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In-situ mineral nitrogen following soil incorporation *Crotalaria grahamiana* and *Mucuna pruriens* biomass and financial benefits of legume short-fallow in Eastern Uganda

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Abstract

Improved fallows have been promoted in Uganda as alternative soil fertility management options to enhance sustainable land management. The major contribution of improved is through biological nitrogen fixation and high quality soil organic matter. An on-farm study was conducted in eastern Uganda to determine the mineral nitrogen contribution of improved fallow and the consequent increased in maize yield and economic benefits to the farmers. Improved fallow of *Crotalaria grahamiana* (Sunhemm) and *Mucuna pruriens* (Velvet bean) were studies because they have gained dominance amongst smallholder farmers in Uganda. The short-duration *C. grahamiana* and *M. pruriens* fallows were compared to farmers' practices of natural vegetation fallow, compost manure and continuous cropping. It was noted that *C. grahamiana* and *M. pruriens* fallow significantly ($p<0.05$) increased soil mineral N at Site 1 at end of fallowing, then a week and the fifth week after incorporating the biomass ($p< 0.05$). Maize yield significantly increased ($p<0.05$) following improved fallows subsequently positively responded to supplement doses of inorganic fertilizer at 60 kg N ha^{-1}. However, high varied and opportunity costs of improved fallows reduced their profitability ($p <0.001$). Consequently, continuous cropping with application of inorganic fertilizer at a rate 60 Kg N ha^{-1} was cost effective with the marginal rate of return of 156% and 65% at Sites 1 and 2, respectively. Therefore, improved fallowing is only a viable soil fertility management option in low income subsistence farming systems.

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Introduction

There is low crop and pasture production in Sub Saharan Africa majorly constrained by poor soil fertility and yet declining nutrients in the soil. It is no longer in dispute that low soil fertility is one of the major factors contributing to poverty and food insecurity in Africa. The consequence has been many smallholder farmers in sub Saharan Africa are retained in the vicious cycle of poverty as they depend on agriculture for their livelihood. Indeed crop yield gaps as result of low soil inputs have been closely linked with household poverty in Africa (Tittonel and Giller, 2013). For instance, average crop yield from farmers' fields is less than 30% of expected potential. Sanchez *et al.* (1997) observed that soil fertility decline is a fundamental biophysical constraint responsible for the declining *per capita* food production in Africa.

Nitrogen is the most limiting nutrient to crop production in sub-Saharan Africa and is being depleted at faster rates that replacement (Sanchez *et al.*, 1997) resulting in negative balances across most farming systems. Soil depletion and degradation are highlighted as the major causes of famine and poverty in sub Saharan Africa (IDRC, 1999). It was estimated that N is depleted at 130 kg compared to 5 kg P and 25 kg K ha^{-1} yr^{-1} in the East African highlands (Smaling *et al.*, 1993). At the local level in Uganda, Wortmann and Kaizzi (1998) estimated negative nutrient balances of N, P and K on small-scaling farming systems in eastern Uganda, especially under annual cropping land use types attributed to removal of harvest and soil erosion. Annual crops land use types occupy over 75% of cultivated land in Uganda dominated by cereals then legumes. Fertiliser use is rated at about 1.7 kg of nutrient (NPK) per hectare per year by 2013 declining from 2.1 kg in 2009 (World Bank, 2014). Low fertilizer use attributed to subsistence characteristic of farmers that cannot afford the cost to meet crop fertilizer requirement. This indicates that mineral fertilizer use by many subsistence farmers is insufficient to meet the N demands by the crops. This situation may not suddenly change even if the governments were to intervene because of limited national resources. For instance, the New Partnership for Africa's Development (NEPAD) Abuja declaration of 2006 to increase fertilizer use to 50 $Kgha^{-1}$ has not been realized even half-way by 2014 in most sub-Saharan nations. Furthermore, there is low quantity and quality of plant and animal manure (Esilaba *et al.*, 2005), which would be cheaper alternative soil inputs at farm level, signaling an alarming trend of nutrient depletion. Therefore, most farming systems in SSA are not sustainable exacerbating the low livelihood opportunities of farmers. The population density is very high in the agricultural productive areas of Africa leading to small farm sizes, which are continuous cultivated. Alternative soil fertility management options have to be sought such as green manures in short fallows.

One potential strategy to improve soil fertility and ameliorate N limitation in systems with minimal use of inorganic fertilisers is use of fast growing N fixing legume species as short duration fallows. Improved short duration fallow with panted leguminous plants that enhance biological nitrogen fixation is one option of the low cost input practices for sustainable soil fertility management (Gentile *et al.*, 2010). Biological nitrogen fixation is estimated to contribute 25 – 280 kg N ha^{-1} yr^{-1} depending on the species (Sanchez *et al.*, 1997). *In-situ* growth and decomposition of the legume biomass releases ammonium and subsequently, nitrate in the soil solution, which are the form nitrogen nutrient is taken up by plants. Rotation of fast growing N fixing tree legumes with cereals increased yield in the N limiting soils of southern Africa (Kwesiga *et al.*, 1999; Masikati *et al.*, 2014) but there are species variation in quantity of N added (Barrios *et al.*, 1997). Earlier, van Noordwijk *et al.* (1995) noted that short-duration fallow legumes increased yields of subsequent crops compared to natural vegetation fallows and continuous cropping systems. Improved fallow has been adopted in several countries in sub-Saharan Africa for improved soil fertility management and nematode control (Desaeger and Rao, 2000; Kiptoi *et al.*, 2007; Nezomba *et al.*, 2010). Higher returns to labour and land have been reported in Western Kenya and Zambia following improved fallows of *C. grahamiana*, *T. vogelii* and *S. sesbans* respectively (Place *et al*., 2000 unpublished; De Wolf *et al*., 2000 unpublished). However, because of variations in costs and prices, the benefits may differ in other regions.

