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Managing legume cover crops and their residues to enhance productivity of degraded soils in the humid tropics: a case study in Bukoba District, Tanzania

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Abstract

In degraded soils, establishment of soil-improving legumes can be problematic and requires investment of labour and other resources. We investigated various aspects of managing herbaceous legumes in farmers' fields in Bukoba District, Tanzania. Biomass and N accumulation by *Crotalaria grahamiana* was 1.1 Mg ha^{-1} and 34 kg N ha^{-1} when established without farmyard manure (FYM) and 3.0 Mg ha^{-1} and 95 kg N ha^{-1} when established with 2 Mg FYM ha^{-1}, and incorporation of the biomass gave an increment of 700 kg ha^{-1} of grain in the subsequent maize crop. Maize grain yield at different application rates of *Tephrosia candida* residues ranged from 1.4 to 3.3 Mg ha^{-1} and from 2.0 to 2.8 Mg ha^{-1} in the high and low rainfall zone, respectively. Application of tephrosia biomass at a rate of 2 Mg ha^{-1} had no significant effect on maize yield whereas rates of 4, 6 and 8 Mg ha^{-1} gave comparable yields. Apparent N recovery efficiencies at all rates of tephrosia residues were maximally 27 and 13% for the high and low rainfall zones, respectively. Mulching with *Mucuna pruriens* suppressed weeds by 49 and 68% and increased maize yield by 57 and 103% compared with the weedy fallow in the respective zones. Incorporated residues had a weaker effect on suppressing weeds and poor labour productivity (2l and 36 kg grain person-day^{-1}) compared with mulched residues (32 and 52 kg grain person-day^{-1}) in the high and low rainfall zone, respectively. These results indicate that if well managed, legume residues have the potential to increase yields of subsequent maize crops on degraded soils.

Introduction

Improved fallows with leguminous cover crops are a promising option to improve crop productivity in the low-income agricultural systems of the humid and sub-humid tropics (Hartemink et al. 2000; Sanchez 2002). The benefits of this technology, however, are likely to be smaller on poor soils where the biomass and nitrogen accumulation by legumes may be limited (Uexküll and Mutert 1994; Houngnandan et al. 2001). Prospects for improving the productivity of legumes on infertile soils have been extensively discussed by Giller (2001) and Hungria and Vargas (2000). Most literature suggests the use of external inputs such as lime (in acidic soils), phosphate fertilisers and starter doses of nitrogenous fertilisers (Uexküll and Mutert 1994; Houngnandan et al. 2001). Although mineral fertilisers are by far the most effective means of providing deficient nutrients in soils, organic resources, such as farmyard manure (FYM) can have additional benefits such as helping to raise the pH of acidic soils. Moreover, organic resources can increase the availability of nutrients like P, K, Mg and micronutrients that are essential for legume growth and N_2-fixation (Ridder and Keulen 1990;

Diels et al. 2002). However, there is insufficient knowledge on response of legumes to application of small quantities of FYM and the expected benefits from combined use of FYM and legume residues.

Legume residue management practices that retain organic matter and the embodied nutrients *in situ* are required to maximise the beneficial effect of improved fallows. Such alternatives to legume removal may include mulching or legume residue incorporation into the soil (Giller et al. 1997). A decision tree to guide the use of plant residues for soil amendment has been developed (Palm et al. 2001). Although the guide seeks to maximise the N use efficiency of organic resources, incorporation of residues into the soil may be difficult when productivity of labour invested is restricted (Roger 1995). High rates of legume residue application may be uneconomic, especially when the corresponding yield increases are not substantial. This is of particular importance where there may be trade-offs associated with use of legume residues for different purposes such as providing fodder or green manure. These lead to a need for flexible guidelines for management of legume residues that take into account of residue availability, alternative uses and practices that demand less labour and result in higher labour productivity.

In light of the above knowledge gaps, three experiments were conducted in farmers' fields in Bukoba District with the objectives: (*i*) to determine the effects of application of small quantities of FYM on biomass accumulation and N yield by legumes; (*ii*) to examine whether extra benefits are realised from combined use of manure and legumes on maize yield; (*iii*) to determine the optimum application rate of legume residues for maize production in Bukoba District; (*iv*) to assess the effect of different legume management practices on weeds and maize yield; and (*v*) to determine the labour cost and labour productivity of legume fallows with different legume residue management practices.

Materials and methods

Study area and legume species used

The experiments were conducted in the high and low rainfall zones of Bukoba District northwest Tanzania (1 °13′–1 °30′ S, 31 °19′–31 °52′ E). Average annual precipitation ranges between 1500 and 2100 mm in the high rainfall zone and 750–1000 mm in the low rainfall zone. Soils at experimental sites are deep, well drained, sandy clay loam (Alumi-humic Ferralsol) in the high rainfall zone and clay loam (Humic Acrisols) in the low rainfall zone (Touber and Kanani 1994). The characteristics of soils at the experimental sites are given in Table 1. Detailed characteristics of the zones are described by Baijukya and Steenhuijsen Piters (1998).

The test legumes were *Crotalaria grahamiana* Wight & Arn (hereafter referred to as crotalaria), *Tephrosia candida* (DC.) Kunth (hereafter referred to as tephrosia) and *Mucuna pruriens* (L.) DC. var. pruriens (hereafter referred to as mucuna). These legumes had been selected by farmers on basis of their growth potential, and suitability for soil

Table 1. Topsoil (0–30 cm) characteristics at the experimental sites.

