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Legume Cover Crops are More Beneficial than Natural Fallows in Minimally Tilled Ugandan Soils

Drake N. Mubiru and Mark S. Coyne*

ABSTRACT

It is important to establish the various effects of legume cover crops on soil physicochemical properties because they have been considered for use as improved fallows (with shorter rest periods) to enhance development and maintenance of soil productivity. Our objectives were to assess: (i) aboveground dry matter yields of legume cover crops; and (ii) cover crop effects on weed infestation and soil physicochemical properties in a minimum tillage management system. Trials were conducted for 2 yr at Kawanda Agricultural Research Institute and on farmers' fields in Mbale and Pallisa districts, eastern Uganda. The experiment layout was a Randomized Complete Block Design (RCBD) in a split-plot arrangement with four replications. Natural and improved fallows were established in the second cropping season of 2004. Cover crops used in the improved fallows included mucuna [*Mucuna pruriens* (L.) DC.var. utiliz], Dolichos lablab (*Lablab vulgaris* Savi cv. Rongai), canavalia [*Canavalia ensiformis* (L.) DC.], and crotalaria (*Crotalaria paulina* Schrank). The fallows were reestablished in the same plots in the second cropping season of 2005 after maize (*Zea mays* L.). Canavalia yielded significantly more dry matter than the other fallows regardless of year or site. With an average yield of 169 kg N ha^{-1} canavalia accumulated significantly more N than the other fallows; all improved fallows produced significantly more N than the natural fallow. Canavalia also accumulated significantly more P than the other fallows; all improved fallows, with the exception of crotalaria, accumulated more P than the natural fallow. There was no significant change in soil physicochemical properties by the improved fallows. All effects considered, improved fallows were more beneficial than natural fallow. A significant improvement in soil physicochemical properties using legume cover crops might be possible, though it may require more than the two cropping cycles used in this study of degraded soils.

One of the main biophysical causes of declining per capita food production in much of sub-Saharan Africa is soil fertility decline on smallholder farms (Sanchez et al., 1997). Food production has not kept pace with the regional average 3% population growth rate per year. The rapid population growth has led to intensive and extensive land cultivation to support daily food and fiber needs. Consequently, fragile and marginal lands have been progressively encroached upon (Bojo, 1996), even against technical advice. Furthermore, continuous land cultivation for crop production without external inputs, and removal of crop residues (Sanchez et al., 1997; Wortmann and Kaizzi, 1998), have replaced the traditional fallow systems that were previously used to rejuvenate soil fertility and maintain sustainable food production (Nandwa and Bekunda, 1998). As a result, large areas have undergone serious soil physical, biological, and chemical deterioration (FAO, 2000) leading to declining soil productivity.

For Uganda in particular, soil productivity decline is evident across the country and manifest in N and P deficiencies (Bekunda et al., 1997) and extremely low crop yields. Agriculture in Uganda, as is the case with the rest of sub-Saharan Africa, is characterized by continuous cultivation without external inputs, nutrient mining, poor soil and water conservation, and low inherent soil fertility (Ssali et al., 1986) among other factors. Nutrient loss through crop harvest (mining), leaching, and erosion far exceeds nutrient inputs from fertilizers, atmospheric deposition, and biological nitrogen fixation (Smaling and Braun, 1996). This imbalance has led to deficiencies in essential plant nutrients (Bekunda et al., 1997; Wortmann and Kaizzi, 1998).

Farmers are unable to compensate for the losses by using inorganic fertilizers due to high costs, which are attributed to high freight charges because Uganda is landlocked (Wejuli et al., 2001) and farmers' insufficient knowledge of fertilizer forms, methods of use, and the potential benefits accruing from their use (Bekunda et al., 1997). Relying on crop residues for agricultural production is not sustainable among smallholder farmers. Such farmers are unable to compensate for the nutrient losses due to the demand for manure and crop residues as fuel and fodder (Palm et al., 1997) and the sheer volumes required to meet the need of crops.

Conservation agriculture (CA) in the form of minimum tillage and maintenance of a soil cover has led to sustainable land productivity in the Americas (Bwalya and Friedrich, 2002) but has not been adequately exploited in Africa (Lal, 1986); yet it

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Abbreviations: CA, conservation agriculture; masl, meters above sea level; RCBD, Randomized Complete Block Design; SOM, soil organic matter.

can be a remedy for soil fertility problems on the continent. The major benefits associated with minimum tillage include, but are not limited to, minimal disruption of soil structure, hence, optimizing infiltration and maintenance of higher levels of organic matter, ensuring soil health, and promoting soil fauna biodiversity and microbial activities (Ferreira et al., 2000). Most soils in Uganda are highly weathered; therefore, inherent fertility is low and soil organic matter is important to maintain good soil physical properties and as the main source of crop nutrients (Ssali and Vlek, 2002).

Maintaining soil cover through the use of legume cover crops (improved fallows) and keeping plant residues on the soil surface preserves and fosters organic matter balances in the soil (Dick, 1982; Calegari, 1998). Improved fallow is a green-manure farming system that is used as a partial fallow replacement in a crop-fallow rotation, while natural fallows are overly grass-based. Because agriculture in Uganda is rain-fed, the cropping seasons coincide with the rainy seasons. The rest periods that automatically follow the cropping seasons are the natural fallows. Improved fallows are deliberately established either in pure stands at the beginning of the rainy season and left to grow through the dry season until the beginning of the following rainy season or are planted toward the end of the rainy season, in fields where food crops such as maize are about to be harvested, and left to grow through the dry season until the beginning of the following rainy season, a practice known as relay cropping.