Elsewhere, potential *M. pruriens* and *C. grahamiana* have been demonstrated. A six-month fallow of *M. pruriens* increased maize yield equivalent to 120 kg N ha^{-1} in Cameroon (Sanginga *et al*., 1996). Relatedly, *C. grahamiana* fallow in Western Kenya resulted in more maize yield than following a natural fallow and continuous cultivation (De Wolf *et al*., 2000 unpublished). Additionally, legume fallows have other positive attributes on soil through increasing organic matter, uptake of nutrients from lower horizons and amelioration of the physical and biological aspects (Schroth *et al*., 1995; Torquebia and Kwesiga, 1996; Nyamadzawo et al., 2009; Gentile *et al*., 2010). Planted leguminous fallow reduced weed intensity saving the farmers cost of weeding (Chikoye *et al*., 2002; Chikoye *et al*., 2008). Improved fallowing has been listed amongst the sustainable land management technologies that have the potential to sequester greenhouse gas emissions and thus mitigate climate change (Woodfine, 2009). Nevertheless, Sanchez *et al.* (1996) observed that legume fallow systems are not a total solution to N deficiency and recommended mineral fertilizer supplement. Consequently, a study was conducted in eastern Uganda to (i) to determined mineral nitrogen pattern of *C. grahamiana* and *M. pruriens* biomass following short fallows compared to farmers' practices of natural vegetation fallow and compost on the sandy soils to target green manure biomass management and (ii) estimating financial benefits of *C. grahamiana* and *M. pruriens* improved fallow compared to the farmers' practices of natural fallow, compost manure and continuous cropping.

Materials and methods

Site description

On-farm researcher-managed experiments were conducted for three seasons on two farm sites located in Osukulu and Kisoko sub-counties, respectively of Tororo District in eastern Uganda. Site 1 was located at GPS coordinates 0° 39/ N, 34° 11/ E, 1193 m above sea level while Site 2 was at 0° 43/ N, 34° 06 / E, 1170 m as. Both sites receive bimodal rainfall between 1000 and 1500 mm with peaks in March to May and October to December for the long and short rains, respectively. The selected experimental fields had been under continuous cropping with mainly growing *Z. mays* L., sorghum (*Sorghum agricola* L.), common bean (*Phaseolus vulgaris* L.), and groundnuts (*Arachis hypogaea* L) as the main crops. These fields had no fertiliser application for the previous three years.

At the start of fallow establishment, composite soil samples were taken for physical and chemical properties characterization. The soil properties analysed for were texture, pH, organic carbon, very sandy, low in organic matter, total nitrogen, available phosphorus and exchangeable bases (calcium, magnesium, potassium and sodium) following procedures describe in Okalebo *et al.* (2002). Briefly, texture was determined following the hydrometer method after oxidizing organic matter with H_2O_2 and particle separated in sodium solution and shaking on rotary shaker for 3 hours. The pH was determined in water (1:2.5 w/v) after shaking o rotary shaker for 30 minutes and pH read using a pH meter. Organic carbon was determined by wet oxidation in potassium dichromate under strong sulphuric acid and heated at 150°C for 30 minutes then titrated with ferrous Ammonium sulphate.

Experimental design and management

The experiments were established in 10 m by 5 m plots at both sites during the long rains. The treatments included (i) Continuous cropping, (ii) Natural vegetation fallow, (iii) Compost manure, (iv) *C. grahamiana* and (v) *M. pruriens*. These treatments were arranged in a randomized complete block design (RCBD) with four replicates at both sites. Treatments (i) to (iii) were the common farmers' practices and represented controls to the improved fallow species. No soil inputs were used in the first and second season. Table 1 summarizes the protocol of the experiment.

In season A, all plots were ox-ploughed, finely prepared with a hand hoe and planted to maize (variety Longe 1). The recommended spacing of 0.7 m by 0.3 m was used while maintaining one plant per hole after thinning at two weeks after planting (WAP). Improved fallows were established as relay crop in between maize rows at six WAP and both species were planted at a spacing of 0.7 m by 0.3 m maintaining one per hole after thinning at three WAP the fallow species. The improved fallow seed was inoculated with rhizobia (strain TAL 314) obtained from the Department of Agricultural Production at Makerere University. After harvesting of the maize crop planted in season A, all the above ground maize stover biomass was removed from the plots.

In the second season (Season B), plots for continuous cropping and compost manure treatments were cultivated and planted with the same maize variety as previously described whereas improved and natural fallow were left grow. Defoliator caterpillar (*Amphicallia pactolicus*) a Lepidoptera arctiidae, attached *C. grahamiana* at both sites and was controlled by application of 0.2 kg a.i. ha^{-1} cypermethrin (Ambush) [cyano(3-phenoxyphenyl)-methly 3-(2,2-dichloroethenyl)-2,2-dimethyl cyclopropanecarboxylate]. During this season, compost manure to be used in the third season was prepared using a composting pit method from cattle manure, chicken dropping and *Lantana camara* which were the common materials used by farmers in the locality for compost.