Soil, corresponding sites and experiments	Zone	pH (H_2O)	Organic Carbon (g kg $^{-1}$)	Total N (g kg $^{-1}$)	P Bray (mg kg^{-1})	Exchangeable cations (cmol$_c$ kg $^{-1}$)			Particle size (%)		
						Ca	K	Mg	Sand	Silt	Clay
Soil at sites used for Experiment 1	High rainfall	4.4	12.5	0.9	6.9	1.2	0.1	0.2	60	21	19
	± s.d.[a]	0.1	3.2	0.2	1.8	0.1	0.0	0.1	2	1	1
Soil at sites used for Experiment 2	High rainfall	5.4	23.2	1.3	15.0	2.8	0.3	0.2	59	21	20
	± s.d.	0.2	4.8	0.1	7.0	1.6	0.2	0.1	4	7	5
	Low rainfall	5.3	15.5	1.2	6.6	3.9	2.8	0.1	29	26	47
	± s.d.	0.1	2.7	0.3	5.7	1.9	0.3	0.1	5	4	1
Soil at sites used for Experiment 3	High rainfall	5.1	23.1	1.5	20.0	0.1	0.0	0.2	62	20	20
	± s.d.	0.1	5.7	0.5	5.0	1.4	3.4	0.1	2	4	2
	Low rainfall	5.3	18.3	1.2	15.4	2.6	2.0	1.0	31	27	42
	± s.d.	0.1	12.3	1.5	5.2	0.2	0.2	0.2	1	3	6

[a] ± s.d., standard deviation.

fertility improvement as well as fodder in the case of mucuna (Baijukya 2004). Due to limited land (in farmer fields), different species were selected for use in different experiments. In previous experiments, crotalaria had high impact on maize productivity but its growth was restricted in poor soils, hence it was used in Experiment 1 where the effect of cattle manure on legume growth was examined. Tephrosia was chosen for Experiment 2 because of its ability to yield large amounts of biomass in different soils. Mucuna was chosen for Experiment 3 because it gives rapid establishment of soil cover and its residues are relatively easy to handle as mulch.

Experiment 1: improving productivity of degraded soils by use of legumes and FYM

To determine the effects of FYM on legume productivity and eventual impact on maize yield, a field experiment was conducted on two farmers' fields, in the villages Butairuka and Kiilima in the high rainfall zone, between February 2002 and February 2003. The villages are separated by a distance of 15 km. Both sites had been abandoned for 1 year due to poor soil fertility and high infestation of couch grass (*Digitaria scalarum*).

In the first season, the effect of FYM on legume growth and N accumulation was tested. After removing the couch grass, by hand cultivation and hand picking, eight 6 m by 13 m plots and four 6 m by 27 m plots separated by 1 m paths, were randomly demarcated per site. Dry FYM was spread on four 6 m by 13 m plots at a rate of 2 Mg ha^{-1} and ploughed under the soil (< 20 cm). Crotalaria was sown in the third week of February 2002 in all FYM applied plots and on other two plots which, did not receive FYM, at a seeding rate of 4 kg seeds ha^{-1}. Weeds were allowed to grow in 6 m by 27 m plots. The treatments were (*i*) weedy fallow (*ii*) crotalaria established without FYM and (*iii*) crotalaria established with FYM. Due to limited size of the fields, the experiment was arranged in a completely randomised design with four replications. Harvest of fallows was done in the fourth week of August (6 months after planting) by cutting three quadrats (3 m^2) at ground level in each plot. Plant shoots were oven dried at 70 °C for 48 h, weighed and sub-samples taken for N determination. Above ground biomass were estimated using the mean weight of samples taken at three locations and the yield expressed in Mg ha^{-1}. The biomass yields and the N mass ratio (% N) in plants tissues were used to estimate the N accumulation, which was expressed in kg ha^{-1}.

In the second season the residual effect of the legume treatments and FYM on growth and yield of maize were assessed in comparison with treatments that received FYM directly. After harvesting the fallows, all plots were split into sub-plots of 6 m by 6 m allowing for paths of 1 m between plots. Dry FYM of the same quality as used earlier was spread and ploughed under on four plots, previously under weedy fallow, to simulate the condition where FYM is applied at the time of sowing maize. Crotalaria residues obtained on respective plots were chopped into smaller pieces (< 15 cm long) and incorporated into the soil using a hand hoe. Maize, variety *Kilima*, was sown in all plots in the first week of September 2002 at a spacing of 0.75 m × 0.45 m, one week after application of treatments. Prior to sowing of maize, all plots received a basal fertilizer of 15 kg ha^{-1} P and 20 kg ha^{-1} K as triple super phosphate (20% P) and muriate of potash (50% K), respectively. Mineral N fertilizer in the form of calcium ammonium nitrate was applied to two of the sub-plots previously under crotalaria with or without FYM and other two of the sub-plots previously under weedy fallow with or without FYM. The rate was 50 kg N ha^{-1} (N_1) in split doses of 25 kg N ha^{-1}, at 4 and 7 weeks after maize emergence. The rest of the plots received no mineral fertilizer (N_0). The experimental design was split plot in two replications, with N rates being the main plots and fallow management i.e. weedy fallow, FYM, crotalaria-FYM and crotalaria + FYM being the sub-plots. The final harvest of maize was done in the third week of February 2003 in three (3 m^2) quadrats in each plot. Maize cobs and stover were oven dried at 70 °C for 48 h, weighed and sub-samples taken for N determination.

Experiment 2: determination of optimum rates of legume residues for maize production

The experiment was conducted in the villages Kiilima (in the high rainfall zone) and Kabirizi (in the low rainfall zone) in the same period as the first experiment. Two sites previously planted with maize without any fertilizer amendment were selected per village. At each site a 13 m by 41 m plot was cleared and tephrosia was established in the fourth week of February 2002 at a seeding rate of 4 kg seed ha^{-1}. Tephrosia was harvested in the second and fourth week of September 2002 in the high and low rainfall zone, respectively. The plots at each site were divided into six 6 m by 6 m plots (allowing for paths of 1 m) in which the following treatments were randomly assigned: (*i*) no fertility amendment (control), (*ii*) mineral fertiliser at 50 kg N ha^{-1}, and (*iii–vi*) tephrosia residues applied at rates of 2, 4, 6 and 8 Mg ha^{-1}. The N content of tephrosia, based on analysis of the whole shoots at 6 months after planting was roughly 2.5% in both zones (Baijukya 2004), Amounts of N added were thus equivalent to 50, 100, 150, and 200 kg N ha^{-1}. Tephrosia residues were chopped into pieces (<15 cm) and incorporated into the soil. The experiment was arranged in a completely randomised design with two replications.