In addition, as part of the production system, cover crops are economically feasible and ecologically sustainable, leading to greater crop productivity, soil and water conservation, and maintenance and recovery of soil fertility (Calegari, 2001). Furthermore, legume cover crops promote economy with nitrogenous fertilizers (Welty et al., 1988; Campbell et al., 1991, 1992), and greater biological balance in the soil (Calegari, 2001), thus decreasing the effects of pests and diseases.

These parameters are essential in maintaining soil productivity especially under resource poor and smallholder conditions. However, there is still need to evaluate the conservation agriculture system, especially the various effects of legume cover crops, and to ascertain their benefits to agricultural production systems in the local environment. The objectives of this study were to: (i) assess aboveground dry matter yields and nutrient accumulation of legume cover crops; and (ii) assess the effect of legume cover crops on weed infestation and soil physicochemical properties in a minimum tillage management system.

MATERIALS AND METHODS

Location Characteristics

Trials were conducted between 2004 and 2006 at Kawanda Agricultural Research Institute and in two rural parishes, Petete, Pallisa district and Busiu, Mbale district, in eastern Uganda. Kawanda, is located 0°25′05″ N and 32°31′54″ E at 1190 meters above sea level (masl), average rainfall is 1224 mm per annum. Petete is at 1071 masl with an average rainfall of 1000 mm per annum. Busiu is at 1215 masl and average rainfall is 1191 mm per annum. Each site has two rainfall seasons: long rains last from March to June while short rains last from September to November. Dry seasons-December to February and July to August are characterized by none to few low intensity isolated showers (Fig. 1A) and higher maximum temperatures (Fig. 1B).

The soils from the research sites were sandy, with sand contents ranging from 560 to 830 g kg^{-1} (Table 1). Soil from the trial field at Kawanda Agricultural Research Institute was a sandy clay. Soil from Pallisa was a sandy loam. Soil from Mbale was a loamy sand. The soil textures are typical for these areas (Ssali, 2000).

Farmer Selection and Experiment Design

Lists of farmers were obtained from Local Council 1 chairpersons and, with assistance from field extension officers, farmers were stratified on the basis of landholding size, food and cash crops grown, and intensity of soil and water conservation. Four farmers with almost equal landholdings and similar management practices were selected from each parish. The experiment layout was a RCBD in a split-plot arrangement with four replications. Fallow management was the main plot and the fallows were the subplots. The fallows were managed in preparation of the following cropping season either by slashing or by herbicide application (50% glyphosate [*N*-(phosphonomethyl) glycine]) at 3 L ha^{-1}. Slashing involved cutting the aboveground dry matter as close to the soil surface as possible and allowing the dry matter to settle on the soil surface.

Improved fallows in pure stands and a natural fallow were established in 4 by 4 m subplots during the short rains of 2004. Cover crops used in the improved fallows included mucuna, lablab, canavalia, and crotalaria. All improved fallows were seeded at a spacing of 75 by 60 cm. The seeds were hand-planted using a sharp stick to pierce the soil surface, allowing for minimum soil disturbance. The fallows were reestablished in the same plots in the second cropping season of 2005 after a crop of maize.

Data Collection and Analysis

A baseline soil analysis was performed by taking soil samples from the 0- to 20-cm depth from each trial field. The samples were dried in open air, ground to pass a 2-mm sieve, and analyzed according to Foster (1971) and Okalebo et al. (2002). Texture analysis was performed using the hydrometer method (Blake and Hartge, 1986b). Soil pH was measured using a soil/water ratio of 1:2.5. Extractable P, K, and Ca were measured in a single ammonium lactate–acetic acid extract buffered at pH 3.8 (Okalebo et al., 2002). Total N was determined using a micro-Kjeldahl block digestion apparatus, and soil organic matter was determined by acid-dichromate digestion. Soil samples were also collected at the end of each fallow period and analyzed as above. After one season of fallow, soil samples were collected using a double-cylinder, hammer driven core sampler to determine bulk density (Blake and Hartge, 1986a).

At the fallow flowering stage, a 0.25-m^2 quadrant placed at four random positions within each plot was used to determine the accumulated aboveground dry matter. Plant samples were dried in an oven at 70°C, ground to pass a 0.5-mm sieve, and analyzed for Ca, Mg, K, P, and total N by wet oxidation (Parkinson and Allen, 1975). Phosphorus was