In the third season, (Season C), all the fallows (*C. grahamiana, M. pruriens* and natural vegetation) were cut down. Similarly, all weeds in the fallow and non-fallow plots were slashed down after identifying the common species. Total fresh biomass of planted legume and natural vegetation fallows and weeds were weighed and sub sampled to determine dry matter and total nitrogen. At the same time, compost manure samples were analyzed at World Agroforestry Centre (formerly ICRAF) laboratory in Nairobi to determine total nitrogen using Kjeldahl acid digestion method and moisture content. This information was used to compute the amount of compost manure (on dry basis) to be applied at rate of 60 kg N ha^{-1} (recommended nitrogen rate for maize). In the field, shrubs and weeds were left for one week to wither and leaves fall off. Thereafter, the legume biomass were incorporated into the soil and fields manually prepared to a fine tilth. Concurrently, compost manure was spread and worked into the soil at a rate of 19.1 t ha^{-1} (Site 2) and 10.1 t ha^{-1} at equivalency of 60 kg N ha^{-1} (Site 1).

Soil Sampling for mineral N

Composite soil sample (0 – 15 cm) was taken for each plot using an auger from nine spots at a grid pattern at planting (0 week), 1, 3, 5, 7, 10 and 15 weeks later. Fresh soil samples were put in a polyethylene bags, clearly labeled and stored in cooler boxes and transported within 24 hours to World Agroforestry Centre, Maseno regional research station, western Kenya. On arrival in the laboratory, about 20 g of each sample was extracted in 2N KCl by shaking on a horizontal shaker at 250 oscillations min^{-1}, filtered through a pre-washed Whatman No.5 filter paper and analyzed for ammonium-N and nitrate-N. Ammonium-N was determined from the extract by a salicylate-hypochlorite and calorimetric method (Anderson and Ingram, 1993) and nitrate-N by cadmium reduction and subsequent determination of the nitrite by calorimetric method. The sum of the ammonium-N and nitrate-N constitute the mineral N expressed on a dry soil basis after oven drying the remaining soil sample at 105 ^{o}C for 48 hrs.

Determination of fallow biomass and grain yield

At the beginning of the third season, all fallow were cut down and fresh weight biomass from the entire plot, and a sub sample oven dried at Maseno laboratory and biomass expressed as total dry matter.

At harvest, all cobs from the harvested area were counted and weighed. The cobs were initially sun dried, threshed and yield estimated at 15.5% moisture content before oven drying at 65 °C for 48 hrs to obtain grain yield on dry matter basis reported in this paper.

For financial evaluation of the treatments, costs data on production, labour and seed were collected based on methodology applied by Bashir *et al.* (1997) from Season A through Season C. Labour costs were valued at the wage rate of hired farm labour even where the farmers did the work. Seed and all other inputs were rated at the prevailing market price in the locality. The benefit foregone during fallowing (opportunity cost of fallowing) was rated at the grain yield returns from continuous maize cropping. Gross benefits were computed as a product of maize grain yield and farm gate price. *C. grahamiana* had additional benefits derived from the value of fuel as given by the farmers. An average value of the two farmers was used to minimise over- or under-estimation. Maize yields on an oven-dry basis were used in economic analysis. This was assumed to account for a higher management level in researcher-managed trials as compared with field management by farmers and to correct for any possible yield overestimation in small experimental plots (CIMMYT, 1988). Maize stovers were not utilised by the farmers and therefore, not valued. Biomass of *C. grahamiana, M. pruriens,* natural vegetation and compost were rated at costs of production and composting respectively (Bashir *et al.*, 1998). These included average maize yield foregone, cost of seed, planting labour and pest control.

Data analysis

Above ground biomass production data were subjected to analysis of variance (ANOVA) using Randomized Complete Block Design (RCBD) procedures of Genstat computer statistical program. On the other hand, mineral N and grain yield data were subjected to analysis of variance using the split plot Genstat procedures with the land use system as whole plots and nitrogen rate as sub plots. To determine site effect, general analysis of variance with site included as a factor was done. Least significance difference at 5% was used to compare the means.

For financial benefits, CIMMYT (1988) approach was adopted using partial budget, dominance analysis and marginal rate of return. The opportunity cost of capital of 10% per season was adopted since it is the most commonly used rate for resource-poor smallholder farmers (Hoekstra, 1985). In the partial budget, gross benefits, total costs that varied by treatments and net benefits were computed. Data used for partial budgeting are presented in Table 2. Net benefit was computed as the difference between gross benefit and total costs that varied. Dominance analysis was used to determine treatments with less comparative net benefit. Thereafter a marginal rate of return was calculated to determine the increase in net benefits by investing in the non-dominated treatments. Benefit-cost ratios were also computed to relate the invested cost to benefits from the land use systems.

Results and discussions

Site characterization soil results

The experimental fields had light textured soils, low in organic matter, slightly acidic and deficient in N and P and therefore considered less fertile as shown in Table 3.

Table 1. Maize-fallow rotation cycles experimental layout.

Treatment	*Season A* *(Long rains)*	*Season B* *(Short rains)*	*Season C* *(Long rains)*
Continuous cropping	Maize	Maize	Maize
Compost manure	Maize	Maize	Maize (+ compost)
Natural fallow	Maize + Natural fallow	Natural fallow	Maize
C. grahamiana	Maize + *Crotalaria*	*Crotalaria* fallow	Maize
M. pruriens	Maize + *Mucuna*	*Mucuna* fallow	Maize

Above ground fallow biomass yield

Improved fallows significantly yielded more above biomass than the natural vegetation at Site 1 but at Site 2, *M. pruriens* did not differ from natural fallow. It important to note that *C. grahamiana* yielded more biomass that natural vegetation at both site. However, not all its biomass was incorporated in soil because the hard stems were removed leaving a fraction of soft biomass tissue (Table 4).

