TROPICAL SOIL MANAGEMENT

Plant Materials for Soil Fertility Management in Subhumid Tropical Areas

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ABSTRACT

***Lantana camara* L., *Senna hirsuta* (L.) Irwin & Barneby, *Tithonia diversifolia* (Hemsl.) A. Gray, and *Aspilia kotschyi* du Petit-Thouars occur naturally in eastern and central Uganda. Trimmings of these species were evaluated for effectiveness in improving soil productivity. The plant trimmings varied for N (13–30 g kg^{-1}), P (1.1–1.8 g kg^{-1}), lignin (11–16%), and polyphenol (1.3–2.5%) concentration. Decomposition rates were higher for incorporation than for surface placement, but placement did not affect maize (*Zea mays* L.) and bean (*Phaseolus vulgaris* L.) yield. Decomposition rates were similar for all species with the same placement method. Potassium and Mg were generally mineralized most and least rapidly, respectively, with intermediate rates for N, P, and Ca. Maize and bean yield increased with application of 4 Mg ha^{-1} dry wt. trimmings of *L. camara*, *S. hirsuta*, and *T. diversifolia*, but only maize eventually responded to *A. kotschyi*. Yields per units of N and P applied were more and less, respectively, with inorganic than with organic treatments, but plant trimmings supplied less P than fertilizer. At the end of the trial period, available soil P was more for the full rate of fertilizer than for the mean of the plant materials. Combining *L. camara* and fertilizer, at 50% rates, resulted in an average of 0.22 Mg ha^{-1} more yield than expected from mere additive effects of the organic and inorganic resources. The value of plant materials may be enhanced by balancing nutrient supply with inorganic fertilizers.**

PER-CAPITA AGRICULTURAL PRODUCTION is declining in sub-Sahara Africa (Sanchez et al., 1996), partially due to low and depleted soil fertility (Vlek, 1993; Bekunda et al., 1997). Increasing pressure on agricultural land and the subsequent abandonment of many traditional maintenance strategies for soil fertility has resulted in negative nutrient balances. According to Stoorvogel and Smaling (1990), about 200 million ha of cropland in Africa has lost 600, 75, and 450 kg ha^{-1} N, P, and K, respectively, during the last 30 yr, primarily by removing crop harvests. Negative balances were determined for farming systems in eastern and central Uganda (Wortmann and Kaizzi, 1998).

Reversal of soil fertility depletion is required to increase per-capita agricultural production (Sanchez and Leakey, 1997) and may be achieved through the use of inorganic and organic inputs. Use of inorganic fertilizers by resource-poor farmers is constrained by inadequate supply, unstable prices of agricultural produce, scarce financial resources, and lack of access to credit. Organic inputs are commonly used in the maintenance of soil productivity (Bekunda and Woomer, 1996), but use is constrained by inadequate supply and labor requirements. Often, however, naturally occurring plants are in sufficient abundance around farmers' fields, along paths, in hedges, and in fields under fallow to be significant resources for nutrient supply to nearby cultivated areas (Lauriks et al., 1999). Uganda farmers recognize the value of these plants in fallow but generally do not cut and apply them as nutrient sources.

Nutrient mineralization patterns during decomposition of organic materials are related to the chemical composition, or quality, of the organic inputs (Heal et al., 1997); climatic conditions; soil physico-chemical environment; and the nature of soil organisms (Swift et al., 1979). Quality characteristics of the organic materials include concentrations of N, lignin, cellulose, hemicellulose, and water-soluble C as well as C/nutrient and lignin/N ratios (Rubins and Bear, 1942; Berg and Staaf, 1981; Melillo et al., 1982; Melillo and Aber, 1984; Reinertsen et al., 1984; Haynes, 1986; Kachaka et al., 1993).

Knowledge of the nutrient contents and mineralization patterns of organic inputs, and their effects on crop productivity, is important to planning their use in fertility management. The objectives of this study were to determine (i) the nutrient contents and mineralization patterns of plants occurring in sufficient abundance to be significant resources in soil fertility management in eastern and central Uganda and (ii) crop response to the application of organic inputs alone or in combination with inorganic fertilizers.