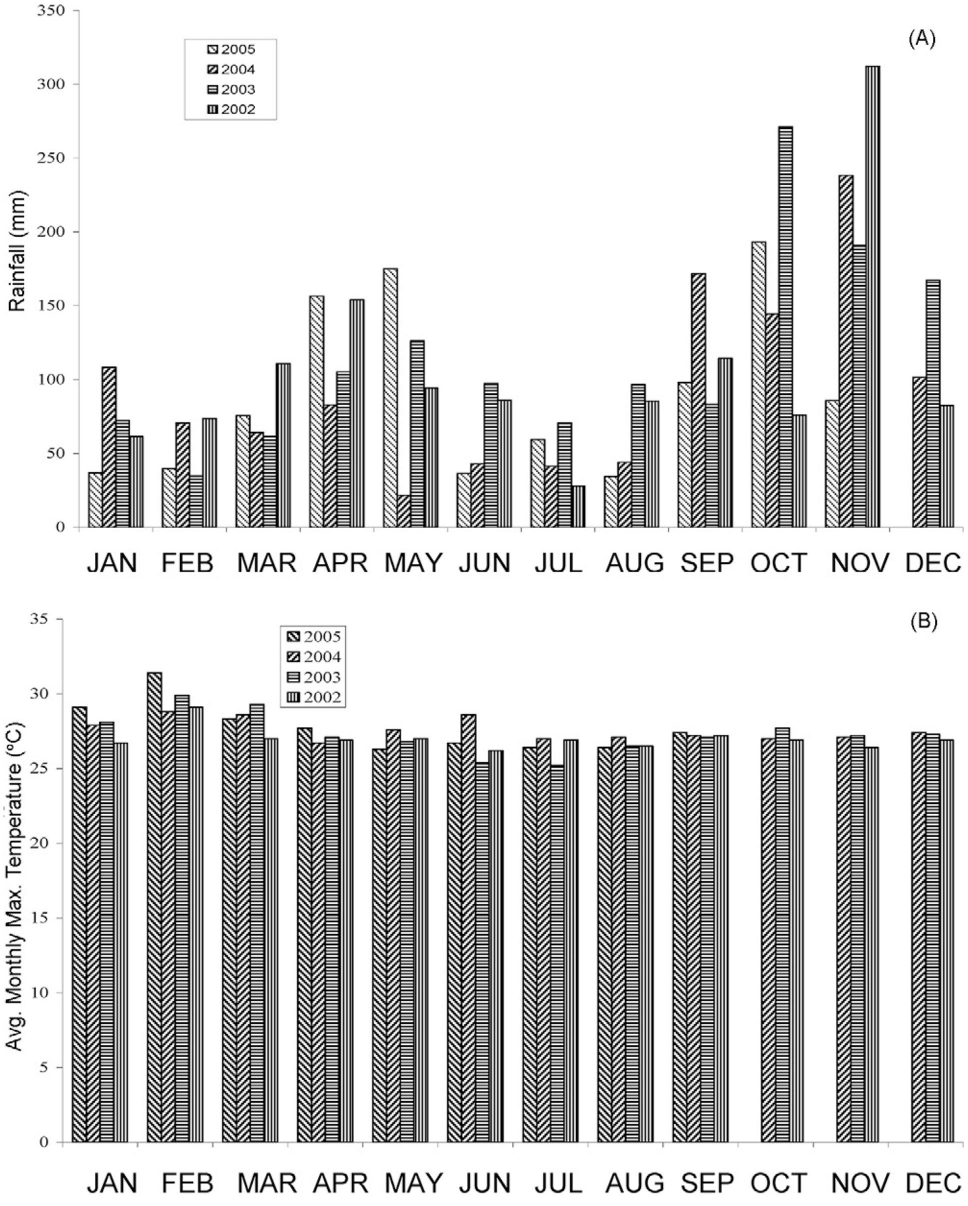

Fig. 1. Mean monthly (a) rainfall and (b) maximum temperature at Kawanda from 2002 to 2005.

determined colorimetrically, and K was determined by flame photometry (Okalebo et al., 2002).

Weeds

Weed densities were determined by counting all weed species enclosed in a 0.25-m^2 quadrant placed at three random positions within each subplot. Individual weed species were counted separately to establish the percentage of particular weed species per quadrant. The weeds were counted 3 wk after the fallows had either been slashed or sprayed with herbicide. Plant specimens were collected, labeled, pressed, and dried for identification at Makerere University herbarium.

Statistical Analysis

Data was examined by ANOVA to determine significant ($P < 0.05$) site, management, and fallow effects and treatment interactions. For variables in which significant treatment interactions were detected, ANOVA was performed on data within each site or management system. Comparison of means were made by LSD all-pair-wise comparisons. All analyses were done using Statistix V. 2.0 (Statistix for Windows, 1998).

RESULTS AND DISCUSSION

Baseline Soil Physicochemical Properties

Soil organic matter (SOM) was below a critical value of 3.0% at all three sites (Table 1). Soil organic matter levels between 3 and 6% are considered adequate for surface soils in Uganda (Foster, 1971), although Foster (1981) demonstrated that a positive response to fertilizer in several crops could occur in soils when organic matter was less than 3.5%. The soil particle-size analysis and SOM results (Table 1) show that Pallisa and Mbale are on lighter soils with less SOM; accordingly the cropping systems in these areas are predominantly annual. Kawanda, which had the highest clay and SOM content, is located in the medium altitude areas with largely perennial cropping systems.

Soil pH at Kawanda was below a critical value of 5.2, while at Pallisa and Mbale it was above the critical value (Table 1). Kawanda is situated in the intensive banana-coffee (*Musa sapientum* L.–*Coffea arabica* L.) lakeshore farming system and

Table 1. Baseline average soil physicochemical properties at the three study sites.