Table 2. Data used in the partial budget.

Data	*Value (US $)*
Labour cost	0.59 day $^{-1}$ (1 day = 6 man hours)
Field preparation labour	36 days = 21.2
Field preparation (continuous)	40% field preparation = 8.5
Labour cost for harvesting	1.5 Mg ha^{-1} of maize required to 5 days
Labour for composting	1 Mg compost required 16 days = 9.4
Incorporating compost	1 Mg requires 3 days
Labour for cutting *Crotalaria* fallow	30% of field preparation labour
Labour for cutting Mucuna	40% of preparation labour
Labour for cutting natural fallow	20% of preparation labour
Applying & incorporating urea	20% of planting labour
Price of maize seed	0.71 kg^{-1}
Price of C. grahamiana seed	0.59 kg^{-1}
Price of M. pruriens seed	0.29 kg^{-1}
Cost of pesticide	2.9 L^{-1}
Spraying labour	2.8 L^{-1}
Cost of Urea	14.7 per 50 kg bag
Transport of urea	19.4 (Geoffrey) & 12.94 (Dina)
Price of maize grain	0.09 kg^{-1}
Opportunity cost for fallow	Value of maize obtained in continuous maize when following
Opportunity cost for capital	10% per season
Maize yields	Presented in Table 6 and 7

Table 3. Soil parameters of the experimental sites.

	pH	*OM*	*N*	*Av. P*	*K$^+$*	*Na$^+$*	*Ca^{2+}*	*Mg^{2+}*	*Sand*	*Clay*	*Silt*
Site		%		mg kg^{-1}	cmol kg^{-1}				Texture (%)		
Site 1	6.1	1.8	0.2	9.1	0.4	0.1	10.7	3.12	75	9	16
Site 2	6.0	1.0	0.18	8.12	0.5	0.1	10.1	3.14	85	8	7
Critical values[1]	5.2	6.0	0.20	15.0	0.2		4.00	0.50			

[1] Source: Critical level according to Okalebo *et al.* (1993).

Biomass of *C. grahamiana*, *M. pruriens* and natural vegetation produced during fallowing was greater at Site 1 than at Site 2 possibly due to inherent site-specific variations in soil fertility as shown in Table 3. Both sites were deficient of N and P but Site 1 had more organic matter and less sandy.

Table 4. Above ground fallow biomass yields (Mg ha^{-1}) at Geoffrey and Dina sites.

	Total biomass		*Biomass incorporated*		
	Site 1	Site 2	Site 1	Site 2	LSD* $_{(0.05)}$
C. grahamiana	6.4	3.7	1.6	1.4	
M. pruriens	7.5	2.1	7.5	2.1	1.22
Natural vegetation	4.0	1.9	4.0	1.9	
LSD $_{(0.05)}$	2.2	0.8	2.0	0.8	

Pattern of mineral nitrogen release

Crotalaria grahamiana and *Mucuna pruriens* increased mineral N at Site 1 after fallowing ($p<0.05$), in the first week ($p<0.001$) and the fifth week ($p<0.05$) compared to natural fallow and continuous maize cropping after incorporating the biomass compared to continuous cropping. On the other hand, no significant mineral N increases were obtained at Site 2 at any of the same day samplings. However, significant differences between sampling dates occurred at both sites. Most and least mineral N was registered in the third week 3rd and 15th weeks at both sites respectively (Table 5).

Table 5. Mineral N following the treatment in eastern Uganda (mg kg^{-1}).

		Sampling time (weeks)							
Site	**Treatment**	0	1	3	5	7	10	15	LSD $_{(0.05)}$
Site 1	C. grahamiana	12.68	15.23	18.56	10.50	8.75	11.2	7.47	
	M. pruriens	12.97	13.51	14.49	8.48	9.88	11.7	5.27	
	Natural fallow	6.79	8.51	11.33	6.78	8.23	9.3	4.91	
	Compost manure	7.86	11.36	16.46	6.52	4.97	7.5	5.00	3.91
	Continuous cropping	7.79	9.04	12.03	6.00	5.29	7.7	5.94	
	LSD$_{(0.05)}$	2.51	2.97	NS	1.99	NS	NS	NS	
	F-probability	<0.001	0.001	>0.05	0.002	>0.05	>0.05	>0.05	
Site 2	C. grahamiana	3.37	18.87	19.79	11.42	4.10	7.31	7.02	
	M. pruriens	2.23	15.57	20.90	8.71	4.64	5.72	6.17	
	Natural fallow	2.17	17.97	16.16	10.07	4.10	10.83	7.10	3.26
	Compost manure	1.80	14.04	19.59	8.09	2.87	5.50	5.35	
	Continuous cropping	1.60	15.64	16.62	7.43	4.25	5.00	6.40	
	LSD$_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	
	F-probability	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	

Table 6. Maize grain yield at two sites following improved fallows in Season C.