Maize variety *Kilima* was sown in the first and fourth week of September 2002 in the high and low rainfall zone, respectively, one week after the residues were incorporated into the soil. Prior to sowing of maize, all plots received a basal fertiliser of P and K as in Experiment 1. Mineral N fertiliser in the form of calcium ammonium nitrate was applied to mineral fertiliser plots at a rate of 50 kg N ha^{-1} in the same way as in Experiment 1. Maize was harvested in the fourth week of February and processed as before. The N uptake in grain and stover from the individual treatments were estimated. The N use efficiency, apparent N recovery efficiency and N utilisation efficiency by maize of N in the applied legume residues was assessed using the following equations:

$$\text{N use efficiency} = \frac{\text{kg yield}}{\text{kg N applied}} \qquad \text{(a)}$$

$$\text{N recovery efficiency} = \frac{\text{kg N uptake}}{\text{kg N applied}} \qquad \text{(b)}$$

$$\text{N utilisation efficiency} = \frac{\text{kg yield}}{\text{kg N uptake}} \qquad \text{(c)}$$

where Yield (Y) $= (Y_{\text{fertiliser}} - Y_{\text{control}})$; N uptake (U) $= (U_{\text{fertiliser}} - U_{\text{control}})$

Experiment 3: legume residue management practices and their effect on weeds, maize yield and labour productivity

The experiment was conducted in the same period as Experiments 1 and 2 in the same villages as Experiment 2, at three sites in each village. Three 6 by 20 m plots and three 6 by 13 m plots, separated by 1 m paths, were demarcated at each site and cultivated to remove weeds and maize stover. Mucuna was sown in the 6 m by 20 m plots (mucuna fallow) in the fourth week of February 2002 at a spacing of 0.5×0.3 m by putting 2 seeds per planting hole. Weeds were left to grow in the 6 by 13 m plots (weedy fallow). Mucuna was harvested in the first week of September 2002 by cutting the stems at the soil surface. The weedy fallow was cultivated and weeds removed from the plots.

The respective weedy and mucuna fallow plots were sub-divided into 6 by 6 m plots allowing for paths of 1 m between the plots. The treatments (*i*) no soil amendment (control) and (*ii*) mineral N fertiliser were randomly assigned to plots which were under weedy fallow whereas mucuna residues were either removed, incorporated into the soil or mulched on plots which were under mucuna fallow. This resulted in additional treatments of (iii) removed residues, (iv) incorporated residues and (v) mulched residues. The removed residue treatment was included to study the effect of mucuna below ground biomass on maize yield. For both residue incorporated and residue mulched treatments, mucuna residues were applied at a rate of 5 Mg (dry biomass) ha^{-1} (about 100 kg N ha^{-1}) within 3–5 days after harvest. The experiment was arranged in a randomised complete block design with three replications per site.

Maize variety *Kilima* was sown in the second week and fourth week of September 2002 in the high and low rainfall zones, respectively, at a spacing of 0.75×0.45 m, immediately after application of treatments (3 days after harvesting the fallow). Prior to sowing of maize, all plots received a basal application of P and K fertilisers as in Experiments 1 and 2. Mineral N fertiliser in the form of calcium ammonium nitrate was applied at a rate of 50 kg N ha^{-1} as in Experiments 1 and 2. Maize was weeded twice and weeds were retained in the plots. Harvesting of maize was done in the third week of February 2003 and data collected as described before.

All field operations were done by a group of six farmers (for each village) aged between 25 and 48 years. The time spent by the group for each field operation was recorded, summed per treatment and converted to person-day equivalents. In Bukoba District, 1 person-day (for work on the farm) is estimated to be 6 h (Nkuba 1997). Weed biomass in the respective treatments was assessed during the first and second weeding which was done at 5 and 9 weeks after sowing. Measurements were taken in 1 m^2 quadrats at three locations in each plot. Weeds were handpicked, oven-dried at 70 °C for 48 h and biomass determined.

Soil sampling and analysis of soils and plant materials

Composite topsoil (0–25 cm) samples were taken from each site at the beginning of each experiment. In each plot, soil was collected and bulked from three locations, sun-dried, and sieved to pass a 2-mm-mesh. Soil pH was determined on H_2O (1:5 w/v), organic carbon by the Walkley–Black wet oxidation method and total N by the micro-Kjeldahl digestion method. Available P was determined by Bray I method (Murphy and Riley 1962), exchangeable cations by ammonium acetate extraction with Ca and Mg estimated by the atomic absorption spectrophotometer (AAS) and K by flame photometer. Particle size distribution was analysed by standard hydrometer method (Page et al. 1982). Total N in legumes residues and maize (grain and stover) was determined by the micro-Kjeldahl digestion method followed by distillation and titration (Okalebo et al. 1993).

Data analysis

Data were analysed with GenStat release 6.1 Lawes Agricultural Trust (Rothamsted Experimental Station) statistical package. Standard errors of the differences between means were calculated. Step-wise regression analysis was performed to examine relationships between the soil chemical parameters, the legume biomass, the N in applied residues and the maize yield.