	Site			
Property	Kawanda	Pallisa	Mbale	Critical values†
pH 1:2.5	4.5	5.9	6.4	5.2
SOM, %	2.7	1.6	1.3	3.0
Total N, %	0.12	0.16	0.14	0.20
Extractable P, mg kg^{-1}	2.14	0.52	5.6	5.0
Extractable K, mg kg^{-1}	151	135	142	150
Extractable Ca, mg kg^{-1}	1078	612	652	350
Extractable Mg, mg kg^{-1}	198	228	171	na
Sand, g kg^{-1}	560	730	830	na
Silt, g kg^{-1}	70	80	75	na
Clay, g kg^{-1}	370	190	95	na

† Levels below the critical values are considered to be yield limiting (Foster, 1971); na = not applicable.

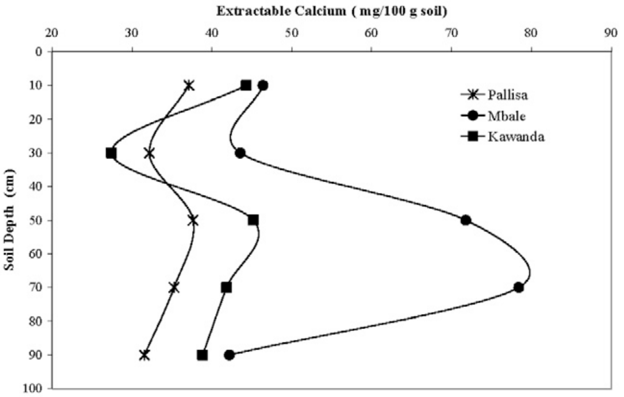

Fig. 2. Variation of extractable calcium with soil depth for soils from Kawanda, Pallisa, and Mbale.

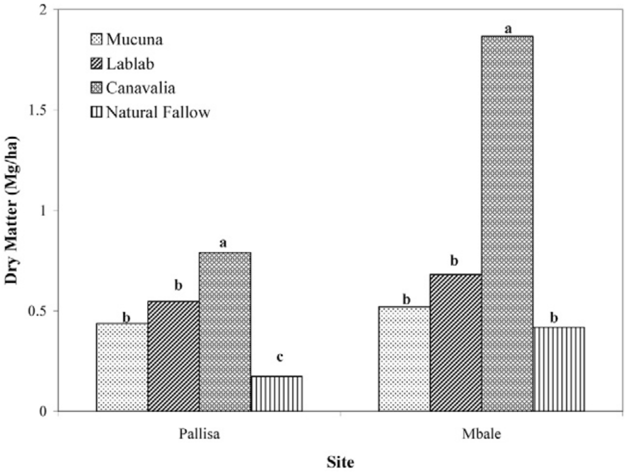

Fig. 3. Fallow aboveground dry matter yield at two of the study sites in 2005. Means are different according to the LSD method ($P < 0.05$) if different letters appear above bars within each site.

many soils in this area have pH levels below the critical value (Ssali and Vlek, 2002; Foster, 1976). The pH trend across the sites observed in this study is attributable to the fact that low-rainfall areas experience little leaching of base-forming cations to lower soil horizons, which results in a relatively high degree of base saturation and pH. However, in more humid areas, such as the medium altitude and along the shores of Lake Victoria, leaching depletes the upper horizon of calcium and other base-forming cations as exhibited in Fig. 2.

On average, all three sites had sufficient extractable Ca according to the critical level (Table 1). Sufficient extractable K was observed at Kawanda only. Sufficient extractable P was observed only at Mbale. All sites had insufficient total N. Most soils in Uganda are characterized by low fertility, mainly N and P deficiencies (Bekunda et al., 1997). However, the soils in Mbale are derived from volcanic ash, and such soils are documented to have high levels of available P (Ssali, 2001). The low levels of K at Pallisa and Mbale are arguably a result of continuous cultivation and/or aboveground plant dry matter removal in harvests or livestock grazing. Plants take up about the same amount of K as N and five to 10-fold as much K as P (Brady and Weil, 1996, p. 479); therefore, continuously cropped soils lose available K more rapidly than other nutrients, which is manifest in large responses to K fertilizers in continuously cropped trials (Ssali, 2001). In addition, the drain on the soil supply of K can be very large if most or all of the aboveground parts are removed in harvest (Brady and Weil, 1996, p. 479). The insufficient levels of N, P, and K pose a major concern, signaling the urgent need for management attention if sustainable crop productivity is to be achieved.

Fallow Aboveground Dry Matter Production

In 2004, there were significant differences in fallow aboveground dry matter yield among sites (Table 2). The mean yield at Pallisa of 4.23 Mg ha^{-1} was significantly higher than that at Mbale (3.41 Mg ha^{-1}) and Kawanda (3.11 Mg ha^{-1}), but differences between Mbale and Kawanda were not significant. Dry matter yield was also significantly different among the fallows. However, there were significant site × fallow interactions; therefore, ANOVA was performed on data within each site (Table 2). At Kawanda and Pallisa, the cavanalia fallow yielded significantly more dry matter than the other fallows, but no other differences were significant. The canavalia fallow also had the highest yield at Mbale, but differences were only significant between canavalia and the natural fallow or lablab. Elsewhere, Aleman and Flores (1993) also observed high aboveground dry matter yield by canavalia, which they attributed to its broad leaves and large sized seedpods.