Main treatments	*N (kg ha^{-1})*	*Maize yield (Mg ha^{-1})*	
		Site 1	Site 2
C. grahamiana	0	4.02	4.15
C. grahamiana	60	4.90	5.12
M. pruriens	0	4.23	3.37
M. pruriens	60	6.07	5.41
Natural fallow	0	2.74	3.11
Natural fallow	60	5.08	5.37
Compost manure	0	2.81	2.65
Compost manure	60	4.82	4.55
LSD$_{(0.05)}$		1.24	1.28

Mineral N pattern and grain yield

The processes of decomposition and mineralization of organic matter in soil release mineral N (NH_4^+ and NO_3^-), which is subsequently taken up by plants. A significant increase in mineral N at Site 1 unlike Site 2 could be attributed to the differences in biomass accumulated and later incorporated in soil (Table 4). Similarly, the higher mineral N observed during first week at Site 1 could be attributed to the fallen litter during fallow (though not quantified). Therefore, more vegetative growth and biomass noted at Site 1 than Site 2 could have had more litter fallen and decomposed by the time of cutting down the fallow explaining the higher mineral N recorded at planting.

The on-set rains at the start of season increased microbial activity to decompose and mineralize organic matter nitrification leading to high concentration of mineral N Earlier, Ikerra *et al.*, (1999) noted than nitrification is more sensitive than ammonification to soil moisture deficit. Ammonification is less sensitive to water stress because the actinobacteria and fungi largely responsible for this process remain active at low water potentials unlike the nitrifying bacteria (Robinson, 1957; Wetselaar, 1968).

Table 7. Maize yield at Site 1 (Mg ha^{-1}).

Main treatment	*N rate*	*Season A*	*Season B*	*Season C*
C. grahamiana	0	1.92	-	4.02
C. grahamiana	60	1.92	-	4.90
M. pruriens	0	1.92	-	4.23
M. pruriens	60	1.92	-	6.07
Natural fallow	0	1.92	-	2.74
Natural fallow	60	1.92	-	5.08
Compost manure	0	1.92	1.10	2.81
Compost manure	60	1.92	1.10	4.82
Continuous cropping	0	1.92	1.10	3.11
Continuous cropping	60	1.92	1.10	4.16
LSD (0.05)				

Table 8. Maize yield at Site 2 (Mg ha^{-1}).

Main treatment	*N rate*	*Season A*	*Season B*	*Season C*
C. grahamiana	0	1.98	-	4.15
C. grahamiana	60	1.98	-	5.12
M. pruriens	0	1.98	-	3.37
M. pruriens	60	1.98	-	5.41
Natural fallow	0	1.98	-	3.11
Natural fallow	60	1.98	-	5.37
Compost manure	0	1.98	1.70	2.65
Compost manure	60	1.98	1.70	4.55
Continuous cropping	0	1.98	1.70	2.65
Continuous cropping	60	1.98	1.70	4.16
LSD (0.05)				

The rate of decomposition hence N release is favored by high tissue concentration of N, low lignin and polyphenols (Palm *et al.*, 1997). Thus, *C. grahamiana* and *M. pruriens* decomposition rates were very fast compared to natural vegetation because of the favorable conditions peaking by the third week indicating the high quality and easy to decompose characteristics. The average tissue totals N for the natural vegetation at Site 1 and Site 2 were 1.42 % and 1.72 %, respectively, yet the critical level is 2.5% (Delve *et al.*, 2000). For example, composition of the natural vegetation at Site 1 included poor quality grasses such as *Cynadon dactylon* and wild sorghum that take long to decompose. On the other hand, there were soft herbaceous annual week of *Desmodium intortum, Galinsoga parviflora* and *Bidens pilosa* at Site 2. Therefore, low N release by natural fallow could be due to comparatively wide (polyphenol + lignin): N. On the other hand, *M. pruriens* and *C. grahamiana* have low ligin and polyphenols in their leaves thus decompose faster releasing a substantial proportion of N. The natural fallow with lignified tissue decomposed slowly and could have immobilized soil N reflected in the lower mineral N from natural fallow than continuous cropping (Table 5), which was consistent with Mafongoya *et al.*, (1997). The differences in decomposition rates of various biomass materials explain the observed significant mineral N variation at different sampling dates. On the other hand, insignificant differences in N released among the treatments sampled on the same day could be attributed to plant uptake and N losses especially NO_3^- - N leaching. Therefore, while ease to decompose is very important for nutrient release, it poses a high risk of nitrogen loss from the C. grahamiana and M. pruriens green manure biomass. For instance, a sharp decline in mineral N noted after the third week (Table 5) could have been a result of nitrate leaching following the rains received during the season.

Table 9. Partial budget at Site 2.

Land use system	*C. grahamiana*		*M. pruriens*		*Natural fallow*		*Compost manure*		Continuous maize	
N rate (kg N ha^{-1})	0	60	0	60	0	60	0	60	0	60
Gross benefit (1st season)	174.70	174.70	174.70	174.70	174.70	174.70	174.70	174.70	174.70	174.70
Gross benefit (2nd season)	0	0	0	0	0	0	150.00	150.00	150.00	150.00
Gross benefit (3rd season)	316.30	388.99	240.30	397.79	224.07	381.86	189.02	331.16	194.14	300.37
Total benefits	491.00	563.70	415.01	572.47	398.75	556.56	513.72	655.87	518.85	625.07
Labour cost (1st season)	18.20	18.20	16.47	16.47	0	0	0	0	0	0
Labour cost (2nd season)	2.94	2.94	0	0	0	0	231.80	231.80	52.98	52.98
Labour cost 3rd season)	31.78	57.20	31.54	58.84	28.66	55.97	57.60	65.15	12.77	38.94
Cost of maize seed	0	0	0	0	0	0	21.18	21.18	21.18	21.18
Cost of fallow seed	35.29	35.29	35.29	41.18	0	0	0	0	0	0
Cost of urea	0	38.24	0	38.24	0	38.24	0	38.24	0	38.24
Fallow opportunity cost	150.00	150	150	150.00	150.00	150.00	0	0	0	0
Total cost that varied	238.25	301.90	239.19	304.72	178.66	244.21	310.58	356.37	86.93	151.32
Net benefits	252.77	261.80	175.83	264.75	220.09	312.36	203.14	299.50	410.74	473.74
Benefit: Cost ratio	2.06	1.87	1.73	1.88	2.23	2.28	1.65	1.84	5.97	4.13