Results

Soil quality and rainfall during the experimental period

Based on the classification by Landon (1991), soils in the high rainfall zone were strongly acid, had medium organic carbon (OC) and available P and were poor in total N, Ca, available K and Mg (Table 1). Soils in the low rainfall zone were slightly acidic with medium contents of OC, available P and Ca, but poor in total N, available K and Mg. Within zones, soils at different sites varied in chemical characteristics mainly due to differences in past management, e.g. fertilisation, past crops grown, etc. The total rainfall during the experimental period was 1855 and 857 mm in the high and low rainfall zone, respectively, which was considered adequate for optimum production of legume species and the maize crop.

Response of legume to FYM application

Application of FYM had no influence on the N content (%) in crotalaria shoots (Table 2). Crotalaria established with FYM accumulated threefold more biomass and N than crotalaria established without FYM. The biomass and N accumulated by crotalaria established with FYM was 51 and 86% higher than that of weedy fallow. Crotalaria established without amendment gave comparable biomass to weedy fallow but it accumulated twice as much N as the weeds.

Maize response to mineral N fertiliser, legume residues, FYM and their combinations

Maize yields after all types of fallow management were highest with mineral N fertiliser (Table 3). Maize grain and total above ground biomass ranged from 0.8 to 3.1 and 1.9 to 7.7 Mg ha^{-1}, respectively, with highest yields observed in the crotalaria + FYM + mineral fertiliser treatment and the lowest yields after weedy fallow with no mineral N fertilisers (control). Relative to the

Table 2. Total N, shoot biomass and N accumulation by six months old weedy fallow and *Crotalaria grahamiana* established without (−) and with (+) farmyard manure in farmer fields, in the high rainfall zone of Bukoba District.

Fallow type	N (%)	Biomass (Mg ha^{-1})	N accumulation (kg ha^{-1})
Weedy fallow	1.3	0.9	12
Crotalaria grahamiana − FYM	3.1	1.1	34
Crotalaria grahamiana + FYM	3.2	3.0	95
SED	1.3	0.5	16

SED, Standard error of differences between means, $P < 0.001$ in all cases.

control, maize yields were increased substantially by manure and crotalaria treatments. Growing crotalaria with manure added in the previous season resulted in slightly higher N uptake (67 kg N ha^{-1}) and yield (6.2 Mg ha^{-1}) compared with manure plus mineral fertiliser applied in the same season (63 kg N ha^{-1} and 5.8 Mg ha^{-1}). Mineral fertiliser further increased maize aboveground biomass after crotalaria + FYM to 7.7 Mg ha^{-1}.

Maize yield response to different quantities of legume residues

Maize yield increased with increasing legume residue rates (Table 4), although the 2 Mg ha^{-1} rate had an insignificant influence on maize yield in both zones. In the high rainfall zone, yields in 4 and 6 Mg ha^{-1} treatments were not significantly different and yields in 8 Mg ha^{-1} and 50 kg N ha^{-1} treatment were similar. In the low rainfall zone, maize yields in 4, 6 and 8 Mg ha^{-1} treatment did not differ significantly, but yield in the 50 kg N ha^{-1} treatment was significantly greater than with tephrosia treatments or the control. Nitrogen uptake in grain and total aboveground biomass also increased with increasing residue rates and largely reflected the differences in yield. There were however, wide variations in yield between sites in both zones. These yield differences were related to the initial soil organic carbon (OC) (with coefficient of determination $r^2 = 0.35$) and soil pH ($r^2 = 0.65$) in the high rainfall zone but only weakly by soil pH ($r^2 = 0.2$) in the low rainfall zone. The general trend was that higher yields were found on soils with high OC contents and pH and *vice versa*.

The efficiency of use of N from tephrosia residues by maize was poor compared with that of N from mineral fertiliser, and was at rates above 2 Mg ha^{-1} not affected by the amount of legume residues applied (Table 5). This was also the case with apparent N recovery efficiency where maxi-

Table 3. N uptake, grain and above ground yield of maize following application of FYM, residues of *C. grahamiana* grown with or without FYM in the previous season in combinations of without (N_0) and with application of 50 kg N ha^{-1} as mineral N fertiliser (N_1).

Fallow treatment	N uptake (kg ha^{-1})						Yield (Mg ha^{-1})					
	Grain			Above-ground biomass			Grain			Above-ground Biomass		
	N_0	N_1	Mean	N_0	N_1	Mean	N_0	N_1	Mean	N_0	N_1	Mean
Weedy fallow	11	27	19	18	45	32	0.8	1.7	1.2	1.9	4.3	3.1
FYM	20	39	30	34	63	49	1.4	2.3	1.9	3.4	5.8	4.6
Crotalaria− FYM	19	30	24	31	51	41	1.1	2.1	1.6	2.8	5.2	4.1
Crotalaria + FYM	42	50	46	67	81	72	2.5	3.1	2.8	6.2	7.7	6.9
Mean	23	37		38	60		1.5	2.3		3.6	5.6	
SED N levels		0.8***			1.2***			0.1***			0.5***	
SED fallow treatments		3.1**			5.1**			0.2**			0.1 **	
SED (N levels × fallow treatments)		ns			2.3*			ns			ns	

Data are pooled results from two farmer fields in the high rainfall zone of Bukoba District.
SED = Standard error of differences between means, $^*P < 0.05$ $^{**}P < 0.01$, $^{***}P < 0.001$. ns, Not significant.

Table 4. Nitrogen uptake and yield response of maize to application of mineral N fertiliser and different quantities of *T. candida* residues under farmer conditions in the high and low rainfall zones of Bukoba District.