In 2005, most areas across the country experienced below normal rainfall, and the performance of the fallows was very poor compared with the previous year. At Kawanda, for example, the cumulative rainfall was 991.1 mm, which was 19% below the normal average (1224 mm yr^{-1}).

Consequently, all improved fallows failed at Kawanda, while at Pallisa and Mbale there was total failure of crotalaria. The mean fallow dry matter yield was significantly higher at Mbale than Pallisa (0.84 vs. 0.52 Mg ha^{-1}) (Fig. 3). Dry matter yield was also significantly different among the fallows. Just as in 2004, there were significant site × fallow interactions; therefore, ANOVA was performed on data within each site (Fig. 3). It is worth noting that during the 2 yr of the study (with normal and below normal rainfall) and at all study sites, canavalia yielded the highest dry matter relative to the other fallows. Apparently it was the cover crop most tolerant to drought. Other studies have also reported canavalia to be drought resistant (Bunch, 1993). Crotalaria totally failed across the sites in 2005. It can therefore be safely concluded that it was the least tolerant to drought. Crotalaria is small seeded, and according to Egli (1998) the initial growth rate of a seedling is

Table 2. Fallow aboveground dry matter yield in 2004.†

Fallow	Dry matter yield Kawanda	Pallisa	Mbale
		Mg ha^{-1}	
Crotalaria	2.23b	3.64b	3.89ab
Mucuna	2.80b	3.76b	3.60ab
Lablab	2.85b	3.57b	2.12b
Canavalia	4.99a	8.55a	5.29a
Natural fallow	2.67b	1.62b	2.13b
Mean	3.11b	4.23a	3.41b

† Different letters within each column or row (site means) indicate statistical difference between fallows and sites at $P = 0.05$ level, using the LSD method.

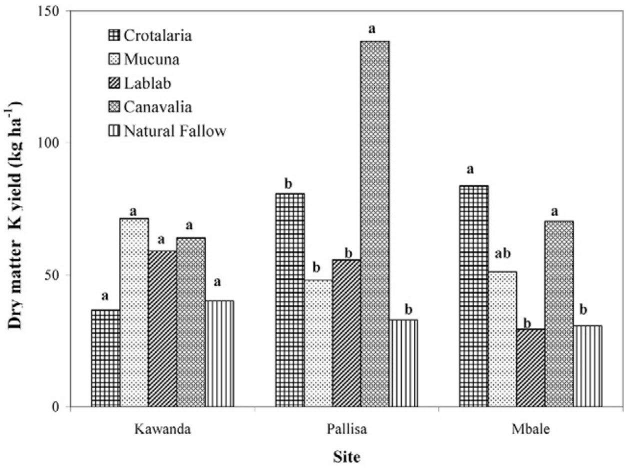

Fig. 4. Fallow aboveground dry matter K yield at the three study sites in 2004. Means are different according to the LSD method ($P < 0.05$) if different letters appear above bars within each site.

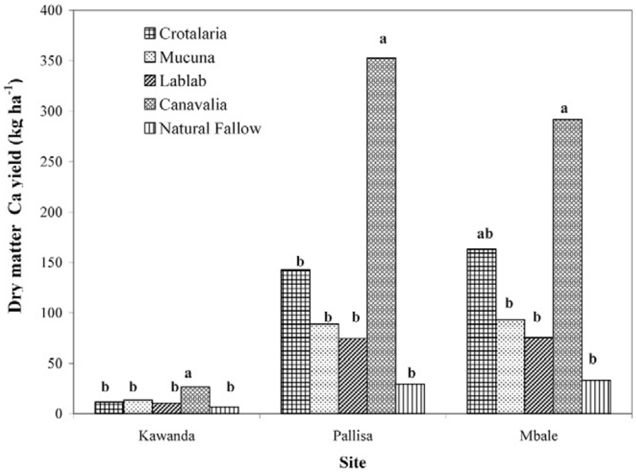

Fig. 5. Fallow aboveground dry matter Ca yield at the three study sites in 2004. Means are different according to the LSD method ($P < 0.05$) if different letters appear above bars within each site.

determined by its seed size. Therefore, under suboptimal conditions, as was the case in 2005, there might have been difficulty in crotalaria establishment. Fischler (1997) also reported difficulty in crotalaria establishment, which he attributed to its small seed size.

Fallow Aboveground Dry Matter Nutrient Accumulation

In 2004, there were no significant site differences in the fallow aboveground dry matter N, P, and K yields. However, significant site differences were observed for Ca and Mg yields. There were also significant site × fallow interactions for K, Ca, and Mg, which indicated that for these nutrients fallow effects were not independent of site effects.

Because there were no significant site × fallow interactions for N and P, fallow means for these nutrients were averaged across the sites (Table 3). Canavalia accumulated significantly more N than the other fallows, while all improved fallows accumulated significantly more N than the natural fallow. With 169 N kg ha^{-1}, canavalia was the most efficient cover crop at accumulating N among the improved fallows. Canavalia also accumulated significantly more P than the other fallows, and all improved fallows, with the exception of crotalaria, accumulated more P than the natural fallow (Table 3). Phosphorus is a major limiting factor for crop production on many tropical and subtropical soils (Norman et al., 1995; Manske et al., 2001; van der Eijk et al., 2006) as a result of high P fixation (Mubiru and Karathanasis, 1994; Osiname et al., 2000) and nutrient mining in traditional land systems (Vlek, 1993; Sanchez et al., 1997). Given the limited access of most smallholder farmers to fertilizer P, it is desirable to identify and incorporate into cropping systems plant species that can mobilize P from soil-P pools, which are unavailable to less P-efficient food crops (Kamh et al., 1999). It emerged from this study that canavalia is not only good at fixing N, but also effective at accumulating P.

