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Nitrogen release from decomposing residues of leguminous cover crops and their effect on maize yield on depleted soils of Bukoba District, Tanzania

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Abstract

Nitrogen release patterns from decomposing shoot residues of *Tephrosia candida, Crotalaria grahamiana, Mucuna pruriens, Macrotyloma axillare, Macroptillium atropurpureum* and *Desmodium intortum* were studied in the laboratory for a period of 22 weeks in a sandy clay soil and 10 weeks in a clay soil using a leaching tube technique. The residual effect of soil incorporated shoot residues of *T. candida, T. vogelii, C. grahamiana, M. pruriens* and *C. juncea* on maize yield was evaluated at four sites each in the high rainfall zone (mean precipitation 2100 mm year^{-1}) and low rainfall zone (mean precipitation 800 mm year^{-1}) of Bukoba District, Tanzania. N mineralised from the legume residues ranged from 24 to 61% of the initial N after 22 weeks in a sandy clay soil and −1 to 34% after 10 weeks in a clay soil. The N mineralisation rates of the residues decreased in both soils in the order *M. atropurpureum* > *M. axillare* > *C. grahamiana* > *D. intortum* > *T. candida* > *M. pruriens* and were mostly strongly related to (polyphenols + lignin)-to-N ratio, lignin-to-N ratio and lignin. Relative to the control, legume residues resulted in two and threefold increase in maize grain yield i.e. from 1.1 to 3.2 Mg ha^{-1} and from 1.4 to 3.8 Mg ha^{-1} in a high and low rainfall zone respectively. However, maize yield response to legume residues was limited when compared with application of 50 kg N ha^{-1} of mineral fertiliser. The % fertiliser equivalency (%FE) of legumes ranged between 25 and 59% with higher values recorded with *C. grahamiana*. At harvest, apparent N recoveries in maize ranged between 23 and 73% of the N applied in the legume residues. Highest recovery was found with application of *C. grahamiana* and least recovery from *T. candida* residues. These results suggested that application of legume residues alone might not be sufficient to meet N requirements and to achieve the yield potential of maize crop in Bukoba soils unless supplemented with small doses of mineral fertilisers.

Introduction

One of the main advantages of N_2-fixing legumes in cropping systems is that they supply substantial amounts of N to the soils when their residues decompose (Giller, 2001; Kang et al., 1999). However, the effectiveness of released N to growing crops can be poor compared with that of mineral fertilisers (Giller et al., 1997; Mulongoy and Van de Meersch, 1988;). The restricted uptake of organic N by the crops is attributed to the lack of synchrony between the N release and N demand by the crop (Palm et al., 1997; Mafongoya et al., 1998). This can arise under two situations; firstly, when mineral N supply comes too late for the crop demand, in the case of slowly decomposing residue materials and secondly when N supply comes too early for

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the crop demand and is lost to the environment, in the case of fast decomposing organic materials (Akinnifesi et al., 1997; Giller and Cadisch 1995; Myers et al., 1994, 1997). Understanding the N release patterns of decomposing legume residues may therefore help in optimising N-use efficiency in the legume-crop rotation systems.

The rates at which the decomposing legume residues release N has been linked to their structural and chemical characteristics or "residue quality", to the soil physical-chemical and biological activities and to environmental factors such as temperature and moisture (Giller and Cadisch, 1995; Palm et al., 2001; Van Veen and Kuikman, 1990). Various indicators such as carbon (C)-to-N ratio, lignin-to-N ratio, polyphenols-to-N ratio and polyphenols plus lignin-to-N ratio for predicting N release from organic materials have been developed (e.g. Mafongoya et al., 1998; Palm and Sanchez, 1991; Palm et al., 1997, 2001); Vanlauwe, et al., 1997). Other quality parameters of organic resources such as condensed tannins, soluble carbon and fibre-bound N have also been reported to modify N release patterns (Handayanto et al., 1997).

In Bukoba District, northwest Tanzania, as in most parts of sub-Saharan Africa, organic resources continue to be a major source of plant nutrients in smallholder farming (Baijukya and de Steenhuijsen Piters, 1998). However, quantities of the traditional major organic input, cattle manure, are declining as only a few households can afford to keep livestock (van de Kop, 1995). The types of organic resources available are maize stover and weeds, poor in nitrogen (N), which cause N immobilisation initially when added to the soils (Giller et al., 1997; Sakala et al., 2000). Attention is now focusing on generating sufficient quantities of organic residues, high in N contents, by introducing N_2–fixing short fallow legumes for rotation with annual crops (Baijukya, 2004). As a first step, farmers have selected some legume cover crops for soil fertility improvement and for fodder basing on biomass yields, tolerance to pests and diseases and adaptability to infertile soils. The ability of these legumes to contribute N and their impacts on the performance of subsequent crops is not well understood.

This study was conducted with the following objectives; (i) to understand the nitrogen release behaviour of farmer selected legume cover crops under laboratory conditions (ii) to determine the effect of application of legume cover crop residues on maize yield in farmers fields with different soils and climatic conditions and (iii) to determine the N fertiliser equivalency of the above ground parts of legume cover crops and the efficiency of use by maize crop.

Materials and methods

Nitrogen release from decomposing legume residues

A nitrogen mineralisation study was conducted using a modified leaching tube technique (Stanford and Smith, 1972). The materials studied were 5 month old residues (dry leaves and stems) of *Tephrosia candida, Crotalaria grahamiana, Mucuna pruriens, Macrotyloma axillare, Macroptilium atropurpureum* and *Desmodium intortum*, grown at Maruku Agricultural Research Institute (ARI Maruku). N release by the decomposing residues were compared in a sandy clay soil (Alumi-humic Ferralsol) and a clay soil (Humic Acrisol). The soils were collected from the high and low rainfall zones of Bukoba District, where they widely occur in annual cropping systems in the respective zones. An unamended soil treatment was included in each case as a control. The characteristics of the soils and legume residues studied are given in Table 1.

The soils were ground to pass a 2 mm sieve and the legume residues ground to <1 mm in a cyclotech mill. Forty-five grams of soil was mixed thoroughly with 45 g of acid-washed sand (w/w). The soil–sand mixture was mixed with plant material at a rate of 100 mg N kg^{-1} soil and added to the leaching tubes. De-ionised water was added to bring the moisture content in the tube to about 70% of the water holding capacity. After setting up of the experiment, the tubes were immediately leached with a leaching solution (containing 1 mM $CaCl_2$; 1 mM $MgSO_4$ and 0.1 mM KH_2PO_4 and 0.9 mM KCl_2) (Cassman and Munns, 1980). The initial leachates (day 0) were analysed for mineral N (NH_4^+ and NO_3^-) and for organic N after Kjeldahl digestion.