MATERIALS AND METHODS

Selection of Species and Chemical Characterization

Species were selected for this study based on the results of a survey conducted in four districts in central and eastern Uganda to assess the availability and utilization of organic materials, especially naturally occurring plants. The sites were the subcounties of Kamonkoli of Palissa district (1°05′N, 34°05′E; 1120 m above sea level), Nabwigulu of Kamuli district (0°57′N, 33°07′E; 1110 m above sea level), Imanyiro of Iganga district (0°35′N, 33°29′E; 1200 m above sea level), and Gombe of Mpigi district (0°28′N, 32°30′E; 1180 m above sea level). Plant samples totaling 10 to 20 kg dry weight were collected for each species to determine nutrient contents and rates of decomposition and mineralization of nutrients. Subsamples were oven-dried at 70°C and milled to 0.5 mm. Concentrations of total N, P, K, Mg, and Ca were determined following digestion with 18 *M* sulfuric acid (H_2SO_4) (Anderson and Ingram, 1993). Total N was determined by distillation and titration (Bremner and Mulvaney, 1982). Phosphorous was measured colorimetrically by the molybdate blue method (Olsen and Dean, 1965). Potassium and Ca were determined using flame spectrometry, and Mg was determined using atomic absorp-

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tion spectrometry. Lignin was determined with the acid detergent fiber method (Van Soest and Wine, 1968), and the extractable polyphenols were determined by the Folin–Denin method (Anderson and Ingram, 1993). Ash-free dry weight was determined for the samples after ashing in a muffle furnace at 550°C for 4 h.

The Mineralization Study

The decomposition study was conducted at Kawanda Agricultural Research Institute (0°24′N, 32°31′E) at an altitude of 1200 m above sea level during the first rains of 1996. The soil was classified as Kandiudalfic Eutrodox with the following surface (0–0.20 m) properties: 19 g kg^{-1} organic C; pH (1:1.5 soil/water) of 5.3; 2.93, 0.91, and 0.13 $cmol_c$ kg^{-1} soil of Ca, Mg, and K, respectively; exchangeable acidity of 2.3 $cmol_c$ kg^{-1} soil; and sandy clay loam texture (Foster, 1971). The site was under maize crop during this study.

The effects of species and method of application on rates of decomposition (mass loss) and mineralization (nutrient release of N, P, K, Ca, and Mg) were measured in a complete factorial arrangement using 30- by 30-cm polyethylene litter bags with a mesh size of 5 mm, allowing access to soil meso- and macrofauna (Swift et al., 1979). The species were *L. camara*, *A. kotschyi*, and *S. hirsuta*, and surface application was compared with incorporation. The litterbags were randomly placed between rows of maize in a field. Incorporated litterbags were buried in the surface soil at a 45° angle (Anderson and Ingram, 1993). Four litterbags for each plant material and method of application were retrieved after 2, 4, 8, and 16 wk for a total of 96 experimental units. The retrieved samples were oven-dried at 65°C to a constant weight. Plant materials were removed from a subsample, weighed, and nutrient concentrations were determined by methods described above. Subsamples were combusted in a muffle furnace at 550°C for 4 h to correct for mixing with mineral soil. Ash-free dry weights were determined and subtracted from the original subsample dry weight to determine the amount of plant material in the subsample. The amount of nutrients remaining was determined as the weight of the plant material multiplied by nutrient concentration.

The single exponential equation, $Y = e^{-kt}$, was used to calculate the decomposition and nutrient release rate constants, k, where Y is the percentage of the initial weight of plant material, or a nutrient, remaining after time t in weeks (Wieder and Lang, 1982). The decomposition rate constants were subjected to ANOVA to determine differences in the patterns and rates of decomposition due to plant materials and placement methods.

On-Station Crop Response Trials

A trial was conducted at Senge Farm of Kawanda Agricultural Research Institute over a period of six seasons. The rainfall was bimodal with an annual mean of 1224 mm and similar amounts for the two rainy seasons. The rainy seasons are typically from March to June (Season A) and from August to December (Season B). Samples of the deep, well-drained, red, sandy clay loam (Rhodic Kandhapludalf) soil taken to a 20-cm depth revealed a pH (1:1.5 soil/water) of 5.0; organic C concentration of 17 g kg^{-1}; available P of 2.25 mg kg^{-1} soil; 3.18, 1.89, and 0.20 $cmol_c$ kg^{-1} soil Ca, Mg, and K, respectively (Foster, 1971).

The treatments were (i) surface application or incorporation of 4 t ha^{-1} (dry weight) of prunings, consisting of leaves and small twigs, of *S. hirsuta*, *A. kotschyi*, *T. diversifolia*, and *L. camara*; (ii) the recommended rate of inorganic fertilizer (100, 21, and 100 kg ha^{-1} N, P, and K, respectively); (iii) half the recommended rate of inorganic fertilizer; and (iv) a control with no amendment. All plant materials were collected near Senge Farm, chopped to <0.10-m length and applied before planting the test crop. The inorganic fertilizers were applied following the recommended practice (P before planting and split applications of N and K at planting and weeding times). The amendments were applied each season for the duration of the study. The treatments were arranged in a randomized complete block design with four replicates.