Table 3. Fallow aboveground dry matter N and P yields across the study sites† (2004).

Fallow	Nutrient yield	
	N	P
	kg ha^{-1}	
Crotalaria	95b	5.05bc
Mucuna	93b	6.47b
Lablab	75b	5.64b
Canavalia	169a	10.58a
Natural fallow	30c	3.16c

† Different letters within each column indicate statistical difference between fallows at $P = 0.05$ level, using the LSD method.

Due to the significant site × fallow interactions for K, Ca, and Mg, data for each site was considered separately. There were no significant fallow effects on dry matter K yield at Kawanda (Fig. 4). However, at Pallisa, canavalia accumulated significantly more K than all other fallows while at Mbale, crotalaria had the highest dry matter K yield, although not significantly greater than mucuna or canavalia (Fig. 4). Fallow yields of Ca and Mg at Kawanda were much lower than at Mbale and Pallisa (Fig. 5 and 6). This could have been due to the low inherent soil Ca and Mg at Kawanda manifest in the low pH at the beginning of the study (Table 1). At the three study sites

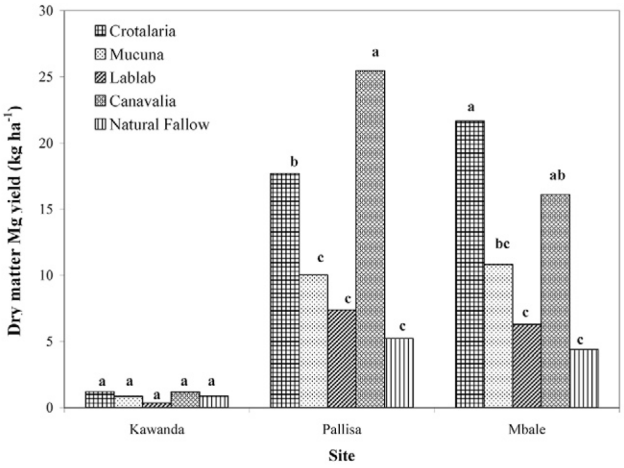

Fig. 6. Fallow aboveground dry matter Mg yield at the three study sites in 2004. Means are different according to the LSD method ($P < 0.05$) if different letters appear above bars within each site.

Table 4. Fallow aboveground dry matter N and Mg yields across the study sites† (2005). There was total failure of crotalaria at all sites.

	Nutrient yield	
Fallow	N	Mg
	kg ha^{-1}	
Crotalaria	–	–
Mucuna	8.05b	2.14b
Lablab	9.35b	2.43b
Canavalia	21.49a	4.33a
Natural fallow	2.50b	1.31b

† Different letters within each column indicate statistical difference between fallows at $P = 0.05$ level, using the LSD method.

Table 5. Fallow aboveground dry matter P, K, and Ca yields at two of the study sites† (2005).

	Nutrient yield					
	Pallisa			Mbale		
Fallow	P	K	Ca	P	K	Ca
	kg ha^{-1}					
Crotalaria	–	–	–	–	–	–
Mucuna	0.44a	5.82a	5.56bc	0.72a	7.06b	3.15b
Lablab	0.89a	12.66a	8.35b	0.70a	11.56b	11.24b
Canavalia	0.99a	15.35a	13.30a	2.19a	31.19a	32.49a
Natural fallow	0.14a	3.35a	2.05c	0.61a	10.59b	5.36b

† Different letters within each column indicate statistical difference between fallows at $P = 0.05$ level, using the LSD method.

canavalia also showed significantly higher Ca yield relative to the other fallows except, at Mbale, where the Ca yield of canavalia was significantly higher than all fallows except crotalaria (Fig. 5). There were no significant fallow effects on dry matter Mg yield at Kawanda (Fig. 6). At Pallisa, canavalia had the highest dry matter Mg yield; at Mbale, it was crotalaria, though the difference between crotalaria and canavalia was not significant (Fig. 6).

In 2005, there were no significant site differences in aboveground dry matter N and Mg yields. However, significant site differences were observed for P, K, and Ca yields. There were also significant site × fallow interactions for P, K, and Ca, which indicated that for these nutrients fallow effects were not independent of site effects.

Because there were no significant site × fallow interactions for N and Mg, fallow means for these nutrients were averaged across the sites (Table 4). The canavalia fallow accumulated significantly more N and Mg than the other fallows. Due to the significant site × fallow interactions for P, K, and Ca, data for each site was considered separately (Table 5). At Pallisa, there were no significant differences in fallow aboveground dry matter P and K yields. However, canavalia had the highest dry matter Ca yield relative to the other fallows and differences were significant. At Mbale, there were no significant differences in fallow aboveground dry matter P yields. However, canavalia accumulated significantly more K and Ca than the other fallows.