The tubes were loosely covered with aluminium foil and transferred to an incubator with controlled temperature (27 °C) and humidity (70%). The experiment was set in a completely rando-

Table 1. Characteristics of (a) soils and (b) legume residue materials used in the decomposition study

(a) Soils[a]	pH (H_2O)	1N KCl	Organic C ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	C:N	P –Olsen ($mg\ kg^{-1}$)	Exchangeable cations ($cmol_c\ kg^{-1}$)			Exch. acidity ($cmol_c\ kg^{-1}$)
							Ca	K	Mg	
Sandy clay soil	5.2	4.6	38.1	2.5	15.0	7.3	0.5	0.18	0.1	1.3
Clay soil	6.1	4.1	20.9	1.4	15.0	7.14	2.4	0.20	0.7	0.6

(b) Legume residues[a]	% N	% P	% K	% lignin	% soluble polyphenols	Lignin: N ratio	Polyphenols: N ratio	(Lignin + Polyphenols): N ratio
Tephrosia candida	2.0	0.1	0.5	15.6	3.4	7.9	1.7	9.6
Crotalaria grahamiana	2.3	0.2	0.8	4.6	1.8	2.0	0.8	2.7
Mucuna pruriens	1.7	0.1	0.5	16.6	2.0	9.6	1.1	10.7
Macrotyloma axillare	2.3	0.3	1.3	8.2	2.1	3.5	0.9	4.4
Macroptillium atropurpureum	2.4	0.2	1.3	9.3	1.7	3.9	0.7	4.6
Desmodium intortum	2.5	0.2	1.0	12.8	4.8	5.2	2.0	7.2

Legume residues were 5 month old and collected at ARI Maruku.
[a]analyses by TSBF/ ICRAF laboratories, Nairobi, Kenya.

mised design with each treatment replicated four times. Leaching was done after 1, 2, 4, 6, 8, 10, 14, 18 and 22 weeks for the sandy clay whereas for clay soil leaching was stopped at 10 weeks. This was because the clay particles had blocked drainage. The leaching was done using 100 mL of a leaching solution in 50 mL aliquots. After each leaching, the moisture content in the tubes was brought back at 70% by removing the excess water with mild suction. The leachates were analysed for mineral N (NH_4^+ and NO_3^-).

Nitrogen mineralisation/immobilisation (expressed in percent) was calculated from the difference in cumulative amounts of mineral nitrogen between soil treated with legume residues and a control at each sampling time divided by the initial nitrogen of the plant residues.

$$N_{min} = \frac{\text{Min N (treat)} - \text{Min N (control)}}{\text{Total residue N added}}$$

The rate constants of nitrogen mineralisation (k) for the residues were estimated assuming a single exponential decay equation (Wieder and Lang, 1982) as: $Y = Y_0 \exp(-kt)$, where Y is the percentage of N remaining of the soil plant mixtures at time t. The k value was obtained as a slope of the linear regressions of ln Y versus t; immobilisation values were omitted. The obtained data on % cumulative N mineralisation/immobilisation and k were correlated with all legume quality data except P and K content in Table 1.

Assessment of maize response to the application of legume residues

Experimental sites and their characteristics

The experiment was carried out on station and in farmers fields in the high (mean precipitation 2100 mm yr^{-1}) and low rainfall zone (mean precipitation 800 mm yr^{-1}) of Bukoba District (1°13′–1°30′ S and 31°19′–31°52′ E), in two seasons (September 2001–January 2002 and March–June 2002). The high rainfall zone occurs on the ridges (appr. 1400 m.a.s.l) with N–S orientation stretching into Lake Victoria, and the low rainfall zone occurs on the leeward side of the ridges 50–60 km from the Shores of Lake Victoria.

The geological material is predominantly Bukoban Sedimentary System in the high rainfall zone, and Karawe–Ankolean Metamorphic and Alluvial System in the low rainfall zone (Touber and Kanani, 1994). The daily rainfall during the experimental period is summarised in Figure 1. In the high rainfall zone, the experiment was conducted at ARI Maruku hereafter called on-station and in the villages Butairuka and Kiilima (four sites in each village). In the low rainfall zone, the experiment was located in the villages Kabirizi (four sites) and Kyaitoke (three sites). The soil types at the trial sites in the respective zones are Alumi-humic Ferralsols and Humic Acrisols and their characteristics are summarised in Table 2.

First maize crop (September 2001–January 2002)
This experiment was in the plots where the adaptability, productivity and N_2-fixation of legume cover crops had been studied between March and August 2001 (Baijukya, 2004). In the previous experiment, treatments comprised 10 legume species, weedy fallow and sole maize crop. Four legume species, namely *Tephrosia candida*, *Crotalaria grahamiana, Crotalaria juncea* and *Mucuna pruriens*, were selected by farmers for use as short fallow crops and were part of the current treatments. The treatments were (i) *T. candida* (ii) *C. grahamiana* (iii) *M. pruriens* residues incorporated into the soil, respectively, (iv) N mineral fertiliser at a rate of 50 kg N ha^{-1} (current recommended rate for maize) in plots previously under maize and (v) a control (without any amendments) in plots previously under weedy fallow. *T. vogelii* residues incorporated into the soil was an additional treatment at the on-station site and incorporated *C. juncea*

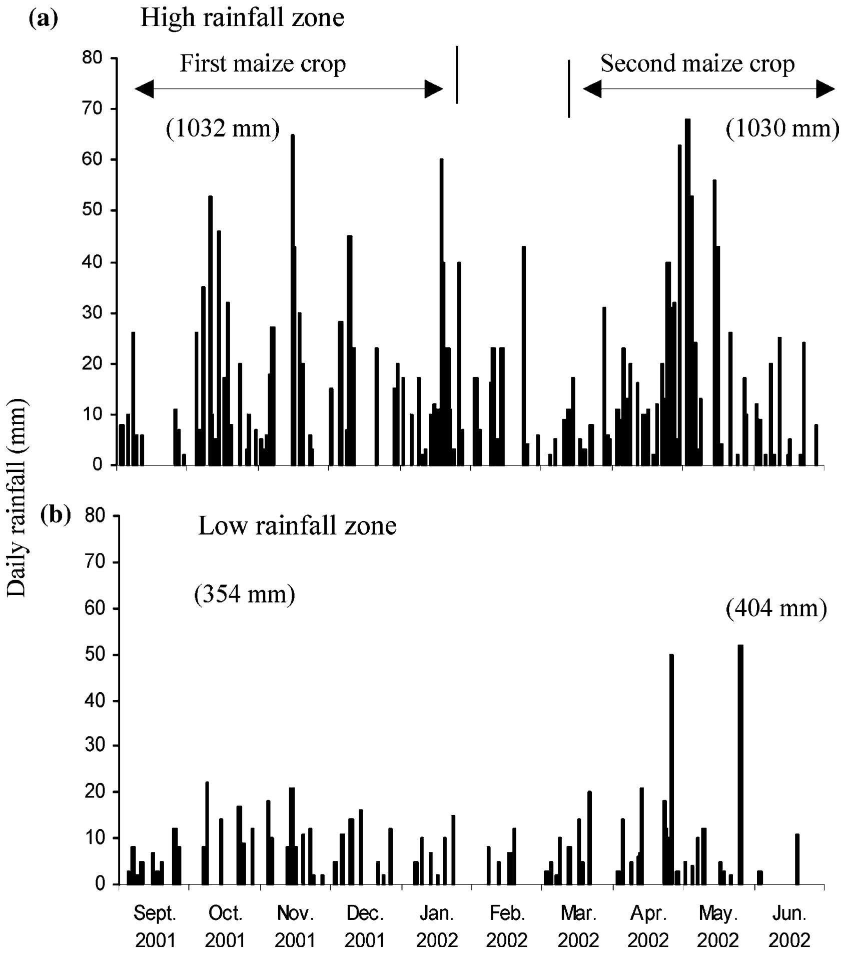

Figure 1. Daily precipitation during the maize growing seasons. Data in parentheses are totals in respective seasons.