The plot size was 6.0 by 4.5 m. 'Longe 1' maize was the test crop during both seasons of 1996 and 1998 while 'K132' bean was the test crop for both seasons of 1997. Maize and bean were planted at the recommended spacings to achieve plant densities of 53 000 and 200 000 plants ha^{-1}, respectively. Field preparation and weeding were done using hand hoes.

On-Farm Crop Response Trials

Trials were conducted on 10 farms in Imanyiro subcounty of Iganga district. The rainfall was similar to Senge Farm in amount and distribution. Yellow-red sandy loam soil on red sandy clay loam subsoil overlying fragmented petroplinthite was the dominant soil type for the trial sites and favored by farmers for maize and bean production. The soils at the on-farm sites were not classified, but the profile characteristics are similar to those of a Plinthic Kandiudalf. The mean chemical properties of the surface soil (0–0.2 m) for these fields were 26.4 g kg^{-1} organic C; pH (1:1.5 soil/water) of 5.8; 3.4 mg Olsen P kg^{-1} soil; and 5.8, 4.9, and 0.62 $cmol_c$ kg^{-1} soil for Ca, Mg, and K, respectively.

Farmers and researchers selected *L. camara* for the on-farm trials because of its abundance. The treatments for the on-farm trials were *L. camara* at 4 t ha^{-1}, the recommended rate of inorganic fertilizers (as at Senge), 50% rates of *L. camara* and inorganic fertilizer in combination, and a control treatment. Each farm had two replicates, and the plot size was 6.0 by 4.5 m. The data were analyzed across farms with the farms treated as locations.

The plant materials were surface-applied, and fertilizer was applied as at Senge. Longe 1 was the test crop and planted at the recommended plant density. Field preparation and weeding were done using hand hoes.

RESULTS AND DISCUSSION

Chemical Composition of the Plant Materials

S. hirsuta and *L. camara* had N concentrations (>26 g kg^{-1} plant material; Table 1) above 14 to 20 g kg^{-1}, the level considered by some to be required for net mineralization (Palm and Sanchez, 1991; Constantinides and Fownes, 1994). The N content of *A. kotschyi* (13.3 g kg^{-1}) was low enough to cause net N immobilization following application. The P contents of the plant materials were <2.5 g kg^{-1}, the estimated critical value for

Table 1. Chemical composition of the prunings of three plant species evaluated in a mineralization study.

Species	N	P	K	Ca	Mg	Lignin	Polyphenol (TAE)†
	g kg^{-1} plant material					%	
S. hirsuta	29.8	1.8	45.6	12.8	4.0	10.89	1.31
L. camara	26.9	1.6	26.8	8.7	5.6	15.93	3.37
A. kotschyi	13.3	1.1	40.2	16.8	2.7	14.42	2.47

† TAE, tannic acid equivalents.

net P mineralization (Blair and Boland, 1978; Smith et al., 1993). *S. hirsuta* and *A. kotschyi* were relatively high in K and Ca, and *A. kotschyi* was relatively low in P and Mg. The lignin and polyphenol contents for *S. hirsuta* and *A. kotschyi* were below the critical values of 15% and 3 to 4%, respectively (Palm, 1995), for net N mineralization. Considering the chemical composition data, the decomposition rate would be highest with *S. hirsuta*, intermediate with *L. camara*, and lowest with *A. kotschyi*.

Decomposition Patterns

The rates of decomposition were similar for all species (Table 2) and were accurately described by the single exponential function with high R^2 values (0.89–0.97). The decomposition rate constants (k) were in the range reported for materials of similar chemical composition (Tian et al., 1992).

Decomposition was slower with surface placement than with incorporation, requiring 7 wk for 50% decomposition with surface application and 5 to 6 wk with incorporation. With surface placement, decomposition presumably was delayed because of variable moisture conditions. Decomposition rates were not much affected by nutrient concentrations, probably due to the many factors affecting decomposition, mineralization, and immobilization under field conditions (Haynes, 1986).

Nutrient Release Patterns

Nitrogen was mineralized without immobilization for all species (Table 3 and Fig. 1). More N was released for incorporated (75%) than for surface-placed (50%) materials at the end of 16 wk, probably due to enhanced microbial activity associated with soil moisture and close contact with the soil for the incorporated samples. Release of N from *A. kotschyi* was especially slow, with 78 and 37% remaining after 16 wk with surface application and incorporation, respectively. Less than 20% of plant N remained after 16 wk for incorporated *S. hirsuta* and *L. camara* compared with 32 to 39% with surface application. The exponential function described the N release pattern well as indicated by the significant r values (Table 3).