Fallow Effects on Weeds

The magnitude of weed infestation at the three study sites was variable (Table 6). The most important weeds in terms of weed density at Kawanda were, in order of decreasing infestation, nutgrass (*Cyperus rotundus* L.) > broadleaf woodsorrel (*Oxalis latifolia* Kunth) > benghal dayflower (*Commelina benghalensis* L.) > hairy beggarticks (*Bidens pilosa* L.). At Pallisa the order was benghal dayflower > nutgrass > hairy beggarticks while at Mbale it was nutgrass > broadleaf woodsorrel > hairy beggarticks > benghal dayflower. Broadleaf woodsorrel was only common at Kawanda and Mbale.

Table 6. Percent weed infestation at the three study sites and two management options.†

	Weed infestation			
	Nutgrass	Hairy beggarticks	Benghal dayflower	Broadleaf woodsorrel
	%			
Site				
Kawanda	39a	6a	12ab	13a
Pallisa	12b	11a	15a	–
Mbale	20b	6a	4b	11a
Management				
Slash	35a	15a	18a	13a
Herbicide	11b	1b	3b	3a

† Different letters within each column indicate statistical difference among sites and between management options at $P = 0.05$ level, using the LSD method.

There were significant site, management, and fallow effects on weed density. However, the site × management and management × fallow interactions were not significant. There was significantly more nutgrass at Kawanda than Pallisa and Mbale (Table 6). There was also significantly more benghal dayflower at Pallisa than Mbale but differences between Kawanda and Pallisa or Mbale were not significant. Densities of hairy beggarticks were not significantly different at the three study sites. At the management level, weed densities were significantly greater in the plots managed by slash relative to those managed by herbicides (Table 6). At the fallow level, significant fallow effects were only observed on nutgrass. The natural fallow had significantly more nutgrass infestation than lablab, but differences among the other fallows were not significant (Fig. 7).

It is plausible that the low levels of weed infestation at Pallisa and Mbale relative to Kawanda could have been as a result of continuous cultivation in the farmers' fields. The per-capita land holdings in Uganda have reduced by 90% (from approximately 8 to 1 ha per person) in a period spanning about nine decades. The small land holdings have precipitated the current scenario of continuous cultivation. Through continuous cultivation the reproductive cycles of the weeds may have been

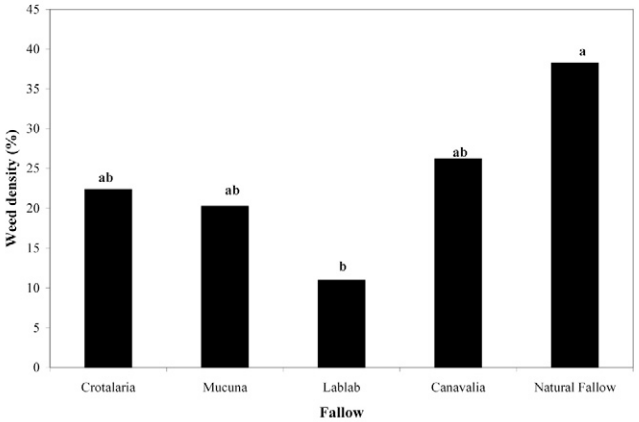

Fig. 7. Nutgrass (*Cyperus rotundus* L.) weed densities among the different fallows. Means are different according to Tukey's HSD ($P < 0.05$) if different letters appear above bars within each site.

Table 7. Soil bulk density as affected by year, site, management, and fallow.

Variable	Bulk density		
	Mean	CV	No. of samples
	Mg m^{-3}	%	
Year			
2004	1.21a	14.1	110
2005	1.19a	13.4	110
Site			
Kawanda	1.18b	10.8	80
Pallisa	1.27a	11.8	80
Mbale	1.15b	17.6	60
Management			
Slash	1.20a	12.3	110
Herbicide	1.20a	15.2	110
Treatment			
Crotalaria	1.19a	12.9	44
Mucuna	1.20a	17.3	44
Lablab	1.19a	11.4	44
Canavalia	1.19a	11.1	44
Natural fallow	1.23a	15.5	44

disrupted. They are not allowed to flower and set seed; thus in the process subsequent levels of infestation are lowered. The higher infestation observed in the plots managed by slash relative to those managed by herbicide could be attributed to the higher rate of residue decomposition under slash management; this left scanty soil cover that did not effectively inhibit weed seeds from germinating.

The low infestation by nutgrass observed in the lablab fallow could have been a result of allelopathic suppression, seed germination inhibition due to the high cover crop residues, or both. According to Barreto (1994) and Parr et al. (1990), creeping and faster growing cover crops suppress weed growth by out-competing them for nutrients, moisture, space, and light. Schenk and Werner (1991) reported that various legumes in the tribe Vicieae (peas, lentils, and vetches) contain beta-(3-isoxazolinonyl) alanine, which is released into soil as a root exudate. This chemical can cause reduced growth in seedlings of various plants, and apparently is an allelopathic compound (Bugg, 1996). However, Frick and Johnson (2002) noted that it is a challenge to separate the effects of resource competition and allelopathy. Nonetheless, in this study it can be safely concluded that lablab, in rotation, may suppress nutgrass in subsequent crops.