Table 2. Chemical and physical properties of topsoil (0–30 cm) of the trial sites at maize planting time

Zone	pH (H_2O)	Organic C (g kg^{-1})	Total N (g kg^{-1})	Available P Bray (mg kg^{-1})	Exchangeable cations ($cmol_c$ kg^{-1})			Particle size (%)		
					Ca	K	Mg	Sand	Silt	Clay
High rainfall (sandy clay soil)	5.3 (4.1–6.3)	21.2 (13.0–42.0)	1.1 (0.6–3.1)	20.0 (5.1–25)	0.7 (0.4–2.1)	0.2 (0.2–3.6)	0.2 (0.1–0.3)	58 (54–62)	26 (22–28)	16 (14–24)
Low rainfall (clay soil)	6.0 (4.9–6.5)	18.3 (11.7–30.6)	1.2 (0.8–2.7)	14.4 (5.6–26)	2.8 (0.9–3.4)	0.8 (1.0–4.2)	0.9 (0.2–1.1)	30 (10–36)	28 (24–30)	42 (34–48)

Data are means and ranges (in parentheses) for 8 sites in the high rainfall zone and 7 sites in the low rainfall zone.

residues was an additional treatment in the low rainfall zone. The mineral fertiliser and weedy fallow treatments replicate current farmer practices and act as reference plots for comparison.

Prior to the maize crop, soil samples were taken from each of the previous treatments to measure the N, P and K stocks. Although belowground parts of legumes residues can provide a significant amount of N in the form of dead tissue and nodules (Cadisch et al., 2002; McNeill et al., 1997; Peoples et al., 2001), measurements in this study were restricted to aboveground part of legume residues, as roots sampling was not possible given the on-farm nature of the experiment.

The above-ground parts of the specific legume species were harvested, weighed, chopped into pieces < 10 cm and incorporated into the soils (about 15 cm) using a hand hoe, in the period of 3–5 days after harvest. The amounts of legume residues applied per site depended on biomass yield of the particular legume species, which was in the range of 1–9 Mg ha^{-1}. Weeds and maize stover in plots previously under weedy fallow and maize were removed from the plots. On-station, the experiment was arranged in a completely randomised block design in four replicates, with plot size of 21 m^2. On-farm, the experiment was arranged in a randomised design with plot size of 34 m^2, each site being a replicate.

The maize variety *Kilima* was sown in the third week of September 2001, one week after legume residues were incorporated into the soil, at a spacing of 0.75×0.45 m by placing three seeds per planting hole. Prior to planting of maize, all plots received basal fertiliser of 15 kg ha^{-1} P and 20 kg ha^{-1} K as triple super phosphate (46% P_2O_5) and muriate of potash (60% K_2O), respectively. The maize pockets without germination were replanted 2 weeks after first sowing. Mineral N fertiliser in the form of calcium ammonium nitrate (Ca $(NO_3)_2$ NH_4NO_3) was applied to + N-fertiliser plots in two splits of 25 kg N ha^{-1}, at 4 and 7 weeks after maize emergence. Maize was weeded manually at regular intervals and weeds were left in the plots.

The maize was harvested between the second and fourth week of February 2002, from the inner 16 m^2 of the plot on-station, and 18 m^2 on-farm. Maize stover from the harvest area was weighed and sub-samples taken for dry matter determination and analysis for the N contents.

Maize cobs were weighed and after shelling, the maize grains were weighed, oven dried at 72 °C for 48 h and re-weighed to determine their dry matter contents. Maize grain yields were expressed at 14% moisture content. Samples of maize grain and stover were taken for the analysis of N contents. The plots were pegged so that data collection was done within the same area during the second maize crop. The effect of mineral N fertiliser and legume residue was calculated as the difference between maize yield after fertiliser amendment and maize yield with no amendment.

Second maize crop (March 2002–July 2002)

The residual fertility of mineral N fertiliser and legume residues was re-assessed on the second maize crop that was planted 1 month after harvesting of the first maize crop (6 months after legume residues were incorporated into the soils). Maize stover was removed from the plots and the plots were weeded, leaving the weeds in the plots. Planting of maize was done in the second week of March. The maize crop received the same management as in the first season except that no additional fertilisers and organic amendments were applied. Harvest of maize was done in the second week of June 2002, and measurement taken on maize cobs, grain and stover as in the first season.

Fertiliser N equivalence and use efficiency

The fertiliser N equivalence (FE) of the legume residues in the respective zones was determined by comparing the changes in maize grain yield following application of mineral N fertiliser assuming a linear response. In earlier studies (Baijukya and Folmer, 2002) the N response curve for maize at ARI Maruku was found to cease to be linear with application of 80 kg N ha^{-1} or more. The first season maize grain yields attained after legume residue incorporation were horizontally projected onto the fertiliser N response curves of the respective zone to determine the fertiliser equivalence (FE). To compare the FE of legume residues in different zones and where the amounts of residue N applied were different, the percent fertiliser equivalency values (%FE) were calculated as:

$$\%\mathrm{FE} = \frac{\mathrm{FE} \times 100}{\mathrm{N}_{\mathrm{applied}}}$$

where $\mathrm{N}_{\mathrm{applied}}$ = actual amount of $\mathrm{N}_{\mathrm{applied}}$ in legume residues.

Nitrogen uptake (kg ha^{-1}) was calculated for grain and total above ground biomass as the N contents (%) multiplied with the yield (Mg ha^{-1}). The efficiency of use of N fertiliser and of the applied legume residue N was calculated as a ratio of changes in maize grain and total aboveground biomass to quantity of nutrient applied. The utilisation efficiency by the maize crop was calculated as the ratio of yield to actual nutrient uptake whereas apparent N recovery efficiency was calculated as the ratio of actual N uptake to N applied.

$$\text{N use efficiency} = \frac{\mathrm{Yield}_{\mathrm{fert}} - \mathrm{Yield}_{\mathrm{control}}}{\mathrm{N}_{\mathrm{applied}}}$$

$$\text{Apparent N recovery efficiency} = \frac{\text{N uptake}_{\mathrm{fert}} - \text{N uptake}_{\mathrm{control}}}{\mathrm{N}_{\mathrm{applied}}}$$

$$\text{N utilisation efficiency} = \frac{\mathrm{Yield}_{\mathrm{fert}} - \mathrm{Yield}_{\mathrm{control}}}{\mathrm{N}_{\mathrm{uptake}}}$$

Soil, plant material and leachate analyses

Soil samples were analysed using the following procedure: pH H_2O (1:5 w/v) and in 0.01 *M* KCl, organic carbon by Walkley–Black wet oxidation method, total N by the micro-Kjeldahl digestion method. Available P was determined by Bray I acid-fluoride method and P in solution determined by ascorbic acid blue colour method of Murphy and Riley (1962), exchangeable cations by ammonium acetate extraction, with Ca and Mg estimated by the atomic absorption spectrometry (AAS) and K by flame photometer. Exchangeable acidity was determined using the KCl method. Particle size distribution was analysed by standard hydrometer method (Page et al., 1982). The plant materials (legume residues, grain and stover) were analysed for total N by the micro-Kjeldahl digestion method followed by distillation and titration. Using the same digestion solution, P was measured colorimetrically by a spectrophotometer and K by flame photometry (Okalebo et al., 1993). Extractable polyphenols were determined by the Folin–Denis method

(Anderson and Ingram, 1996). Lignin was determined by the acid detergent fibre method (Goering and van Soest, 1970). Mineral N (NH_4^+ and NO_3^-) in the leachates were determined using a colorimetric method (Temminghoff et al., 2000). All analyses were done with two replicates, from which the mean was calculated.

