 161 kg ha^{-1} respectively. By mixing *C. odorata* and maize stover material (e.g.1:1; Maize stover 5Mg ha^{-1} +*C. odorata* 5 Mg ha^{-1}) the nutrient content of the mixture was 269 kg ha^{-1} which was greater than that of sole maize stover but less than sole *C. odorata* treatment.

Synchrony and maize yield

Mixing of the two contrasting plant materials (maize stover and *C. odorata*) was aimed at minimizing the release of nutrients from *C. odorata* and prolonging the release period through immobilization and subsequent release to the growing plant when the nutrients are most needed. In their experiments Mulongoy *et al.* (1993) showed that it was possible to reduce the rate of decomposition by mixing high and low quality woody plant materials. Mixing of residues could only produce yield levels, which fall between those obtained from the contrasting quality residues. This reduction in maize grain yield induced by addition of maize stover was due to N immobilization (Makumba *et al*., 2007). Increasing proportion of stover in the mixture increased N immobilization, hence reduction in N uptake by the maize resulting in smaller maize grain yield. Apart from the possible immobilization of nutrients following mixing, the mixing has reduced the nutrient content as compared with the *C. odorata* treatment alone. Handayanto *et al*. (1997) demonstrated that mixing punings of different qualities reduced the residue quality and the total amount of N released. The smaller maize grain and biomass yield levels in the maize stover treatment were due also to the smaller amount of nutrients (122 kg NPK ha^{-1}) in 10 Mg ha^{-1} of maize stover as compared to 379 kg NPK in 10 Mg ha^{-1} *C. odorata* plant material. This means that efforts to improve the synchronization of nutrient release with plant demand were compromised by the reduction in the amount of nutrients available to the crop. However, considering the sole maize stover treatment, mixing of the two contrasting residues rather improved the nutrient content of the mixture as well as nutrient release as manifested in the greater maize grain yield in the mixtures than the sole maize stover treatment. As the proportion of *C. odorata* material increased in the mixtures, nutrient contents increased, N immobilization reduced, resulting in greater nutrient release, and greater maize grain yield.

Chromolaena odorata and maize debris possess very contrasting chemical properties. The carbon content of the two residues were quite close which confirms findings of Jenkinson (1981) and Kachaka *et al*. (1993) that most plant residues contain constant amount of carbon, ranging from about 40% to 50%. According to Obatolu and Agboola (1990) and Tetteh (2004), these nutrients were found to be greater in *C. odorata* plant material than in cowdung.

Conclusion

The main reason for synchronizing nutrient supply and crop demand, is to improve the efficiency of nutrient uptake, minimize nutrient loses, and increase productivity of cropping systems.

From the results of this study a number of conclusions can be drawn. Decomposition is faster in the rainy season than in the dry season. Burying (incorporation) of the residues in the rainy season resulted in increased rate of decomposition, thus reducing the half-life (t_{50}) of the residues by about 50%. Decomposition in the dry season is however not consistent due to variable moisture and meso- and macro-fauna availability.

The study has also confirmed findings by other Scientists (especially from temperate regions) that residues are diverse in quality, with rates of decomposition and mineralization depending on the climatic condition and placement (i.e. incorporation into the soil or surface application). This study has established that the rate of decomposition of plant materials depended more on the polyphenol:N ratio than both the C:N ratio and the polyphenol content. Also, considering the low quality maize stover material, mixing of maize stover and *C. odorata* materials resulted in greater yields than the sole maize stover thus improving nutrient uptake efficiency. Mixtures with greater proportion of maize stover had reduced maize grain yield due to N immobilization. With declining use of fertilizer by farmers due to high cost, the use of nutrient rich plant materials such as *C. odorata* as a sound alternative for farmers to provide nutrients to the main crop has become very necessary.

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