Maize yield

Improved fallows increased grain yield maize yield ($p < 0.05$) compared to natural vegetation, compost manure and continuous cropping at both sites (Table 6). Application of N fertiliser resulted in significantly higher yield in all the main treatments except C. *grahamiana* ($p < 0.001$). This implied that C. grahamiana provided sufficient nitrogen reducing contribution of inorganic fertilizer N.

Improved fallows have been reported increased maize yield in subsequent season by contributing nutrient especially nitrogen and high quality organic matter (Buresh and Cooper, 1999). It was further noted that continuous cropping realized 2.6 – 2.8 tha^{-1} of grain yield compared to 4.0 – 4.2 th^{-1} following *C. grahamiana* and 3.4 – 4.2 tha^{-1} from *M. pruriens* (Table 6) indicating great potential of improved fallows in ameliorating soil fertility constraints in low income farming communities.

Economic analysis

Average maize yields of seasons A and B presented in Table 7 and 8 for Site 1 and 2, respectively, were used in economic analysis of the treatments.

Partial budget

Treatments *C. grahamiana, M. pruriens*, compost manure and N fertiliser application significantly increased total varied costs at both sites ($p < 0.001$). In addition, main treatments and sub treatment of N fertiliser interactively increased total variable costs ($p < 0.001$). Compost manure resulted in the highest cost followed by both *M. pruriens* and *C. grahamiana* and the lowest costs were obtained under continuous maize cropping followed by natural fallow (Tables 9 and 10).

Table 10. Partial budget at Site 1.

Land use system	C. grahamiana		M. pruriens		*Natural fallow*		*Compost manure*		Continuous maize	
N rate (kg N ha^{-1})	0	60	0	60	0	60	0	60	0	60
Gross benefit (1st Season)	169.38	169.38	169.38	169.38	169.38	169.38	169.38	169.38	169.38	169.38
Gross benefit (2nd season)	0	0	0	0	0	0	97.06	97.06	97.06	97.06
Gross benefit (3rd season)	461.51	538.97	470.30	632.61	338.96	545.48	248.14	425.14	274.58	426.65
Total benefits	630.89	708.35	639.67	801.98	508.34	714.86	514.58	691.57	541.02	692.09
Labour cost (1st season)	8.24	18.24	16.47	16.47	0	0	0	0	0	0
Labour cost (2nd season)	2.94	2.94	0	0	0	0	145.92	145.92	51.08	51.80
Labour cost 3rd season)	38.88	51.92	34.55	55.49	29.09	51.02	50.05	52.49	14.57	35.26
Cost of maize seed	0	0	0	0	0	0	36,000	21.47	21.18	21.78
Cost of fallow seed	35.29	35.29	41.18	41.18	0	0	0	0	0	0
Cost of urea	0	38.24	0	38.34	0	38.34	0	38.34	0	38.34
Fallow opportunity cost	97.06	97.06	97.06	97.06	97.06	97.06	0	0	0	0
Total cost that varied	186.41	243.68	189.26	248.43	126.15	186.31	211.26	257.82	87.55	146.48
Net benefits	444.48	464.65	450.41	553.55	382.19	528.55	303.32	433.75	453.46	545.61
Benefit: Cost ratio	3.38	2.91	3.37	3.23	4.02	3.84	2.43	2.68	6.19	4.72

On the hand, improved fallows increased total benefits only at Site 2 ($p< 0.05$) while nitrogen fertiliser application significantly increased total benefits at both sites ($p < 0.001$). At this site, compost manure produced the highest and natural fallow the lowest total benefits (Table 9) but improved fallows were better than farmers' practices at Site 1e (Table 10). While applying nitrogen fertiliser increased total benefits of the main treatments, no significant increase was registered under *C. grahamiana* at both sites.

Table 11. Dominance analysis.

Site	*Land use system*	*N rate (kg ha^{-1})*	*Total costs that varied US$ ha^{-1})*	*Net benefits (Ug. Shs ha^{-1})*	Dominance
Site 1	Continuous maize	0	87.55	453.46	
	Natural fallow	0	126.15	382.19	D*
	Continuous maize	60	146.47	545.61	
	Natural fallow	60	186.31	528.55	D
	C. grahamiana	0	186.46	444.48	D
	M. pruriens	0	189.26	450.41	D
	Compost manure	0	211.42	303.32	D
	C. grahamiana	60	243.70	464.65	D
	M. pruriens	60	248.43	553.55	
	Compost manure	60	257.82	433.75	D
Site 2	Continuous maize	0	86.93	410.73	
	Continuous maize	60	151.64	473.74	
	Natural fallow	0	178.66	220.09	D
	C. grahamiana	0	238.25	252.76	D
	M. pruriens	0	239.19	175.82	D
	Natural fallow	60	244.21	312.36	D
	C. grahamiana	60	301.90	261.80	D
	M. pruriens	60	304.72	267.75	D
	Compost manure	0	310.58	203.14	D
	Compost manure	60	356.37	299.50	D

Furthermore, the main treatments significantly increased net benefits only at Site 2 ($p < 0.001$). Paradoxically, continuous maize cropping had highest net benefits than compost manure and fallows (Table 9). Applying nitrogen fertiliser increased the net benefits at both sites ($p < 0.001$). Continuous cropping had the highest benefit-cost ratio followed by the natural fallow. However, applying nitrogen fertiliser generally reduced the ratio (Tables 9 and 10).