Table 2. Decomposition rate constants for three species with surface application and incorporation.

Species and placement	k (wk^{-1})	r^2
S. hirsuta (surface)	0.099[b]†	0.95
S. hirsuta (incorporated)	0.128[a]	0.93
L. camara (surface)	0.099[b]	0.97
L. camara (incorporated)	0.125[a]	0.96
A. kotschyi (surface)	0.087[b]	0.89
A. kotschyi (incorporated)	0.117[a]	0.90

† Within columns, means followed by the same letter are not significantly different by Duncan's Multiple Range Test ($P < 0.05$).

Release of P was slower with incorporation (34% released) than with surface application (66% released) for the first 8 wk, but similar amounts (72%) were released by 16 wk for each method of application (Fig. 2). The early delay in P release with incorporation is unexplained because rates of decomposition were higher with incorporated than with surface-applied materials (Table 2). A net release of P occurred only after 2 wk for incorporated *S. hirsuta* and *A. kotschyi*. This delay was expected because P concentration was well below the estimated critical level for net mineralization of 2.5 g kg^{-1} plant material (Blair and Boland, 1978; Smith et al., 1993; Gachengo et al., 1999). Phosphorus was readily mineralized for the incorporated *L. camara*, however, which had less P concentration than the *S. hirsuta* but higher concentrations of lignin and polyphenols. Despite the delay in P release, the exponential function accounted for >84% of the variation in P release for all treatments except surface-applied *A. kotschyi* (Table 3).

Rapid K release occurred for all plant materials (Fig. 3). The K release was most rapid for incorporated *A.*

Table 3. Exponential functions describing nutrient release for different plant species and the corresponding *r* values.

	Method of placement			
Nutrient	Surface applied	r	Incorporated	r
		S. hirsuta		
N	$y = 116.6e^{-0.293t}$	0.93*	$y = 116.6e^{-0.388t}$	0.99**
P	$y = 114.7e^{-0.309t}$	0.99**	$y = 174.3e^{-0.322t}$	0.92*
K	$y = 368.5e^{-0.881t}$	0.95*	$y = 371.6e^{-0.866t}$	0.96*
Mg	$y = 121.3e^{-0.104t}$	0.85	$y = 166.3e^{-0.247t}$	0.79
	$y = -4.0t^2 + 15.6t + 87.4$	0.99**	$y = -9.5t^2 + 40.9t + 67.3$	1.00**
Ca	$y = 111.1e^{-0.138t}$	0.99**	$y = 111.7e^{-0.192t}$	0.96**
		L. camara		
N	$y = 131.9e^{-0.244t}$	0.98**	$y = 167.0e^{-0.444t}$	0.97**
P	$y = 138.3e^{-0.321t}$	0.95*	$y = 129.1e^{-0.235t}$	0.92*
K	$y = 255.3e^{-0.619t}$	0.95*	$y = 242.0e^{-0.634t}$	0.93*
Mg	$y = 118.5e^{-0.193t}$	0.96*	$y = 151.5e^{-0.259t}$	0.84
	$y = 0.84t^2 - 17.9t + 113.5$	0.96**	$y = -4.7t^2 + 12.9t + 88.6$	0.96**
Ca	$y = 111.0e^{-0.134t}$	0.96**	$y = 147.9e^{-0.347t}$	0.96**
		A. kotschyi		
N	$y = 104.5e^{-0.065t}$	0.97**	$y = 113.7e^{-0.210t}$	0.94*
P	$y = 117.0e^{-0.245t}$	0.93*	$y = 176.7e^{-0.322t}$	0.82
K	$y = 398.1e^{-0.884t}$	0.95*	$y = 306.6e^{-0.764t}$	0.94*
Mg	$y = 121.6e^{-0.085t}$	0.81	$y = 148.3e^{-0.138t}$	0.65
	$y = -4.58t^2 + 20.0t + 85.7$	0.99**	$y = -11.7t^2 + 59.3t + 53.4$	0.97**
Ca	$y = 182.1e^{-0.580t}$	0.99**	$y = 125.9e^{-0.457t}$	0.97**

* Significant at the 0.05 level.
** Significant at the 0.01 level.

