2011

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Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)

Journal of Agriculture and Rural Development in the Tropics and Subtropics
Vol. 112 No. 1 (2011) 1–10
urn:nbn:de:hebis:34-2011101139312 ISSN: 1612-9830 – journal online: www.jarts.info

Leguminous cover crops differentially affect maize yields in three contrasting soil types of Kakamega, Western Kenya

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Abstract

Maize production in smallholder farming systems in Kenya is largely limited by low soil fertility. As mineral fertilizer is expensive, green manuring using leguminous cover crops could be an alternative strategy for farmers to enhance farm productivity. However due to variability in soil type and crop management, the effects of green manure are likely to differ with farms. The objectives of this study were to evaluate *Mucuna pruriens* and *Arachis pintoi* on (i) biomass and nitrogen fixation (^{15}N natural abundance), (ii) soil carbon and nitrogen stocks and (iii) their effects on maize yields over two cropping seasons in Kakamega, Western Kenya. *Mucuna* at 6 weeks accumulated 1–1.3 Mg ha $^{-1}$ of dry matter and 33–56 kg ha^{-1} nitrogen of which 70 % was nitrogen derived from the atmosphere (Ndfa). *Arachis* after 12 months accumulated 2–2.7 Mg ha^{-1} of dry matter and 51–74 kg N ha^{-1} of which 52-63 % was from Ndfa. Soil carbon and nitrogen stocks at 0–15 cm depth were enhanced by 2-4 Mg C ha $^{-1}$ and 0.3–1.0 Mg N ha^{-1} under *Mucuna* and *Arachis* fallow, irrespective of soil type. Maize yield increased by 0.5-2 Mg ha $^{-1}$ in *Mucuna* and 0.5–3 Mg ha^{-1} in *Arachis* and the response was stronger on Nitisol than on Acrisol or Ferralsol. We concluded that leguminous cover crops seem promising in enhancing soil fertility and maize yields in Kenya, provided soil conditions and rainfall are suitable.

Keywords: *Arachis pintoi*, green manure, *Mucuna pruriens*, nitrogen fixation, *Zea mays*

1 Introduction

The generally low maize yield in smallholder farming systems in Kenya is attributed to a decline in soil fertility (Mugwe *et al.*, 2008). Recommendations made by scientists to enhance soil fertility include mineral fertilizer use and the addition of animal manure (Okalebo *et al.*, 2006). Whereas mineral fertilizer may be expensive for most smallholder farmers (Salasya *et al.*, 2007), the use of manure is limited because (i) it is not sufficiently available particularly at the recommended application rates (5–10 Mg ha^{-1}), (ii) it is bulky and labor-intensive for transportation and application, and (iii) its quality is often poor (Odendo *et al.*, 2006; Okalebo *et al.*, 2006). In the last decades, the use of leguminous cover crops has been widely promoted as an alternative strategy to enhance soil fertility in croplands (Becker & Johnson, 1998). Additionally, these leguminous species are likely to improve the quality of fodder for animals when associated to grasses (Jones & Bunch, 2003). Across Africa, the use of cover crop legumes to increase maize production has received substantial attention. Species like *Mucuna pruriens* have been used successfully to control weeds and improve farm productivity in West Africa (Carsky *et al.*, 2001). Similarly, scientists from East Africa acknowledged an increase in maize grain yield of 0.4 to 1.0 Mg ha^{-1} over farmers' practice due to incorporation of 22 weeks old *Mucuna pruriens* (Kaizzi *et al.*, 2006). Unlike *Mucuna*, there are many leguminous cover crops that have not been widely cultivated in Africa although being practiced in other parts of the

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world. These cover crop legumes include *Arachis pintoi*, which is a prostrate, stoloniferous, perennial tropical legume (Baruch & Fisher, 1996). *Arachis* is widely cultivated in South America and Australia because it can improve soil nitrogen balances through biological nitrogen fixation and its persistence in legume-grass pastures (Jones & Bunch, 2003).