Table 12. Marginal rate of return of non-dominated treatments.

Site	*Treatment*	*N (kg ha^{-1})*	*Total costs that varied (US\$ ha^{-1})*	*Net benefits (US\$ ha^{-1})*	Marginal rate of return (%)
Site 1	Continuous maize	0	87.55	453.46	
	Continuous maize	60	146.48	545.61	156
	M. pruriens	60	248.43	553.55	8
Site 2	Continuous maize	0	86.92	431.92	
	Continuous maize	60	151.33	473.74	65

Dominance analysis indicated that generally continuous cropping with and without inorganic nitrogen fertiliser were the most profitable at both site whereas the other main treatments were dominated indicating that the increase in total cost that varied did not translate to increased net benefits. However, *M.* pruriens was equally profitable at Site 1 (Table 11).

*Treatments marked D in the last column are "dominated"

Marginal rate of return

Benefits of non-dominated treatments as marginal rate of return indicate a high value when shifting from continuous cropping with to without nitrogen fertiliser applied (60 kg n ha^{-1}) at both sites (156% and 65% at Site 1 and 2, respectively). There was also a slight marginal rate of return (8%) between continuous maize with fertiliser and use of *M. pruriens* supplemented with nitrogen fertiliser noted Dina 2 (Table 12).

Conclusion

Improved fallows increased mineral N and grain yields more than farmers' practices (natural fallow, compost manure and continuous cropping) at Site 1 but no effect was noted at Site 2. Thus, where as *C. grahamiana* and *M. pruriens* fallows improved soil fertility hence productivity in this study, more site studies are advisable since there could be a site-specific-fertility constraint. Soil fertility issues are increasingly becoming site specific especially in the subsistence systems where there exists variable soil management practices both in space and time.

Though the farmers would generate profits through use of improved fallows, the use of inorganic fertiliser after continuous cropping resulted in better economic benefits. The increase in yield after improved fallow for one season did not compensate for the extra costs of labour for the seed, planting, management and harvesting the fallow and the missed season, hence dominated. However, benefits of improved fallow biomass could increase after the residual effect in the subsequent season unlike the inorganic fertilisers. Most interesting is that improved fallow technology is more cost effective than compost manure. Realising that continuous cropping is not sustainable and most farmers use compost for fertility management, improved fallow technology should be promoted.

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References

Anderson JM. Ingram JS. 1993. Tropical Soil Biology and Fertility. A Handbook of Methods. Second edition. CAB International, Wallingford, Oxon, UK, 221 p.

Barrios E, Kwesiga F, Buresh RJ, Sprent JI. 1997. Light fraction soil organic matter and available nitrogen fallowing trees and maize. Soil Science Society of America Journal **61,** 826 – 821.

Chikoye D, Ekelembe F, Lum AF, Schulz S. 2008. Legume-maize rotation and nitrogen effects on weed performance in humid and subhumid tropics of West Africa. Crop Protection **27,** 638 – 647.

CIMMYT. 1988. From agronomic data to farmer recommendations: *An economic training manual. Complete revised edition. CIMMYT, Mexico, D.F.*

Delve R, Gachengo C, Adams E, Palm CA, Candisch G, Giller KE. 2000. The Organic Resource Database. In: Report of the Tropical Soil Biology and Fertility Programme TSBF 1997-98, 20 – 22 p.

Desaeger J, Rao MR. 2000. Parasitic nematode populations in natural fallows and improved cover crops and their effects on subsequent crops in Kenya. Field Crops Research **65,** 41 – 56.

DeWolf J, Rommelse R, Pisanelli A. 2000. Adoption of improved fallow technology in western Kenya: potential and reception by farmers. *International Centre for Research in Agroforestry, Nairobi (mimeo).*

Esilaba AO, Byalebeka JB, Delve RJ, Okalebo JR, Ssenyange D, Mbalule M, Ssali H. 2005. On farm testing of integrated nutrient management strategies in eastern Uganda. Agricultural Systems **86,** 144 – 165.

Gentile R, Vanlauwe B, Kavoo A, Chivenge P, Six J. 2010. Residue quality and N fertiliser do not influence aggregate stabilization of C and N in two soils with contrasting texture. Nutrient Cycling in Agroecosystems **88,** 121 – 131.

Hoestra DA. 1985. Choosing the discount rate of analysing Agroforestry systems/technologies from private viewpoint. Forest Ecology Management **10,** 177-183.

IDRC. 1999. Cover Crops: Improving soil fertility in Africa. Website http://www.idrc.ca/reports

Ikerra ST, Maghembe JA, Smithson PC, Buresh RJ. 1999. Soil nitrogen dynamics and relationships with maize yields in a *Gliricidia*-maize intercrop in Malawi. *Plant and Soil 00: 1 – 10.* Kluwer Academic Publishers. Printed in the Netherlands.