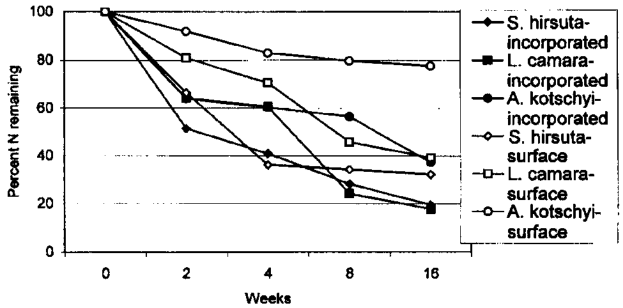

Fig. 1. Nitrogen release from incorporated and surface-applied decomposing plant materials over a 16-wk period.

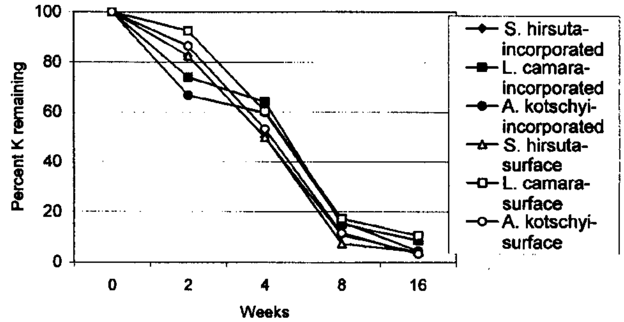

Fig. 3. Potassium release from incorporated and surface-applied decomposing plant materials over a 16-wk period.

kotschyi and slowest for surface-applied *L. camara* during the first 2 wk. Thereafter, patterns of release were similar for both placement methods and all plant materials. The amount of K in the materials retrieved after 8 wk ranged from 7 to 17% for surface-applied *S. hirsuta* and *L. camara*, respectively, and <10% remained for all materials at the end of 16 wk. Potassium is easily leached from decomposing organic materials, and these results agree with those of other investigators (Swift et al., 1981; Palm and Sanchez, 1990; Tian et al., 1992; Thomas and Asakawa, 1993). More than 86% of the variation in K release for all species was accounted for by their exponential functions (Table 3).

Calcium was released more slowly than N, P, and K for all materials except (*A. kotschyi* (Fig. 4). The mean rate of Ca release was higher with incorporation than with surface application, with 23 and 42%, respectively, remaining after 16 wk. The rate of release was related to Ca concentration in the tissue (Table 1) and was highest for *A. kotschyi*. The generally slow release of Ca agreed with the results of Swift et al. (1981). The exponential function gave a good description of the Ca release pattern (Table 3).

Magnesium was slowly released compared with other nutrients, and a net release of Mg occurred only after 8 wk in the case of *S. hirsuta* and *A. kotschyi*, after which the rate of release became similar to that of *L. camara* (Fig. 5). Mineralization of Mg was less with surface application (59% remaining) than with incorporation (40% remaining). The percent of Mg release was highest for incorporated *L. camara* and lowest for surface-placed *A. kotschyi* and was positively related to the initial Mg content of the plant materials. The slow release of Mg was in agreement with the results reported by Swift et al. (1981). The release of Mg was well described by the exponential function for surface-placed *L. camara* while a polynomial function better described Mg release for other materials (Table 3).

The On-Station Trials

Applications of *S. hirsuta*, *T. diversifolia*, and *L. camara* contained more N, K, Ca, and Mg than the full rate of fertilizer application but considerably less P (Table 4). Nitrogen and P applied with *A. kotschyi* were considerably less than with fertilizer, and a slow release was expected. Net releases of N and P from application time were expected for these species considering the results of the mineralization trial as well as for *T. diversifolia*, which has comparably high nutrient concentrations and decomposes with rapid nutrient release (Nziguheba et al., 1998; Gachengo et al., 1999).

Maize yield was not affected by the method of plant material application, possibly because much of the surface-applied materials were incorporated during the first weeding. The quicker release of nutrients with incorporation of the plant material apparently did not benefit the crop sufficiently to be a determinant of yield. High quality material, such as *T. diversifolia* and *S. hirsuta*, might be expected to give greater maize yield response when incorporated because of the potential to lose N to volatilization with surface application. In other research conducted in Malawi, however, N loss was less with surface application of high quality materials than with incorporation (Jones et al., 1997). Maize performance may be depressed by incorporation of low quality

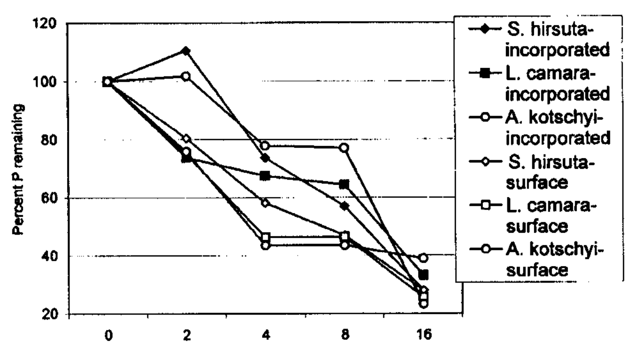

Fig. 2. Phosphorus release from incorporated and surface-applied decomposing plant materials over a 16-wk period.