Treatment	Amount of N applied (kg ha^{-1})	High rainfall zone				Low rainfall zone			
		Yield (Mg ha^{-1})		N uptake (kg ha^{-1})		Yield (Mg ha^{-1})		N uptake (kg ha^{-1})	
		Grain	Above-ground biomass	Grain	Above-ground biomass	Grain	Above-ground biomass	Grain	Above-ground biomass
Control	0	1.2	3.0	19	31	1.8	4.6	30	45
50 kg N ha^{-1}	50	3.2	7.9	50	76	3.1	7.8	49	71
2 Mg ha^{-1}	50	1.4	3.6	22	35	2.0	4.9	32	47
4 Mg ha^{-1}	100	2.4	5.9	37	57	2.5	6.1	39	58
6 Mg ha^{-1}	150	2.7	6.6	42	63	2.7	6.7	42	62
8 Mg ha^{-1}	200	3.3	8.2	51	78	2.8	6.9	41	64
SED		0.5***	0.5***	4***	5***	0.3**	0.8***	5***	7***

SED, Standard error of differences between means, $^{**}P < 0.01$, $^{***}P < 0.001$.

mum values of less than 27 and 13% were recorded for the total above ground biomass in the high and low rainfall zones, respectively. All treatments had comparable values of N utilisation efficiency except the 2 Mg ha^{-1} treatment where response was poor. Apparent recovery and use of mineral N fertiliser in the above ground biomass were more efficient in the high rainfall zone (99 kg biomass kg N^{-1} and 90%) compared with the low rainfall zone (39 kg biomass kg N^{-1} and 52%).

Effect of mineral fertiliser and mucuna residue management practices on weeds in maize crop

Relative to the weedy fallow (control), residue removal led to an increase in total weed biomass in association with maize of 14% in the high rainfall zone but had a negligible effect in the low rainfall zone (Table 6). In both zones, incorporated residues reduced weed biomass by 20%. Mulched residues reduced weed biomass by 49% in the high rainfall zone and 68% in the low rainfall zone. Application of mineral N fertiliser increased total weed biomass by 44% and 11% in the high and low rainfall zones, respectively.

Maize yield and N uptake under different types of mucuna residue management

In the high rainfall zone, a yield increase of 43 and 57% in grain and of 47 and 53% in total above-ground biomass was recorded with incorporated residues and mulched residues, respectively (Table 7). Maize yields in removed residues and the control plots were comparable. Overall, the highest yield was obtained with application of mineral N fertiliser, which was double the yield of the control. In the low rainfall zone, maize yield with mulched residues and mineral N fertiliser treatments were not significantly different from each other but were both double the yield in the control. Incorporated residues increased grain yield by 57% whereas removed residues increased yield by 33%.

The total N uptake ranged between 31 and 63 kg ha^{-1} in the high rainfall zone and between 45 and 94 kg ha^{-1} in the low rainfall zone, with the treatment effects following a similar trend as for maize yield. Maize grain and total above-ground biomass were positively correlated with N uptake ($r^2 = 0.93$ in the high rainfall zone and $r^2 = 0.86$ in the low rainfall zone). However, wide variations in yield and N uptake were observed between sites and could be explained by the site differences in initial soil pH ($r^2 = 0.64$ and 0.56) and initial soil N ($r^2 = 0.53$ and 0.65) for the high and low rainfall zone, respectively.

Labour demand and productivity of mucuna fallow with different types of residue management

In the high rainfall zone, growing maize with incorporated residues required 26 and 27 more person-days compared with growing maize with removed residues and mulched residues (Table 8).

Table 5. Nitrogen efficiency ratios of grain and total above ground biomass for maize following application of mineral N fertilizers and different quantities of *T. candida* residues under farmer conditions in the high and low rainfall zones of Bukoba District.

Treatment	High rainfall zone						Low rainfall zone					
	N use efficiency (kg kg $N_{applied}{}^{-1}$)		N utilization efficiency (kg kg $N_{uptake}{}^{-1}$)		Apparent N recovery efficiency (kg N_{update} kg $N_{applied}$)		N use efficiency (kg kg $N_{applied}{}^{-1}$)		N utilization efficiency (kg kg $N_{applied}{}^{-1}$)		Apparent N recovery efficiency (kg N_{update})	
	Grain	Above ground biomass	Grain	Above ground biomass	Grain	Above ground biomass	Grain	Above ground biomass	Grain	Above ground biomass	Grain	Above ground biomass
50 kg N ha $^{-1}$	39	99	64	108	0.61	0.90	25	64	68	122	0.39	0.40
2 Mg ha^{-1}	4	14	58	67	0.05	0.09	4	9	42	87	0.09	0.11
4 Mg ha^{-1}	11	28	66	119	0.18	0.27	6	15	64	149	0.11	0.12
6 Mg ha^{-1}	10	24	63	135	0.15	0.22	7	15	62	124	0.10	0.13
8 Mg ha^{-1}	10	26	65	111	0.16	0.24	5	13	62	154	0.06	0.10
SED	2***	8***	5*	ns	0.05***	0.07***	3***	7***	23*	30*	0.05**	0.09***

SED, Standard error of differences between means, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$; ns = not significant.

Table 6. Effect of weed fallow, mineral N fertiliser and different management of mucuna residues on weed biomass (Mg DM ha^{-1}) associated with maize crop, observed in farmer fields at first weeding (5 weeks after sowing) and second weeding (9 weeks after sowing) in the high and low rainfall zone of Bukoba District.

Management	High rainfall zone			Low rainfall zone		
	First weeding	Second weeding	Total	First weeding	Second weeding	Total
Weedy fallow	0.44	0.22	0.66	0.50	0.30	0.80
50 kg N ha^{-1}	0.65	0.30	0.96	0.58	0.31	0.89
Removed residues	0.52	0.23	0.75	0.47	0.29	0.76
Incorporated residues	0.37	0.17	0.54	0.42	0.21	0.63
Mulched residues	0.22	0.12	0.34	0.17	0.09	0.26
SED	0.05	0.04	0.04	0.07	0.06	0.06

SED, Standard error of differences between means, $P < 0.001$ in all cases.