Statistical analysis

Analysis of variance was conducted on maize grain, total aboveground biomass yield and for N use efficiencies using GENSTAT (Genstat release 6.1 Lawes Agricultural Trust). Standard error of the difference between means was calculated. The correlation coefficients were calculated between the soil chemical parameters, the legume biomass and N applied and maize yield (grain and total above ground biomass).

Results

Chemical composition of soils and legume residues

The sandy clay soils from the high rainfall zone were strongly acidic, with high organic C and exchangeable acidity compared to the clay soils from the low rainfall zone (Tables 1 and 2). In both zones, prior to maize establishment, no significant differences in soil N, P and K (data not presented) were apparent between plots previously under weedy fallow, maize and legume fallows. The legume species *T. candida* and *M. pruriens* had lower N contents, intermediate soluble polyphenol contents but high lignin contents. *D. intortum* had high N content, intermediate lignin content and high soluble polyphenols contents whereas *C. grahamiana, M. atropurpureum* and *M. axillare* had high N contents and low lignin and soluble polyphenol contents (Table 1). Except for *T. candida* and *M. pruriens*, which had low percentages of P and K, contents of these nutrients in other legume residues were comparable.

N released from decomposing legume residues

The proportion of N released from the residues as mineral N ranged from 25 to 61% for the sandy clay soil and from −1 to 26% in the clay soil after 22 and 10 weeks of incubation, respectively (Figure 2). In the sandy clay soil, *T. candida, M. pruriens, M. axillare* and *D. intortum* showed net immobilisation in the first 2 weeks of incubation (Figure 2b). A similar trend was observed in the clay soil except for *M. axillare*, which exhibited net immobilisation from the first week (Figure 2b). After 4 weeks, re-mineralisation of N was observed on these residues, but relative to unamended soil, *M. pruriens* continued to immobilise N up to 10 weeks. Residues of *C. grahamiana*, *M. axillare* and *M. atropupureum* showed net mineralisation from the first week of incubation in the two soils.

The proportions of N mineralised and the mineralisation rate constants (k) varied between legume residues and were significantly correlated with some of the legume quality attributes namely N, lignin, lignin-to-N ratio and (lignin + polyphenols)-to-N ratio (Table 3). Moreover, in both soils the proportions of N mineralised were more strongly correlated with the (lignin + polyphenols)-to-N ratio compared to other quality attributes (Figure 3). There were however, differences in the coefficients for linear regressions between the N mineralised and the k of legumes residues incubated in sandy clay and in clay soil. In sandy clay soil, the lignin-to-N ratio and the (lignin + polyphenols)-to-N ratio were more strongly related to the proportion of mineralised N than it was in a clay soil.

Maize yield response to the application of mineral fertilisers and legume residues

In the first season, maize yield (grain + stover) increased with application of mineral fertilisers and legume residues (Tables 4 and 5). On-station, the average total dry matter production was 2 Mg ha^{-1} with control and 8.9 Mg ha^{-1} with application of 50 kg N ha^{-1} of mineral fertiliser. The mean total dry matter yield on control was 30 and 34% of the maximum yield achieved with application of 50 kg N ha^{-1} of mineral fertiliser in the high and low rainfall zone, respectively. In the high rainfall zone, the total dry matter yield following application *T. candida*, *C. grahamiana* and *M. pruriens* was 83, 54 and 66% of the yield level with application of 50 kg N ha^{-1} of mineral fertiliser. The corresponding yields of similar treatments in the low rainfall zone were 86, 56, 74 and 65%, respectively.

Maize yield varied between sites as depicted by yield ranges (Table 5). Without fertility amendment, the variation in yield among sites was explained by the initial soil N, $r^2 = 0.54$ (high rainfall zone) and 0.68 (low rainfall zone) and soil pH, $r^2 = 0.65$ (high rainfall zone) and 0.57 (low rainfall zone). This effect disappeared after application of legume residues and mineral N fertiliser. In the high rainfall zone, maize yield was positively correlated with the quantities of legume N and residues applied particularly those