In Western Kenya, the smallholder farming system is characterized by a large diversity in soil type, farm management and available resources that creates gradients in soil fertility both between and within farms (Tittonell *et al.*, 2005; Vanlauwe *et al.*, 2006). Thus, the effectiveness of cover crop legumes to improve maize production is likely to differ with farms and as a function of soil type and farm management. This study was conducted on three contrasting soil types of Western Kenya (i) to determine biomass and nitrogen fixation by *Mucuna* and *Arachis* (ii) to quantify the effect of *Mucuna* and *Arachis* fallow on soil carbon and nitrogen stocks and (iii) to evaluate the effects of *Mucuna* and *Arachis* on maize yields over two cropping seasons.

2 Materials and Methods

2.1 Description of experimental sites

This study was conducted between 2008 and 2009 at three sites of Kakamega, Western Kenya namely (i) the Kenya Agricultural Research Institute (KARI) in Kakamega, (ii) Lubao sub-location and (iii) Virhembe sub-location. All three sites are situated within a 2–30 km distance from Kakamega town (034° 46’ E latitude, 00° 17’ S longitude). The three sites have contrasting soil types that are representative for the region, respectively eutric Nitisol, (KARI) ferralo-orthic Acrisol (Lubao) and nito-rhodic Ferralsol (Virhembe), according to the FAO classification (FAO, 1990). The soils differed in chemical properties (Table 1), while climatic conditions were similar. Mean temperature of the three localities was 21 °C and mean annual rainfall ranged from 1600 to 2200 mm with a distinct bimodal pattern. Maize is grown both in the short rainy season (August to November) and in the long rainy season (March to July). The study on Nitisol was conducted on a research farm at KARI where maize varietal trials have been previously conducted with regular application of mineral fertilizer. Trials on Acrisol and Ferralsol were conducted in farmers’ fields where maize and common bean were grown for more than 10 years prior to this study. Two fields with fertility gradient (moderate vs. low) were selected in each of the study sites to obtain a fair representation. The study sites will be subsequently referred to by their soil types as Nitisol, Acrisol and Ferralsol.

2.2 Trial design and management

The experimental fields were under a weedy fallow that was cleared using cutlasses and tilled manually using a hand hoe. The trial design was a randomized complete block with four replicates and individual plot sizes of 6 m × 5 m (30 m2). The treatments comprised:

(i) Farmer’s practice (control treatment): Treatment plots were tilled manually using a hand hoe during seed bed preparation without addition of external inputs. Maize cultivar HB 520 was seeded on the 4th September 2008 for the short rainy season crop and on the 22nd of March 2009 for the long rainy season crop at a 60 cm × 25 cm spacing. Two maize seeds were sown per planting hole and thinned to one plant per hill two weeks after emergence. Weeds were controlled by hand hoe only once at two weeks after maize seeding.

(ii) Green manure: *Mucuna pruriens* var. *utilis* was used as green manure. *Mucuna* was seeded two weeks before planting maize i.e. on the 20th of August 2008 and on the 8th of March 2009 for the short and the long rainy season crops, respectively. One *Mucuna* seed was planted per hole at a 20 cm × 30 cm spacing. Mineral phosphorus (30 kg ha^{-1}) was applied as triple superphosphate to the planting holes at *Mucuna* seeding. Maize was seeded as in (i). At six weeks after seeding, *Mucuna* was incorporated between the rows of four week-old maize using a hand hoe.

(iii) Zero tillage combined with the use of a cover crop: Treatment plots were not tilled. *Arachis pintoi* accession CIAT 18744 was used as cover crop. *Arachis* was planted on August 20 at the onset of the short rainy season of 2008 at a spacing of 20 cm × 20 cm (one seed per hole) two weeks prior to maize seeding. Maize was seeded as in (i). In addition, mineral nitrogen (100 kg ha^{-1}) was applied to maize as urea with 40 %, 30 % and 30 % applied at planting, four and six weeks after maize seeding, respectively, while mineral phosphorus (100 kg ha^{-1}) was applied as triple superphosphate at maize seeding. After establishment, *Arachis* was maintained as permanent live ground cover for the duration of the experiment.