A similar trend was observed in the low rainfall zone though with a higher labour requirement per treatment. In both zones, growing maize with removed residues or mulched residues demanded about 22 person-days more compared with growing maize on a previously weedy fallow. Maize grown with mucuna residue, removed or mulched, demanded about 20 person-days more compared with maize grown with application of mineral N fertiliser. Growing maize with incorporated residues required 43–47 and 40–41 person-days more compared with growing maize on a weedy fallow and with application of mineral N fertiliser, respectively, with the trend being the same in both zones.

Returns to labour ranged between 20 and 53 kg grain person-day^{-1} in the high rainfall zone and between 33 and 70 kg grain person-day^{-1} in the low rainfall zone, with the highest return observed with 50 kg N ha^{-1} treatment (Table 8), followed by mulched residues. In both zones, removing and or incorporating residues gave comparable returns to labour invested. In the low rainfall zone, application of mineral fertiliser gave returns to labour of 24, 33, 32, 31 kg grain person-day^{-1} higher than the treatments control, removed residues, incorporated residues and mulched residues, respectively. In the low rainfall zone, the returns to labour are somewhat lower and varied between 18 and 37 kg grain person-day^{-1} with a similar trend as in the high rainfall zone.

Discussion

Effect of farmyard manure on biomass and N accumulation by crotalaria

Application of FYM on degraded soils increased the biomass and N accumulation by crotalaria (Table 2). The observed influence of FYM on crotalaria growth could be due to its liming effect

Table 7. Effect of weed fallow, mineral N fertiliser and different management of mucuna residues on N uptake and yield of maize under farmer conditions in the high and low rainfall zones of Bukoba District.

Management	High rainfall zone				Low rainfall zone			
	Yield (Mg ha^{-1})		N uptake (kg ha^{-1})		Yield (Mg ha^{-1})		N uptake (kg ha^{-1})	
	Grain	Above ground biomass	Grain	Above ground biomass	Grain	Above ground biomass	Grain	Above ground biomass
weedy fallow	1.4	3.4	20	31	2.0	5.1	30	45
50 kg N ha^{-1}	2.9	7.2	46	63	4.3	10.7	66	94
Residues removed	1.4	3.4	20	30	2.7	6.8	40	59
Residues incorporated	2.0	5.0	28	43	3.2	8.0	44	68
Residues mulched	2.2	5.2	31	45	4.2	10.4	61	89
SED	0.2	0.5	3	4	0.4	0.9	5	8

SED, Standard error of differences between means, $P < 0.001$ in all cases.

Table 8. Estimated labour requirements (person days) and return in maize grain to labour invested (kg grain/person day) under farmer conventional farming (weed fallow) in relation to use of mineral fertilisers and different management of mucuna residues in the high and low rainfall zones of Bukoba District.

Type of management	Type of field operation	High rainfall zone			Low rainfall zone		
		Labour required (pers-day)	Total labour (pers-day)	Return to labour (kg pers- day^{-1})[a]	Labour required (pers-day)	Total labour (pers-day)	Return to labour (kg pers- day^{-1})[a]
Weedy	Land cultivation	33	49	29	33	58	43
fallow	Weeding of maize	16			23		
50 kg N ha^{-1}	Land cultivation	33	55	53	35	61	70
	Fert, application	5			5		
	Weeding of maize	17			21		
Residues	Removing residues	4	70[b]	20	5	81[b]	33
removed	Weeding of maize	15			25		
Residues incorporated	Incorporating residues	32	96[b]	21	30	101[b]	36
into the soil	Weeding of maize	13			20		
Residues	Mulching residues	5	69[b]	32	6	81[b]	52
mulched	Weeding of maize	13				12	
SED			2	5			4

[a] Calculated as yield (kg) in Table 7 divided by total labour invested.

[b] Include labour for land cultivation, sowing and weeding (43 person days), and uprooting mucuna (8 person days).

SED, Standard error of differences between means, $P < 0.01$ in all cases.

ameliorating the problems of soil acidity, and the supply of multiple nutrients (Bandyopadhay 2003; Ridder and Keulen 1990). The FYM used in the current experiment had N, P, Ca, K and Mg contents of 2.0, 0.5, 0.6, 2.6 and 0.4% qualifying it as good quality when compared with other values for manure reported in Africa (Kop 1995).

Effect of application of FYM, crotalaria residues, mineral N fertiliser and their combination on maize yield

Maize yields in all types of fallow management were higher with mineral N fertiliser (N_1), where the yields from the treatments FYM + mineral N fertiliser and crotalaria + mineral N fertiliser, were equal to the sum of the yields in the control, the yield increment from application of FYM and/or crotalaria, and the yield increment from application of mineral N fertiliser. These results suggest an additive effect of nutrients from these sources. A similar observation was reported in the humid tropics of West Africa when FYM was applied in combination with cowpea residues and or urea fertiliser (Iwuafor et al. 2001). Combining crotalaria residues with FYM or crotalaria residues with FYM plus mineral N fertiliser resulted in an added increment of 1400 and 600 kg of maize grain ha^{-1}, respectively, possibly as a result of adding nutrients other than N from the decomposing FYM (Table 3).

Maize response to the application of different quantities of tephrosia residues

Maize yield increased with increasing application rates of tephrosia residues (Table 4) but the N recovery efficiencies were poor at all rates of residue application (Table 5). The observed increase in maize yield could be attributed to better soil physical conditions, enhanced root growth and increased nutrient capture. The poor N recovery efficiency from the applied residue N could be a result of poor decomposability of tephrosia residues as they are rich in reactive polyphenols and lignin (Palm et al. 2001). Plant residues with (lignin + polyphenol): N ratio > 7 are reported to decompose and release N slowly (Mafongoya et al. 1998), which in our case, may have affected the synchrony of N supply by tephrosia residues and N demand by the maize as the residues were applied shortly before the sowing of maize.