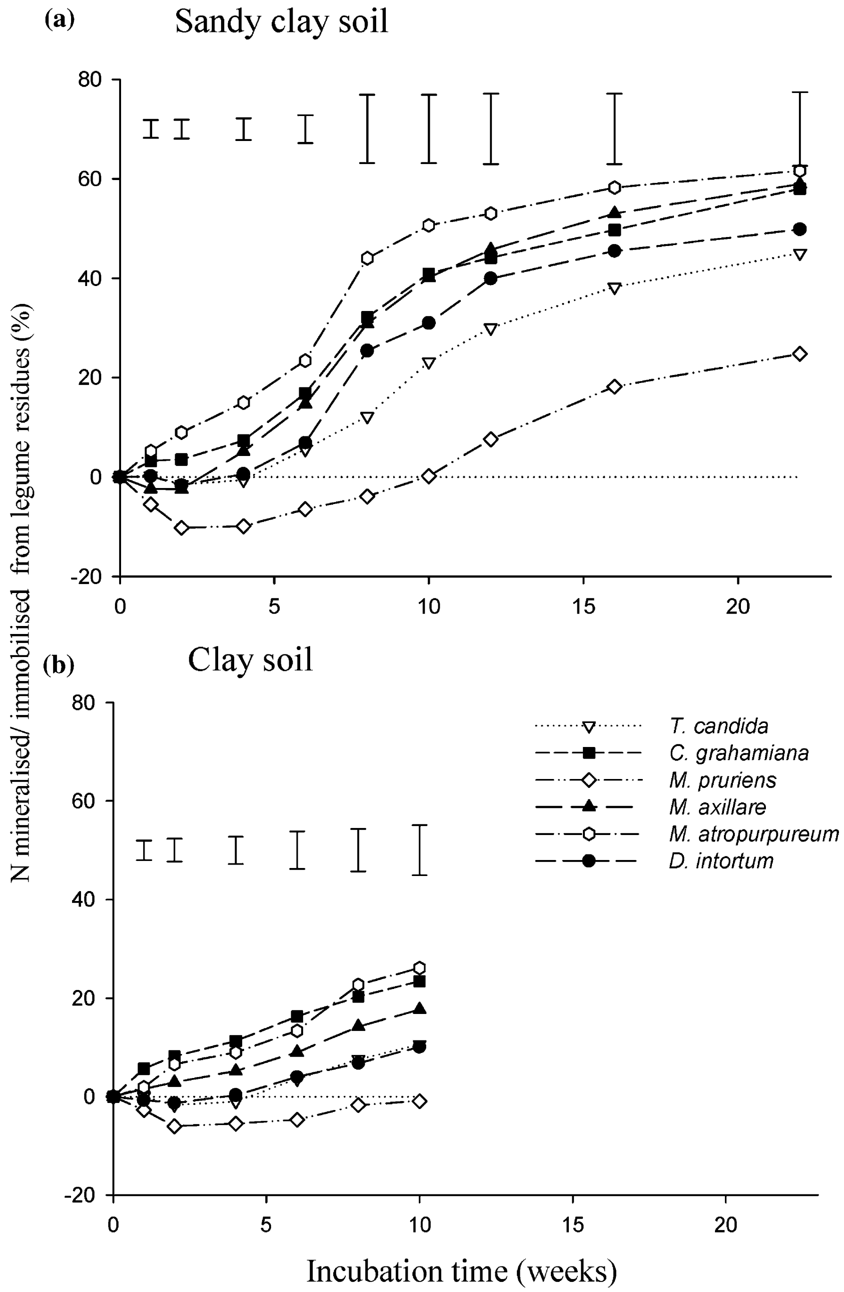

Figure 2. Cumulative N (%) of the initial added N of various legume residues mineralised/immobilised in (a) sandy clay soil and (b) clay soil under leaching condition. Vertical bars are standard error of difference in treatment means (SED).

Table 3. Coefficients of determination (R^2) between quality variables of legume residues and their N mineralisation rate constants under leaching conditions over 22 weeks in a sandy clay soil, and 10 weeks in a clay soils

Residue quality	Coefficient of determination (R^2) for			
	N mineralised in		N mineralisation rate constant (k) in	
	Sandy clay soil	Clay soil	Sandy clay soil	Clay soil
N (%)	0.78*	0.56	0.64	0.43
Lignin (%)	0.67*	0.73*	0.63	0.25
Lignin-to-N ratio	0.79**	0.65**	0.75*	0.26
(Lignin + polyphenols)-to-N ratio	0.83**	0.71**	0.73*	0.35

*Significant at $P < 0.05$, **significant at $P < 0.01$.

of *T. candida* and *C. grahamiana* (Figure 4). The relationship was weaker in the low rainfall zone except for *C. juncea* residues.

Maize yields in the second season were poor compared with the first season, but the residual effect of mineral N fertilisers and legume residues was still strong (Figure 5). In this season, higher maize yields were obtained on legume residue applied plot compared with mineral N fertilisers although yields in plots previously applied with mineral N fertiliser were higher than in unfertilised controls. The highest yield was obtained with applied *T. candida* and *M. pruriens* residues, with the effect being generally stronger in the low rainfall zone than in the high rainfall zone.

Fertiliser equivalency (FE) values of legume residues

The FE ranged from 13 kg for *C. grahamiana* to 38 kg for *T. candida* (Table 6 and Figure 6). The FE of the same legume residues applied in different zones showed only slight differences. A different pattern was obtained when the %FE was calculated (putting the amounts of residue N applied into account). In both zones, higher %FE value was observed with *C. grahamiana* and lower value with *C. juncea*. Generally, the %FE of same residues applied in different zones showed only slight differences.

Nitrogen uptake and use efficiency

Total nitrogen uptake by maize in the control plots ranged from 18 kg N ha^{-1} on station to 31 kg N ha^{-1} on-farm; in all cases more than 50% was taken up in the grain (Tables 7 and 8). With the application of mineral N fertiliser and legume residues, N uptake by maize was doubled to quadrupled with respect to the control. The efficiency of use of nutrients applied was higher for the mineral fertilisers than for legume residues. N from *C. grahamiana* residues was more efficiently used compared with N from residues of other legume species. Nitrogen utilisation efficiency by maize was not affected by the N source and was in the range of 57 and 69 kg of grain produced, and 97 and 115 kg for the total above ground biomass per kg N taken up. At harvest, the first maize season had recovered more than 100% of the applied mineral N fertiliser, 80% of being accounted for in the grain. N recovery by maize from the applied residues were less than 50% of the N applied except for *C. grahamiana* from which more than 70% of the N was recovered in the high rainfall zone.

Discussion and conclusions

N released from decomposing legume residues

The rates at which N was released from the decomposing legume residues (Figure 2) reflected their differences in chemical composition (Table 1), most strongly to lignin-to-N ratio and (polyphenols + lignin)-to-N ratio (Table 3, Figure 3). It has been shown that plant materials with lignin-to-N ratio above 6 and (polyphenols + lignin)-to-N ratio above nine releases N slowly in the initial stages (Palm et al., 2001). Lignin in the plant materials are reported to intertwine with the cell wall, physically protecting cellulose and other cell wall constituents from degradation (Chesson, 1997) whereas higher soluble polyphenols can form complexes with proteins and protect them from decomposition

(Davies et al., 1964). This may possibly be the case in the present study as *M. pruriens* and *T. candida* which were slow in releasing N had lignin-to N ratio and (polyphenols + lignin)-to-N ratios above the general critical values (Palm et al., 2001). To the contrary, rapid mineralisation of N from *M. atropurpureum, M. axillare* and *C. grahamiana* residues in the initial period could be related to their relatively high N contents, low contents of soluble polyphenols and lignin making them easily decomposable.

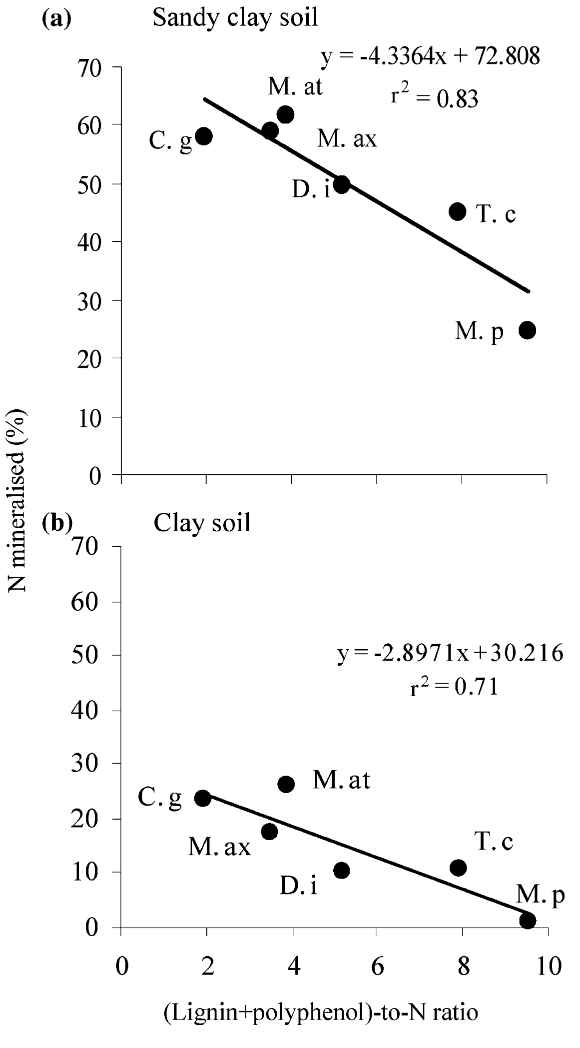

Figure 3. Relatioship between the proportion of legume residue N mineralised (%) and (lignin + polyphenol)-to-N ratio under leaching condition after (a) 22 weeks in a sandy clay soil and (b) 10 weeks in clay soil. Symbols represents; T. c = *T. candida*, C. g = *C. grahamiana*, M. p = *M. pruriens*, M. ax = *M. axillare*, M. p = *M. atropurpureum* and D. i = *D. intortum*.