2.3 Data collection, calculation and analysis

In the current study, only above-ground biomass accumulation of the leguminous cover crops was considered. The above-ground biomass of *Mucuna* was determined at six weeks after seeding in both cropping seasons. *Mucuna* plants in each treatment plot were cut at ground level and weighed (including litter) to obtain the total fresh weight. Sub samples of 500 g were oven-dried at 70 °C until constant weight. The dried sub samples were finely ground (1 mm) and kept

Table 1: *Climatic conditions and soil characteristics of three contrasting soil types of Western Kenya*

Parameter	*Soil type*		
	Nitisol	*Acrisol*	*Ferralsol*
Altitude (masl)	1534	1558	1569
Latitude	N 00° 16.962’	N 00° 19.180’	N 00° 14.548’
Longitude	E 034° 46.073’	E 034° 47.793’	E 034° 51.129’
Annual rainfall (mm)	1978	1612	2232
Mean temperature (°C)	21	21	21
Soil texture	Clay-loam	Sandy-loam	Clay
Sand (%)	12.9	61.2	10.8
Silt (%)	33.6	20.0	27.0
Clay (%)	53.5	18.8	62.2
pH (H_20)	5.4	5.4	4.9
Total C (%)	4.1	1.4	3.0
Total N (%)	0.3	0.1	0.2
Available Bray-P (mg kg^{-1})	3.4	7.7	2.3
Exchangeable K (cmol kg^{-1})	0.7	0.2	0.8
Bulk density (g cm^{-3})	1.1	1.2	1.1

Soil analysis method: Okalebo *et al.* (2002).

until analysis. The above-ground biomass accumulation of *Arachis* was determined sequentially at three-months intervals from seeding until 12 months and total above-ground biomass was determined at maize harvest. *Arachis* plants within two randomly selected quadrates (60 cm × 60 cm) in each treatment plot, were cut at ground level, bulked (including litter) and weighed to obtain the fresh weight and a sub sample of 200–500 g oven-dried at 70 °C until constant weight. The dried sub samples were finely ground (1 mm) and kept until analysis. A five milligram sample was weighed from each ground *Mucuna* and *Arachis* sample and analyzed for nitrogen (N) concentration with an automatic elemental analyzer (EA Euro 3000). Phosphorus (P) and potassium (K) in *Mucuna* and *Arachis* were measured after dry-ashing and extraction with 6M HCl (Mussgnug *et al.*, 2006). P was measured colorimetrically with a spectrophotometer (Eppendorf ECOM 6122) and K was measured with a flame photometer (Eppendorf Elex 6361). The percentage of nitrogen derived from the atmosphere (%Ndfa) of *Mucuna* and *Arachis* was estimated by the δ^{15}N Natural Abundance Method (^{15}N NAM) as in equation (1) and the proportions of N obtained from the atmosphere (Ndfa) and from the soil (Ndfs) were calculated as in equation (2) (adopted from Gathumbi *et al.*, 2002). Total N accumulated by *Mucuna* and *Arachis* was calculated as the sum of Ndfa and Ndfs. Maize in the treatment plots was used as reference crop for ^{15}N analysis. The *B*-value (natural discrimination of heavy ^{15}N isotope by nitrogenase enzyme complex) of 1.64‰ was used for *Mucuna* (Gathumbi *et al.*, 2002). The *B*-value of *Arachis* was not available. Hence, the *B*-value of *Arachis hypogaea* (–1.87‰) was used (Maskey *et al.*, 2001).

$$\%\text{Ndfa} = \frac{\delta^{15}N_{maize} - \delta^{15}N_{Aracis\,or\,Mucuna}}{\delta^{15}N_{maize} - B} \times 100 \tag{1}$$

$$\%\,\text{Ndfa or Ndfs} = \frac{\%\,\text{Ndfa or}\,\%\,\text{Ndfs}}{100} \times \text{quantity of N in DM} \tag{2}$$

whereby *B* represents the δ^{15}N of *Mucuna* and *Arachis* (*A. hypogaea* in this case) grown in N-free medium, DM is total dry matter of *Mucuna* and *Arachis*, and % Ndfs = 100 – % Ndfa.