In this study, no significant yield difference could be observed between tephrosia residues applied at 4, 6 or 8 Mg ha^{-1} (Table 5). This is an indication that in the short term 4–6 Mg ha^{-1} would be an optimal rate of residue application in both the high and low rainfall zones. However, this may vary with the type of legume species used. Tephrosia yielded between 55 and 300 (mean 125) kg N ha^{-1} on 12 on-farm sites in the high rainfall zone and between 50 and 260 (mean 143) kg N ha^{-1} on 10 on-farm sites in the low rainfall zone after 5 months growth in 2001 (Baijukya, 2004). As a general rule of thumb, only legumes producing above 2 Mg ha^{-1} of biomass (50 kg N ha^{-1}) would be expected to provide better yield response for maize in the following season (Gilbert 2000). Although our results confirm this rule, they also indicate that the impact of residues is not necessarily from N provision as this depends on many factors including the quality of the legume biomass in terms of N release and the management of residues. Adding larger amounts of residues would contribute to a more rapid restoration of soil organic matter, which would have longer-term advantages through restoring the productivity of degraded soils. If this is a primary aim, legume residues will not be ideal for this purpose given their relatively fast decomposition rates.

Effect of legume residue management practices on weed biomass and maize yield

Weed biomass was highest in the mineral N fertiliser treatment and in weedy fallow compared to other treatments (Table 6). This was largely a result of improved N availability to the weeds (with applied mineral N), the lack of suppression by the residue mulch as well as seed dispersal from mature weeds that were in the plots before maize was planted. Maize in the incorporated residues treatment established better and had good ground cover compared with removed residues treatments, which could be a reason for lower weed biomass when residues were incorporated into the soil.

In the high rainfall zone, incorporated and mulched residues resulted in similar maize yields whereas in the low rainfall zone, mulched residues gave higher yields compared with incorporated residues (Table 7). These results indicate that under sufficient and stable soil moisture and temperatures (high rainfall zone), decomposition and nutrient availability from mucuna residues could be the same whether placed on the surface or incorporated into the soil. A similar observation was reported at Ibadan, Nigeria (Vine 1953). Vanlauwe et al. (2001) and Cobo et al. (2000) also reported a minor difference in the total amount of mineral N between soil incorporated and surface applied mucuna residues. However, different results could be obtained in conditions with irregular soil moisture availability and temperatures, as is the case in the low rainfall zone. In such conditions mulched residues could help to conserve soil moisture and enhance better establishment of crops. In this study, maize plants in plots with mulched residues remained green for a longer period, which is a sign of higher water availability in the rooting zone (Giller 2002). In both zones, maize yield response was relatively higher with application of mineral N fertilizer due to better supply of N at tasseling and at cob filling stages (at 6 and 12 weeks after planting) which are peak periods of demand for N in maize (Keating et al. 1991).

Labour productivity of improved fallows with different legume residue management practices

Labour productivity is among the key factors that may determine the adoption of legume technology by smallholder farmers. In this study, labour productivity was poor under residue removed and residue incorporated treatments compared with weedy fallow and mineral N fertilizer (Table 8). This is because of the extra labour required to establish and weed legumes, and remove or incorporate residues into the soil. On the other hand, mulched residues gave higher labour productivity than other types of residue management. This is because mulch suppressed weeds and reduced the labour required for weeding of maize. Our results are in agreement with the findings by Roger (1995), although his work was done in rice production systems and with different legume species. These results suggest that the entry point of legumes into smallholder farms should not only focus on improving soil fertility. Other immediate farmer problems which can be solved by planting of legumes e.g. labour in land preparation and weeding could lead to wider adoption of legumes as was the case with mucuna in Benin (Versteeg and Koudokpon, 1990).

Conclusions

Enhancement of legumes establishment with application of small doses of FYM can improve their biomass and N accumulation, and when used as green manure they can improve the fertility of degraded soils, compared with unamended legumes and weedy fallow of the same duration. It was shown that application of legume residues at rates above 4–6 Mg ha^{-1} may not result in further substantial yield increment, and also that the contributions from legume roots are less important in the short term. Measurable improvements in soil productivity can be achieved in smallholder farms when mucuna residues are used as mulch as it impedes the growth of weeds, improves soil water conservation and supplies nutrients to crops when decomposing. The observations made from this study raise the need for more flexible guidelines on use of plant residues, which take into account not only the plant quality characteristics (as proposed in the decision guide for use of plant resources) but also the agroecological conditions, labour availability and labour productivity.

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References

Baijukya F.P. 2004. Adapting to changes in banana-based farming systems of Northwest Tanzania. The potential role of Herbaceous Legumes. Doctoral Thesis, Wageningen University, the Netherlands.

Baijukya F.P. and de Steenhuijsen Piters B. 1998. Nutrient balances and their consequences in the banana-based land use systems of Bukoba District, Northwest Tanzania. Agric. Ecosyst. Environ. 71: 147–58.

Bandyopadhay P.K. 2003. Farmyard manure, lime and magnesium induced yield of jute *(Chorchorus caspuralis L.)* and nutrient availability in acid soils of eastern India. Food, Agric. Environ. 1: 194–196.

Cobo J.G., Barrios E., Kass D.C.L. and Thomas R. 2000. Nitrogen mineralization and crop uptake from surface applied legume leaves of green manure species on tropical volcanic soils. Biol. Fertil, Soils 36: 87–92.

Diels J., Aihou K., Iwuafor E.N.O., Merckx R. and Lyasse O. 2002. Options for soil organic carbon maintenance under intensive cropping in the West-African Savanna. In: Vanlauwe B., Sanginga N. and Merckx R. (eds), Integrated Plant Nutrient Management in sub-Saharan Africa: From Concept to Practice. CAB International, Wallingford, pp. 334–356.