Despite having higher N, low lignin and total soluble polyphenol contents, residues of *D. intortum* exhibited a short-term N immobilisation possibly due to the presence of polyphenolic compounds in the form of condensed tannin (Getechew et al., 2000). According to Handayanto et al. (1997) the type of polyphenol compounds is a more important determinant in decomposition of plant residues than the absolute quantities.

Up to 10 weeks of incubation, the rates of N release from residues were higher in the sandy clay soil than in the clay soil. Similar trends, though with different residues have been reported in other studies (e.g. Ehaliotis et al., 1996; Jansen, 1994; Sakala et al., 2000; Van Veen et al., 1985). All authors argued that higher clay contents facilitate stabilisation of small residue particles, the microorganisms and their metabolites, thereby slowing the decomposition and N turnover. This was possibly the case in the present study as the N release patterns of residues were similar in both soils the differences being the rate of N release (Figure 2). Even though the process of immobilisation and stabilisation of decomposition products may be undesirable, it may facilitate a more prolonged N availability particularly in areas with high rainfall such as Bukoba District, where the mineralised N is liable to be lost by leaching if not immediately absorbed by crops.

Reports on N release patterns of these legume species are scarce. However, in a similar leaching incubation experiment, *M. pruriens* decomposing in a sandy soil from Zimbabwe also showed a prolonged N immobilisation up to 20 weeks of incubation (Chikowo, 2004). Under field conditions however, *M. pruriens*, and *M. atropurpureum* residues were found to release more than 50% of their N in less than 30 days (Duda et al., 2003; Ibewiro et al., 2000). Although the present results are difficult to extrapolate to field conditions, they shed light on the complex relationship between residue quality and N release of legume cover crops, which have been identified as useful species in the tropics.

Effect of legume application on maize yield and their % fertiliser equivalents

In the prevailing annual cropping system in Bukoba District, maize is cultivated after 5–6 months

Table 4. Effect of mineral nitrogen fertiliser application and incorporation of legume residues on maize yield at ARDI Maruku

Treatment	Amount of N applied (kg ha^{-1})	Grain yield (Mg ha^{-1})	Total above ground yield[a] (Mg ha^{-1})
Control	0	0.9	2.0
Mineral N fertiliser[b]	50	3.6	8.9
Tephrosia candida	129	2.5	6.2
Tephrosia vogelii	41	1.6	3.9
Crotalaria grahamiana	57	2.2	5.3
Mucuna pruriens	69	2.3	5.0
SED[c]		0.4***	0.9***

For legume species, the amount of N applied equals to the amount of N in residues produced on the site.
[a]Include grain and stover.
[b]$Ca(NO_3)_2NH_4NO_3$.
[c]Standard error of the difference in means, ***$P < 0.001$.

Table 5. Effect of mineral nitrogen fertiliser application and incorporation of legume residues on maize yield in the high and low rainfall zone of Bukoba District

Treatments	High rainfall zone			Low rainfall zone		
	Amount of N applied (kg ha^{-1})	Grain yield (Mg ha^{-1})	Total above ground yield[a] (Mg ha^{-1})	Amount of N applied (kg ha^{-1})	Grain yield (Mg ha^{-1})	Total above ground yield[a] (Mg ha^{-1})
Control	0	1.1 (0.7–1.7)	2.9 (1.8–4.4)	0	1.4 (0.5–2.5)	3.4 (1.4–6.4)
Mineral N fertiliser	50	3.8 (1.7–5.0)	9.9 (4.3–12.8)	50	3.8 (2.7–5.1)	9.8 (7.0–13.2)
Tephrosia candida	124 (38–224)	3.2 (1.2–4.5)	8.2 (4.0–11.7)	134 (50–161)	3.3 (2.5–4.5)	8.5 (6.5–11.6)
Crotalaria grahamiana	33 (7–61)	2.0 (1.2–3.0)	5.3 (3.1–7.7)	22 (15–39)	2.2 (1.5–3.0)	5.7 (4.0–7.7)
Crotalaria juncea	–	–	–	66 (26–96)	2.2 (1.5–3.1)	6.4 (3.7–11.8)
Mucuna pruriens	87 (25–168)	2.5 (1.2–4.2)	6.5 (3.1–10.9)	94 (17–274)	2.9 (1.3–4.8)	7.4 (3.4–12.3)
SED[b]		0.5***	1.2***		0.4***	1.1***

Data in parentheses are ranges. For legume species, the amount of N applied equals to the amount of N in residues produced on the site.
[a]Include grain and stover.
[b]Standard error of difference in means, *** $P < 0.001$.

of weedy fallow or rotated with sweet potato in the same period. The natural potential N supply of these soils to the maize crop during the experiment was 31 and 29 kg N ha^{-1} in the high and low rainfall zone respectively as inferred from the N uptake in the control treatments (Table 8). This natural N supply resulted in average maize grain yields of 1.1 and 1.4 Mg ha^{-1} in the high and low rainfall zone respectively, slightly higher than the district average which is given as 0.9 Mg ha^{-1} (Bukoba District Council, 2001). The slightly higher maize grain yields (of 0.2–0.5 Mg ha^{-1}) in our experiment may be a result of combination of use of an improved maize variety and a good season.

Maize yield response to application of mineral N was higher compared to application of legume residues (Tables 4 and 5) implying that application of legume residues alone cannot produce yields levels expected on Bukoban soils. The results suggest the need for an integrated system of soil fertility management that combines organic and inorganic N fertilisers (Giller et al., 1997). The observed increase in maize yield with application of legume residues compared with the control (Tables 4 and 5, Figure 5) demonstrate that legume residues make a significant contribution to crop production. The results further indicate that application of mineral fertilisers can be reduced if legume residues are applied. Similar results have been reported in the humid areas of Uganda (Wortmann et al., 1994), in the Kenya highlands (Niang et al., 2002) and in the moist savanna region of West Africa (Sanginga et al., 1988). The observed higher maize yield on control plots in the low rainfall zone could be a result of favourable soil pH and the availability