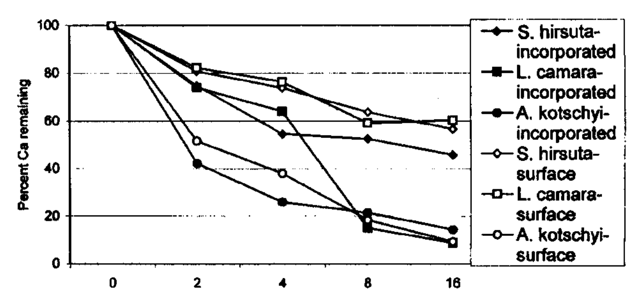

Fig. 4. Calcium release from incorporated and surface-applied decomposing plant materials over a 16-wk period.

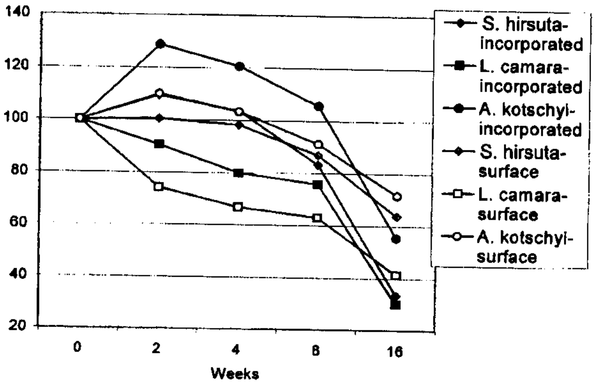

Fig. 5. Magnesium release from incorporated and surface-applied decomposing plant materials over a 16-wk period.

material such as *A. kotschyi* compared with surface application because less N immobilization is expected with surface application. Ugandan farmers generally do not incorporate applied plant materials (Wortmann and Kaizzi, 1998). Surface application requires less labor than incorporation and may have additional benefits until the crop canopy is well developed including weed suppression, increased infiltration, and reduced runoff and soil erosion.

Maize grain yield was significantly increased with the application of fertilizer at full and half rates, and by application of *T. diversifolia* and *S. hirsuta*, in all seasons (Table 5). Maize yield in response to the application of *T. diversifolia* and *S. hirsuta* was similar to the half rate of inorganic fertilizers. Yield response to *T. diversifolia* application was significantly less than with the full rate of fertilizer only in the 1996A season, and yield response to *S. hirsuta* was significantly less than with the full rate of fertilizer for both seasons of 1996. The benefits of applying all plant materials increased over seasons, and the magnitudes of response to these materials became more similar to the response to fertilizer after several seasons of application (Fig. 6).

Application of the intermediate quality *L. camara* resulted in significant maize yield increases after the first season. Yields with *L. camara* were less than with the half rate of fertilizer in 1996 but comparable to the half rate in 1998, demonstrating cumulative residual effects. The cumulative effect of the *L. camara* plant residues was such that maize response to *L. camara* was similar in 1998B to the response for the higher quality plant materials (Fig. 6). The response to *L. camara* may have been constrained by low P availability because little was supplied and the level of available soil P was low (2.25 g kg^{-1}).

Table 4. Nutrients supplied in 4 Mg ha^{-1} of dry matter by immature plant material of four species.

	N	P	K	Ca	Mg
	kg ha^{-1}				
S. hirsuta	119.2	7.2	182.4	51.2	16.0
L. camara	107.6	6.4	107.2	34.8	22.4
A. kotschyi	53.2	4.4	160.8	67.2	10.8
T. diversifolia	140.0	11.2	190.0	52.0	20.0
Fertilizer, full	100.0	21.3	104.3	0.0	0.0

Table 5. Maize grain yield over four seasons as affected by application of various plant materials and inorganic fertilizers.