Fallow Effects on Soil Physicochemical Properties

Soil Bulk Density

Bulk density did not significantly change at any site during the study (Table 7). However, the bulk densities at the three sites were significantly different. The mean bulk density at Mbale (1.15 Mg m^{-3}) and Kawanda (1.18 Mg m^{-3}) was significantly lower than that at Pallisa (1.27 Mg m^{-3}). Fallow management and the fallows themselves had no significant effect on the soil bulk density, which was attributed to the short period during which the fallows were established. As observed by other workers (Voorhees and Lindstrom, 1984; Karunatilake et al., 2000; McGarry et al., 2000) benefits of improved fallows to soil in terms of bulk density and soil structure improvement typically require continuity and much longer periods to become manifest.

Table 8. Linear correlation coefficients between soil properties.†

Variable	pH	SOM	N	P	K	Ca
pH						
OM	–0.54**					
N	–0.52**	0.86**				
P	0.31**	–0.11	–0.17‡			
K	0.74**	–0.53**	–0.40**	0.06		
Ca	0.72**	–0.14	–0.05	0.27**	0.75**	
Mg	0.66**	–0.42**	–0.25**	–0.01	0.85**	0.84**

** Significant at the $P \leq 0.01$.

† SOM = soil organic matter.

‡ Significant at the $P \leq 0.10$.

Soil Chemical Properties

In 2005, one season after establishing the fallows, there were no significant management or fallow effects in soil for OM, pH, N, P, K, Ca, and Mg. Kawanda had significantly more soil OM and N than Pallisa and Mbale; however, differences between Mbale and Pallisa were not significant. The trend Kawanda > Mbale > Pallisa was the same for SOM and N, indicating their interrelationship. Overall, there was a significant linear correlation between SOM and soil N ($r = 0.86$, $P < 0.01$) (Table 8). On the other hand, the trend Mbale > Pallisa > Kawanda was the same for pH, K, Ca, and Mg, apparently indicating an interrelationship between pH and the extractable bases depicted by the significant linear correlation coefficients ranging from $r = 0.66$ to 0.74, $P < 0.01$ (Table 8). Other investigators (Foster, 1971, 1976) in Uganda found SOM to be significantly correlated with total N ($r = 0.92$, $P < 0.01$).

From Year 1 to Year 2, after one season of maize between the two fallow periods, there was a decrease in SOM, N, P, and Ca. However, the decrease observed for P was not significant. On the other hand, there were significant increases in pH, K, and Mg. The fact that the cover crops performed poorly in the second year could have contributed to the decrease in SOM due to poor dry matter production, whereas the decrease in N and Ca concentrations could have come as a result of leaching and poor recycling of nutrients. At the site level, there were highly significant differences in SOM, pH, N, P, K, and Ca, but differences in soil Mg were not significant. The trend Kawanda > Mbale > Pallisa was the same for SOM and N, whereas the trend Mbale > Pallisa > Kawanda was the same for pH, P, K, and Ca, as was the case in Year 1. The natural fallow had relatively higher aboveground K and Mg concentrations (data not presented). Because the improved fallows did not establish well, there were more grasses, which probably led to the accumulation of soil K and Mg.

Generally there was no significant improvement in the soil physicochemical properties by the improved fallows. Pikul et al. (1997) observed that an improvement in soil fertility using legume cover crops might be possible, though it might require many additional cropping cycles.

CONCLUSIONS

The nutrient status of the soils at the three study sites was attributed to the soil parent materials, climatic factors, and cultural practices. Differences in fallow aboveground dry matter production between the years and among the sites were partly a function of the differences in the weather conditions and the soil physicochemical properties. In turn, aboveground dry matter production was a major determinant of the aboveground dry matter nutrient accumulations. Cover crops that produced higher aboveground dry matter accumulated more nutrients. Continuous cultivation, resulting from socioeconomic problems such as population pressure, has led to a situation of low levels of weed infestation on farmers' fields at Pallisa and Mbale relative to the researcher-managed fields at Kawanda.

The relatively higher rate of residue decomposition under slash management left scanty soil cover, which did not effectively inhibit weeds seeds from germinating and was responsible for the higher levels of weed infestation observed in plots managed by slash compared with those managed by herbicide.

Plots with lablab fallow had the lowest nutgrass infestation, which was due to either allelopathic suppression, seed germination inhibition due to high cover crop residues, or both. Therefore, lablab may suppress nutgrass in a fallow-crop rotation cropping system. Canavalia yielded significantly more dry matter than the other fallows regardless of year or site. It also emerged to be the cover crop most tolerant to drought, whereas crotalaria was least tolerant. Generally, the canavalia fallow also had the highest aboveground dry matter nutrient yield. A combination of high dry matter and nutrient yield plus tolerance to drought made canavalia the best cover crop among those evaluated in this study.

Generally there was no significant improvement in the soil physicochemical properties by the improved fallows. In that regard, in addition to improved fallows, supplemental nutrients are required to improve the nutrient status of the soil. That notwithstanding, with all things considered, the improved fallows were more beneficial than the natural fallow because in most cases the natural fallow had the lowest aboveground nutrient concentrations and dry matter accumulation compared with the improved fallows. As has been observed by other investigators, a significant improvement on soil physicochemical properties using legume cover crops might be possible, though it might require many additional cropping cycles, especially on severely degraded soils.

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