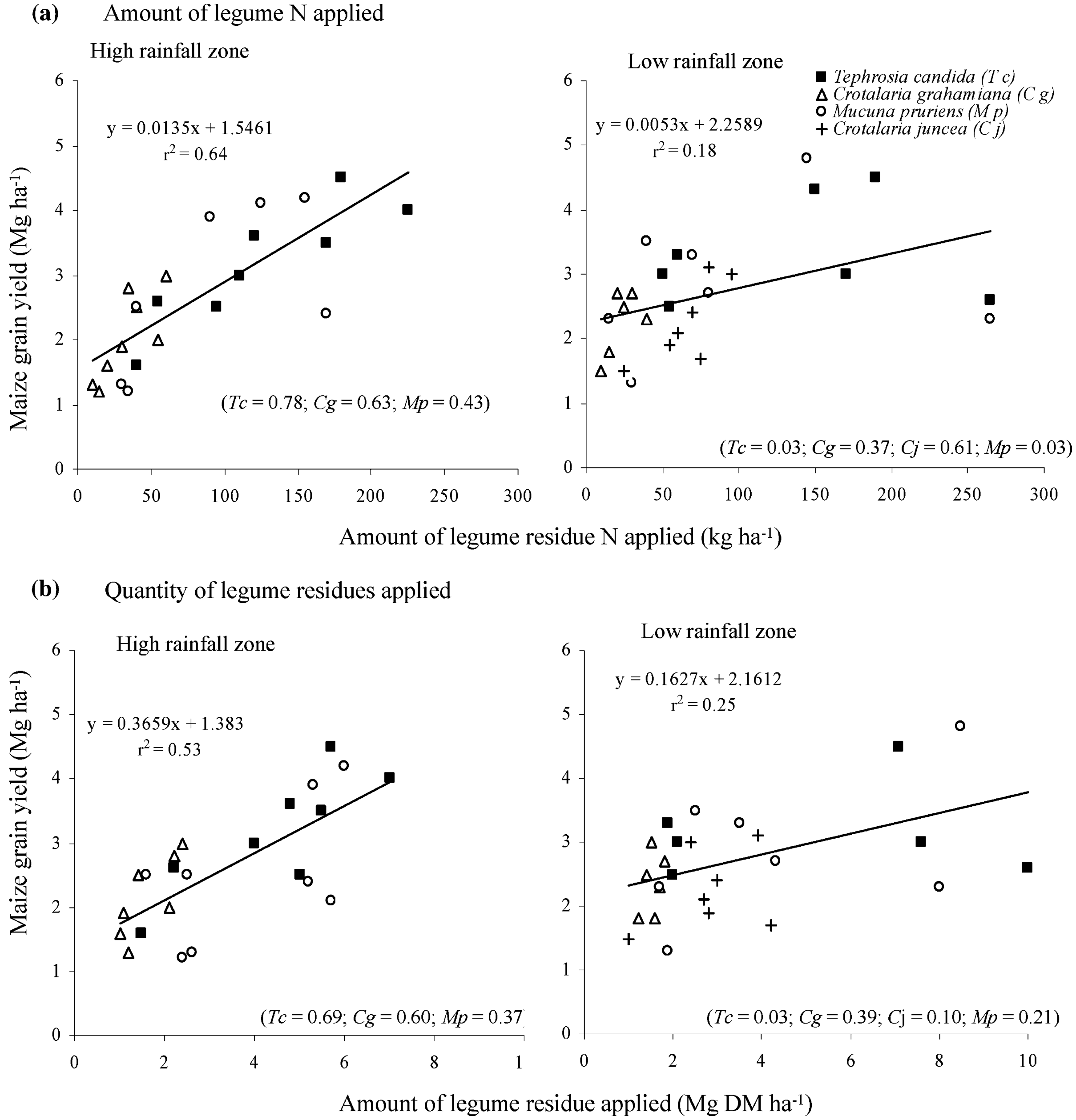

Figure 4. Relationships between (a) amounts of legume residue N applied and (b) quantities of legume residue applied and observed maize grain yield in the high and low rainfall zones of Bukoba District.

of Ca and Mg compared with soils in the high rainfall zone (Table 1), and a good season. Overall, there was little difference in crop yield between the zones largely because of good season (in terms of rainfall) for maize even in the low rainfall zone.

The corresponding amounts of N that would have been released from *T. candida, C. grahamiana* and *M. pruriens* were in the order of 38, 18 and 27 kg ha^{-1} in the high rainfall and 31, 13 and 21 kg ha^{-1} in the low rainfall zone, calculated basing on %FE figures (Table 6). Considering the amount of residue N applied, the N mineralised from *C. grahamiana* residues was high compared with that from *T. candida* and *M. pruriens* residues. These results on %FE agree

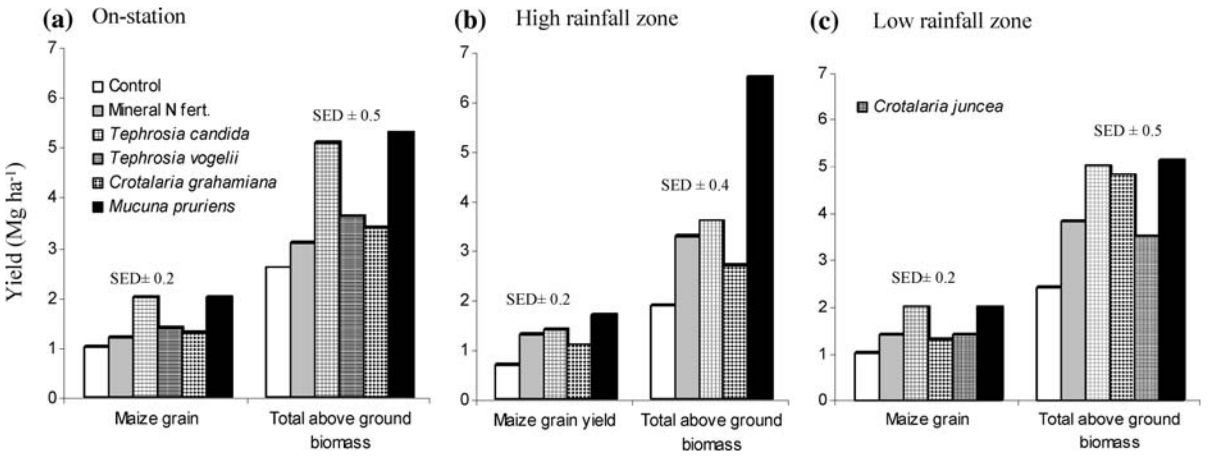

Figure 5. Effect of mineral fertiliser N application and incorporation of legume residues into the soil on grain and total above ground yield of the second season maize at (a) on-station (b) in the high rainfall zone and (c) in the low rainfall zones. SED = Standard error of differences in treatment means.

Table 6. N FE and percentage fertiliser equivalence (%FE kg N ha^{-1}) of legume residues

Legume residue	High rainfall zone		Low rainfall zone	
	FE	%FE	FE	%FE
Tephrosia candida	38	31	33	25
Crotalaria grahamiana	18	55	13	59
Crotalaria juncea	–	–	13	20
Mucuna pruriens	27	31	28	30

well with those of leaching incubation studies where N mineralisation was poor for *M. pruriens* and *T. candida* (Figure 2). The foregoing results and the varied correlation between the amounts of legume residue applied and maize yield (Figure 4) may indicate difference in the temporal pattern of N availability from legume residue to the maize. The comparatively higher maize yields with application of legume residues in the first season were likely not only due to N contribution