Treatment	Maize grain yield				
	1996a	1996b	1998a	1998b	Mean
	Mg ha^{-1}				
S. hirsuta	3.23^{bc}†	3.63^{bc}	2.45^{ab}	4.09^{ab}	3.35^{bc}
A. kotschyi	2.83^{d}	2.69^{d}	1.80^{cd}	2.91^{c}	2.56^{d}
L. camara	3.01^{cd}	3.29^{c}	2.05^{bc}	3.67^{b}	3.01^{c}
T. diversifolia	3.35^{bc}	3.77^{ab}	2.54^{a}	3.96^{ab}	3.41^{b}
Fertilizer (recommended rate)	4.23^{a}	4.28^{a}	2.51^{ab}	4.55^{a}	3.89^{a}
Fertilizer (one-half recommended rate)	3.67^{b}	4.12^{ab}	2.41^{ab}	3.75^{b}	3.49^{b}
Control	2.57^{d}	2.63^{d}	1.33^{d}	1.59^{d}	2.03^{e}

† Within columns, means followed by the same letter are not significantly different by Duncan's Multiple Range Test ($P \leq 0.05$).

Maize yield with the application of the low N material, *A. kotschyi*, was significantly less than with the other plant materials in all seasons except 1996A when the effect of *A. kotschyi* was similar to that of *L. camara* (Table 5). The benefits of the cumulative residual effects of continuous application of *A. kotschyi* were late to be expressed but were apparent in 1998B (Fig. 6). Considering the delay in achieving significant benefits and the moderately high K content of *A. kotschyi*, this plant material might be better utilized as mulch for banana (*Musa* spp.), which has a high K demand. Alternatively, it might be efficiently used in combination with inorganic fertilizer on low K soils.

Maize yield responses were generally related to the amounts of N and P applied in the plant material although rates of P mineralization were not always consistent with P concentration (Fig. 2). The N contents of *S. hirsuta* and *T. diversifolia* were high enough (Heal et al., 1997), and their lignin and polyphenol levels low enough, to have early and rapid mineralization (Reinertsen et al., 1984; Haynes, 1986; Kachaka et al., 1993). Nutrient supply was less with *L. camara* and possibly delayed due to its high polyphenol and lignin content and possibly high hemicellulose and cellulose contents (not measured). The delayed benefit associated with *A. kotschyi* was also presumably related to its low quality. However, the net immobilization of nutrients was never so severe that it resulted in decreased yield compared with the control.

Bean yield, as with maize, was not significantly affected by the method of plant material application, and

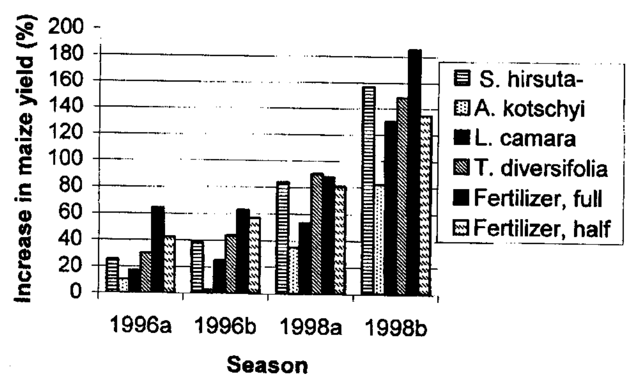

Fig. 6. Increases in maize yield expressed as a percent of the control yield.

Table 6. Bean seed as affected by application of various plant residues and inorganic fertilizers.

Treatment	Bean seed yield		
	1997a	1997b	Mean
	Mg ha^{-1}		
S. hirsuta	1.053^{a}†	0.735^{a}	0.984^{a}
A. kotschyi	0.830^{bc}	0.585^{b}	0.707^{c}
L. camara	0.928^{ab}	0.559^{b}	0.743^{bc}
T. diversifolia	0.925^{ab}	0.786^{a}	0.855^{ab}
Fertilizer (recommended rate)	0.943^{ab}	0.814^{a}	0.878^{a}
Fertilizer (one-half recommended rate)	0.875^{ab}	0.653^{ab}	0.788^{abc}
Control	0.633^{c}	0.367^{c}	0.500^{d}

† Within columns, means followed by the same letter are not significantly different by Duncan's Multiple Range Test ($P \leq 0.05$).

plant material effects were similar to those for maize yield. Bean yield was increased with the application of all plant materials during 1997A except for *A. kotschyi* (Table 6). Yield with *A. kotschyi* was less than with *S. hirsuta* in both seasons and less than with *T. diversifolia* in 1997B. Bean yields with the organic amendments were similar to the yields with inorganic fertilizers in 1997A. The full fertilizer rate resulted in yields comparable to those with *S. hirsuta* and *T. diversifolia* but more than with *L. camara* and *A. kotschyi*, which gave similar yields to the half rate of fertilizer. The relatively poor bean performance in the second season of 1997 is attributed to excessive rainfall (670 mm for the 3-mo season) associated with the El Nino effect.