Jama B, Roland J. Buresh RJ, Place F. 1998. *Sesbania* trees fallow on phosphorus deficiency sites: Maize yield and financial benefits. Agronomy Journal **90,** 717 – 726.

Jama B, Swinkels RA, Buresh RJ. 1997. Agronomic and economic evaluation of organic and inorganic sources of phosphorus in western Kenya. Agronomy Journal **89,** 597 – 604.

Kiptot E, Hebinck P, Franzel S, Richards P. 2007. Adopters, testers or pseudo-adopters? Dynamics of the use of improved tree fallows by farmers in western Kenya. Agricultural Systems **94,** 509 – 519.

Kwesiga F, Franzel S, Place F, Phiri D, Simwanza CP. 1999. *Sesbania sesban* improved fallows in Eastern Zambia: Their inception, development and farmer enthusiasm. Agroforestry systems **47,** 49-66.

Mafongoya PL, Giller KE, Palm CA. 1997. Decomposition and nitrogen release pattern of tree prunings and litter. Agroforestry Systems **38,** 77 – 97.

Masikati P, Manschadi A, van Rooyen A, Hargreaves J. 2014. Maize–mucuna rotation: An alternative technology to improve water productivity in smallholder farming systems. Agricultural System **123,** 62 – 70.

Nezomba H, Tauro TP, Mtambanengwe F, Mapfumo P. 2010. Indigenous legume fallows (indifallows) as an alternative soil fertility resource in smallholder maize cropping systems. Field Crops Research **115,** 149 – 157.

Nyamadzawo G, Chikowo R, Nyamugafata P, Giller KE. 2007. Improved legume tree fallows and tillage effects on structural stability and infiltration rates of a kaolinitic sandy soil from central Zimbabwe. Soil and Tillage Research **96,** 182 – 194.

Palm CA, Myers RJK, Nandwa S. 1997. Combined use of organic and inorganic nutrients for soil fertility maintenance and replenishment. *In:* R.J. Buresh, P.A. Sanchez and F. Calhoun (eds.) Replenishing soil fertility in Africa. SSSA Special Pub. No. 51, Madison, Wisconsin, 193 – 218 p.

Place F, Franzel S, DeWolf J, Rommelse R, Kwesiga F, Niang A, Jama B. 2000. Agroforestry for sol fertility replenishment: Evidence on adoption process in Kenya and Zambia. A paper presented at the workshop on understanding adoption process for natural resource management practices in sub-Saharan Africa, held at ICRAF Hq, 3rd –5th July 2000.

Robinson JBD. 1957. The critical relationship between soil moisture content in the region of wilting point and mineralisation of natural soil nitrogen. Journal of Agricultural Sciences **49,** 100 – 105.

Sanchez PA, Izac AM, Valencia IM, Pieri C. 1996. Soil fertility replenishment in Africa. In: Breth, S.A. (ed) Achieving greater impact from research investment in Africa. Mexico city; Sasakawa Africa Association. 200 – 208 p.

Sanchez PA, Shepherds KD, Soule MJ, Place FM, Buresh RJ, Izac AMN, Mokwunye AU, Kwesiga FR, Ndiritu CG, Woomer PL. 1997. Soil fertility replenishment in Africa: An investment in natural resource capital. In: R.J. Buresh, P.A. Sanchez and F. Cachoun (Eds.). Replenishing soil fertility in Africa. SSSA special publication No. 51. Soil Science Society of America, Madison, Wisconsin, USA. 1 – 46.

Sanginga N, Ibewiro B, Houngnandan P, Vanlauwe B, Okugun JA. 1996. Evaluation of symbiotic properties and nitrogen contribution of *Mucuna* to maize growth in the derived savannas of West Africa. Plant and Soil **179,** 119-129.

Schroth G, Kolbe D, Pity B, Zech W. 1995. Searching for criteria for selecting efficient tree species for fallow improvement with special reference to carbon and nitrogen. Fertiliser research **42,** 297 – 314.

Smaling EMA, Stoorvogel JJ, Windmeijer PN. 1993. Calculating of soil nutrient balances in Africa at Different Scales. II District Scale. Fertiliser Research **35,** 237 - 250.

Tittonell P, Giller KE. 2013. When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. Field Crops Research **143,** 76 – 90.

Torquebiau EF, Kwesiga F. 1996. Root development in a *Sesbania sesban* fallow – maize system in Eastern Zambia. Agroforestry systems **34,** 193 – 211.

Van Noordwijk M, Sitompul SM, Hairiah K, Listyarini E, Syekhfani LMS. 1995. Nitrogen supply from rotational or spatially zoned inclusion of Leguminosae for sustainable maize production on an acid soil in Indonesia. In: R.A. Grudon, N.J. Rayment, G.E and Probert, M.E. (eds.) Plant – Soil interactions at low pH. Kluwer, Dordrrecht, Netherlands, 779 – 784.

Wetselaar R. 1968. Soil organic nitrogen mineralisation as affected by low soil water potential. Plant Soil **29,** 9 – 17.

World Bank. 2014. Fertiliser consumption (Kg per hectare of arable land). Accessed on 18th April 2014.

Wortmanna CS, Kaizzi CK. 1998. Nutrient balances and expected effects of alternative practices in farming systems of Uganda. Agriculture, Ecosystems and Environment **71,** 115 – 129.