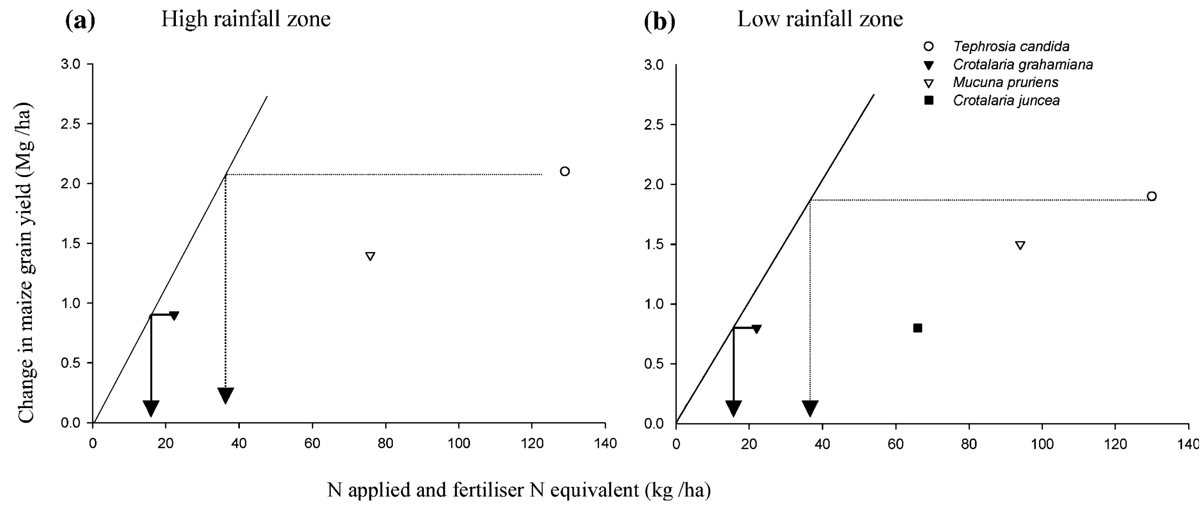

Figure 6. Relationship between change in maize grain yield and fertiliser N application in the (a) high rainfall zone and (b) low rainfall zone. The one to one lines present the linear response of maize to mineral N fertiliser The horizontal lines compare the applied legume residue N at the same level of maize yield due to application of mineral N fertiliser. For the sake of legibility only two lines are shown.

but also to other additional effects such as improved soil aeration, water infiltration and moisture retention (Giller, 2002; Myers et al., 1997).

Efficiency of use of legume N by maize crop

N uptake by maize following application of mineral N fertiliser was higher than the amount

Table 7. N uptake and efficiency ratios of grain and total biomass yield for maize as a function of application of mineral N fertiliser and incorporation of legume residues at ARDI Maruku

	N uptake (kg ha^{-1})		Fert. N use efficiency (kg kg $N_{applied}^{-1}$)		N utilisation efficiency (kg kg N_{uptake}^{-1})		Nitrogen recovery efficiency (kg N_{uptake} kg $N_{applied}^{-1}$)	
	Grain	Total above ground biomass[a]	Grain	Total above ground biomass[a]	Grain	Total above ground biomass[a]	Grain	Total above ground biomass[a]
Control	12	18	–	–	–	–	–	–
Mineral fertiliser	53	80	54	137	65	109	0.81	1.25
Tephrosia candida	35	55	8	35	68	113	0.20	0.32
Tephrosia vogelii	23	33	18	64	57	110	0.21	0.31
Crotalaria grahamiana	30	49	24	65	68	113	0.35	0.62
Mucuna pruriens	30	44	23	56	64	113	0.35	0.47
SED[b]	5***	8***	10**	25**	ns	ns	0.14**	0.22**

[a]Include grain and stover.
[b]Standard error of the difference in means, $^{**}P < 0.01$, $^{***}P < 0.001$, ns = not significant.

Table 8. N uptake and efficiency ratios of grain and total biomass yield for maize as a function of application of mineral N fertiliser and incorporation of legume residues in the high and low rainfall zones of Bukoba District; means are for data collected at eight sites in the high rainfall zone and at seven sites in the low rainfall zone

	N uptake (kg ha−1)		N use efficiency (kg kg $N_{applied}^{-1}$)		N utilisation efficiency (kg kg N_{uptake}^{-1})		Nitrogen recovery efficiency (kg N_{uptake} kg $N_{applied}^{-1}$)	
	Grain	Total above ground biomass[a]	Grain	Total above ground biomass[a]	Grain	Total above ground biomass[a]	Grain	Total above ground biomass[a]
High rainfall zone								
Control	16	31	–	–	–	–	–	–
Mineral fertiliser	57	92	54	110	59	114	0.90	1.35
Tephrosia candida	45	74	18	45	69	108	0.26	0.42
Crotalaria grahamiana	29	47	30	78	68	100	0.43	0.73
Crotalaria juncea	nt	nt	nt	nt	nt	nt	nt	nt
Mucuna pruriens	37	58	22	58	62	115	0.33	0.50
SED[b]	6***	11***	8***	19***	ns	ns	0.11***	0.16***
Low rainfall zone								
Control	20	29	–	–	–	–	–	–
Mineral fertiliser	62	97	48	123	58	97	0.81	1.23
Tephrosia candida	49	78	18	47	69	116	0.20	0.23
Crotalaria grahamiana	33	51	38	110	65	114	0.35	0.42
Crotalaria juncea	35	54	14	47	64	110	0.23	0.38
Mucuna pruriens	42	63	24	63	63	111	0.35	0.47
SED[b]	7***	10***	10*	28*	ns	ns	0.16**	0.27**

nt = Not tested.
[a]Include grain and stover.
[b]Standard error of the difference in means, $^{*}P < 0.05$ $^{**}P < 0.01$ *** $P < 0.001$, ns = not significant.

applied (Tables 7 and 8). Applying 50 kg N ha^{-1} of mineral fertiliser resulted in maize crop mining extra 20-kg N ha^{-1} probably due to better growth and better soil N capture. The efficiency of use of mineral fertiliser N was high compared with legume residue N, implying that use of mineral fertilisers along with legume residues can increase the N use efficiency of crops. The first maize crop recovered about 30 to 70% of the legume residue N, which were two to threefold the recovery in the control (Tables 7 and 8). This is within the range of 27–70% recovery reported for legume cover crops (Giller, 2001; Harris and Hesterman, 1990; Ibewiro et al., 2000). The contribution of below-ground residue N to maize yield was not accounted for, in this experiment, although other authors suggest that substantial amounts of N can be added below-ground by legumes (Cadisch et al., 2002; McNeill et al., 1997; Peoples et al., 2001). Given the limited response seen to additions of above-ground legume materials in these experiments (Tables 4 and 5), we consider the belowground contribution of the legumes to be negligible. Roots are slow to decompose (Cadisch, et al., 2002; Uquiaga et al., 1998; Vanlauwe et al., 1997), thus they play a more important role in building of soil structure rather than in nutrient supply.

The results of this study show that application of legume residues can contribute significantly to the overall productivity in low-external input agricultural system of Bukoban District, as they add nutrients and enhance efficient management and utilisation of soil resources by the plant. However, application of legume residues alone cannot achieve the potential crop yield on Bukoban soils unless managed with frequent application of small doses of mineral fertilisers as top dressing in order to ensure synchrony with crop demand (Giller, 2002).

Owing to presence of organic resources with differential N release patterns, and the extremely poor resource base of many farmers in the district, more flexible guidelines for management of both organic and mineral fertilisers proposed by Palm et al. (2001) and Giller (2002), are important. In our previous study (Baijukya, 2004) farmers mentioned shortage of labour to grow and incorporate legumes (a factor, which was not accounted for in the present study) as a constraint to legume use. Therefore the net effect of labour requirement, economic benefits of legume use and legume residue interactions with mineral fertilisers need to be investigated with farmers to determine the appropriateness of the technology.

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