Given the yield responses, and the greater amounts of N and K supplied by *S. hirsuta* and *T. diversifolia* (Tables 4–6), nutrient recovery by the crops appeared to be greater with the fertilizers, especially with the half rate of application, than with the organic inputs. For the half rate of fertilizer, full rate of fertilizer, and the mean of the plant material treatments, the mean maize yield increases were 29, 18, and 9 to 11 kg kg^{-1}, respectively, of applied N and 28, 18, and 3 to 9 kg kg^{-1}, respectively, of applied K. This was not expected. Nutrient release from organic inputs was more gradual and presumably more in synchrony with crop nutrient demand than with the inorganic fertilizers. More yield gain per unit of applied nutrient was therefore expected with the plant materials. The split application of N and K fertilizers, however, may have contributed to yield response with inorganic fertilizer. Also, yield response to applied plant materials may have been constrained by soil P availability, which was 8.8 and 4.3 mg kg^{-1} for the full fertilizer treatment and the mean of the plant material treatments, respectively, at the end of the trial period.

Table 7. Maize grain yield as affected by application of prunings of *L. camara* and inorganic fertilizers (results from 10 on-farm trials conducted over five seasons).

Treatment	Maize grain yield				
	1997a	1997b	1998a	1998b	1999a
	Mg ha^{-1}				
L. camara	2.43^{ab}†	1.19^{b}	3.81^{b}	1.87^{bc}	3.47^{c}
L. camara+ Fertilizer (50% rates)	2.82^{a}	1.98^{a}	4.63^{ba}	2.31^{b}	4.14^{b}
Fertilizer	2.97^{a}	2.41^{a}	4.70^{a}	3.13^{a}	4.68^{a}
Control	1.95^{b}	1.01^{b}	2.76^{c}	1.19^{c}	2.21^{d}
LSD (0.05)	0.71	0.56	0.86	0.78	0.29

† Within columns, means followed by the same letter are not significantly different by Duncan's Multiple Range Test ($P \leq 0.05$).

On-Farm Trials

Fertilizer application resulted in significantly improved maize yield, with gains of about 1 and 2 Mg ha^{-1} in the 1997 and 1998–1999 seasons, respectively, compared with the control (Table 7). Maize yield increases with *L. camara* alone, compared with the control, were statistically significant in the 1998A and 1999A seasons only. The fertilizer-plus-*L. camara* (50:50% rates) treatment resulted in increased maize yields in all seasons, but the yields were significantly less than with the full rate of fertilizer in the 1998B and 1999A seasons.

The percent increase in maize yield with applied *L. camara* was similar to that of the on-station trials with an increasing cumulative effect. More response in both sets of trials may have occurred with better P supply because the median value for Olsen P at the on-farm trial sites was determined to be 3.4 mg kg^{-1}, and available P was even less at the on-station trial site. The amount of P applied in fertilizer was three times that applied with the sole *L. camara* treatment (Table 4) while the amounts of N and K applied varied from 100 to 108 kg ha^{-1} for the fertilizer and *L. camara* treatments. The mean yield increases over that of the control treatment were 114, 98, and 82 kg kg^{-1} P applied for sole *L. camara*, fertilizer plus *L. camara* at half rates, and fertilizer alone, respectively, while response to applied N and K declined as more *L. camara* was applied. Efficient use of such plant materials apparently requires application of inorganic P.

CONCLUSIONS

Decomposition occurred more rapidly when the plant materials were incorporated compared with surface application, but application method did not affect yields. Immobilization of N and P was expected due to high levels of lignin and polyphenols in *L. camara* and the low N and P concentrations for *A. kotschyi*. With the exception of Mg and possibly P in *S. hirsuta*, however, mineralization of nutrients occurred for these plant species without temporary immobilization. The mineralization rates of N, Ca, and Mg were more dependent on their respective concentrations rather than on other plant tissue characteristics.

Concentrations of N, lignin, and polyphenols influenced yield response. The higher quality materials, *T. diversifolia* and *S. hirsuta*, were as effective as inorganic fertilizer at increasing maize and bean yield after several seasons of continuous application. Materials of lower quality are potentially useful without fertilizer if used continuously, but their effects may be negligible in the first season. A low N, but high K, material such as *A. kotschyi* might be more efficiently used as mulch applied to banana than as a nutrient source for maize or bean, unless used in combination with inorganic fertilizers on low K soils. Plant materials generally contain inadequate

P to be a source of nutrients in balance with crop demand and may be more effectively used in combination with inorganic P. Plant materials similar to those studied are best when surface-applied, thereby reducing labor requirements while improving soil cover until the crop canopy is well established.

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