Gilbert R.R. 2000. Best-bet green manures for smallholder maize-based cropping systems of Malawi. In: Ritchie J.M. (eds), Proceedings of the Final Workshop of the Farming System Integrated Pest Management Project, Club Makohola, Mangochi, Malawi. National Resource Institute, pp. 239–255.

Giller K.E. 2001. Nitrogen Fixation in Tropical Cropping Systems, 2nd ed. CAB International, Wallingford.

Giller K.E. 2002. Targeting management of organic resources and mineral fertilisers: Can we match scientist's fantasies with farmer's realities? In: Vanlauwe B., Sanginga N. and Merckx R. (eds), Integrated Plant Nutrient Management in sub-Saharan Africa: From Concept to Practice. CAB International, Wallingford, pp. 155–171.

Giller K.E., Cadisch G., Ehaliotis C., Adams E., Sakala W.D. and Mafongoya P.L. 1997. Building soil nitrogen capital in Africa. In: Buresh R.J., Sanchez P.A. and Calhoun F. (eds), Replenishing Soil Fertility in Africa. SSSA Special Publication No. 51. SSSA, Madison, WI, pp. 151–192.

Hartemink A.E., Buresh R.J., van Bodegom P.M., Braun A.R., Jama B. and Janssen B.H. 2000. Inorganic nitrogen dynamics in fallows and maize on an Oxisol and Alfisol in Kenya. Geoderma 98: 11–33.

Houngnandan P., Sanginga N., Okogun A., Vanlauwe B. and van Cleemput O. 2001. Assessment of soil factors limiting growth and establishment of mucuna in farmer's fields in the derived savanna of Benin Republic. Biol. Fertil. Soil 33: 416–422.

Hungria M. and Vargas M.A.T. 2000. Environmental factors affecting N_2-fixation in grain legumes in the tropics, with emphasis on Brazil. Field Crops Res. 65: 151–164.

Iwuafor E.N.O., Aihou K., Jaryum J.S., Vanlauwe B., Diels J., Sanginga N., Lyasse O., Deckers J. and Merckx R. 2002. On-farm evaluation of the contribution of sole and mixed application of organic matter and urea to maize grain production in the Savannah. In: Vanlauwe B., Sanginga N. and Merckx R. (eds), Integrated Plant Nutrient Management in sub-Saharan Africa: From Concept to Practice. CAB International, Wallingford, pp. 185–197.

Keating B.A., Godwin D.C. and Waitiki J.M. 1991. Optimizing nitrogen input in response to climatic risk. In: Muchow R.C. and Bellamy M. (eds), Climatic Risk in Crop Production Models and Management in the semi-arid Tropics and sub-Tropics. CAB International, Wallingford, pp. 329–355.

van de Kop P.J. 1995. The Role of Cattle in Nutrient Fluxes of the Banana-based Agro-ecosystem of Bukoba District, Tanzania. MSc thesis, Department of Agronomy/Department of Soil Science and Plant Nutrition, Wageningen Agricultural University, Wageningen.

Landon R. 1991. Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the

Tropics and Subtropics. Booker Tate, Longman Scientific & Technical Publishers, Harlow, UK.

Mafongoya P.L., Giller K.E. and Palm C.A. 1998. Decomposition and nitrogen release patterns of tree prunings and litter. Agrofor. Syst. 38: 77–97.

Murphy J. and Riley J.P. 1962. A modified single solution of the determination of phosphate in natural waters. Anal. Chem. Acta 27: 31–36.

Nkuba J.M. 1997. The diversity of the Bukoban Farming System and its household typology. MSc thesis, Department of Agriculture, University of Queensland.

Okalebo J.R., Gathua K.W. and Woomer P.L. 1993. Laboratory Methods of Soil and Plant Analysis. A Working Manual, TSBF, Nairobi.

Page A.L., Miller R.H. and Keeney D.R. 1982. Methods of Soil Analysis, Part 2. Soil and Microbiological Properties, 2nd ed. American Society of Agronomy, Madison, Wisconsin, USA.

Palm C.A., Gachengo C.N., Delve R.J., Cadisch G. and Giller K.E. 2001. Organic inputs for soil fertility management in the tropical agroecosystems: application of an organic resource database. Agric. Ecosyst. Environ. 83: 27–42.

de Ridder N. and van Keulen H. 1990. Some aspects of the role of organic matter in sustainable intensified arable farming systems in the West-African semi-arid tropics (SAT). Fert Res. 29: 299–310.

Roger P.A. 1995. Biological N_2-fixation and its management in wetland rice cultivation. Fert. Res. 42: 261–276.

Sanchez P.A. 2002. Soil fertility and hunger in Africa. Science 295: 2019–2020.

Touber L. and Kanani J.R. 1994. Land forms and soils of Bukoba District. Bukoba District Council, Bukoba District Rural Development Programme, Bukoba, Tanzania.

von Uexküll H.R. and Mutert E.W. 1994. Rehabilitation and lasting improvement of degraded land in Indonesia. In: Giessener Beitrage zur Entwicklungsforsohung. Zentrum Tropeninstitut, Giessen, Germany, pp. 47–65.

Vanlauwe B., Wendt J. and Diels J. 2001. Combined application of organic matter and fertiliser. In: Tian G., Ishida F. and Keatinge J.D.H. (eds), Sustaining Soil Fertility in West Africa. SSSA Special Publication no. 58, Soil Science Society of America, Madison, Wisconsin, USA, pp. 247–279.

Versteeg M.V. and Koudokpon V. 1990. Mucuna helps control imperata in southern Benin. WAFSRN Bull. 7: 7–8.

Vine H. 1953. Experiments on the maintenance of soil fertility at Ibadan, Nigeria, 1922–1951. Emp. J. Exp. Agric. 12: 65–85.