Soil carbon (C) and nitrogen (N) stocks were quantified (Mg ha^{-1}) after two seasons of treatment application. The C and N stocks were calculated as the product of bulk density and percentage of total C or N in the soil. Total C and N were measured using an automatic elemental analyzer (EA Euro 3000) while bulk density was calculated as (3) according to standard method (Okalebo *et al.*, 2002).

$$\text{Bulk density}\ (g\,cm^{-3}) = \frac{wt_1 - wt_2}{V} \tag{3}$$

whereby wt_1 is the initial weight (g) of soil after sampling, wt_2 is the final weight (g) of soil after drying in an oven at 105 °C for 2 days and V is the volume (cm^3) of a metal cylinder (volume: 100 cm^3, height: 5 cm) used for sampling.

Maize grain yield was determined 16 weeks after seeding from a 2 m × 1.2 m harvest area in the middle rows of each treatment plot. The maize cobs were harvested, dried and threshed, and yield was reported at 13 % moisture content.

Data on soil C and N stocks and maize yields generated were subjected to analysis of variance using the SPSS statistical package (SPSS Inc., 2008). Mean separation was done by Tukey test ($P < 0.05$).

3 Results

3.1 Biomass accumulation and nitrogen fixation

The above-ground dry matter of *Mucuna* differed across sites and was approximately 10 to 20 % higher in the long than in the short rainy season (Table 2). Irrespective of the cropping season, largest biomass accumulation of *Mucuna* was observed on the Acrisol and lowest on the Ferralsol. The N, P and K concentrations of *Mucuna* also differed across sites (Table 2) and ranged between 3.3–4.6 %, 0.32–0.34 % and 0.25–0.32 %, respectively. Generally, the nutrient concentrations of *Mucuna* reflected the inherent soil N, P and K in the three sites.

Sequential biomass accumulation of *Arachis* followed the seasonal rainfall patterns of the study sites (Figure 1). The lowest biomass accumulation was observed in February (2009) when rainfall was lowest at all the sites. As the rains became more frequent between March and August, the biomass increased steadily with a peak at 12 months after seeding. Total above-ground biomass accumulated by *Arachis* was about 40% higher on the Acrisol and Nitisol compared with the Ferralsol (Table 3). Irrespective of the soil type, nutrient concentrations of *Arachis* were on average 2.7%, 0.33% and 0.36%, respectively for N, P and K (Table 3).

The percentage N obtained from the atmosphere (%Ndfa) and from the soil (%Ndfs) by *Mucuna* was similar in both cropping seasons (Table 4). However, differences in %Ndfa and %Ndfs were observed across sites. *Mucuna* derived between 68–70% N from the atmosphere and the remainder from the soil. The %Ndfa by *Arachis* was approximately 10% lower than that of *Mucuna* at all the sites (Table 4).

Contrary to *Mucuna*, marked differences were noted in %Ndfa by *Arachis* across sites with highest values observed on the Nitisol and lowest on the Ferralsol. Total N accumulated by *Mucuna* differed across sites and seasons (Figure 2). *Mucuna* accumulated 10–18 kg N ha $^{-1}$ more in the long than in the short rainy season with the largest increase on the Nitisol. Total N accumulated by *Arachis* was 40% more on the Nitisol and Acrisol than on Ferralsol (Figure 2). Generally, nitrogen accumulated by *Arachis* was higher than that accumulated by *Mucuna* although the latter had a higher %Ndfa than the former.

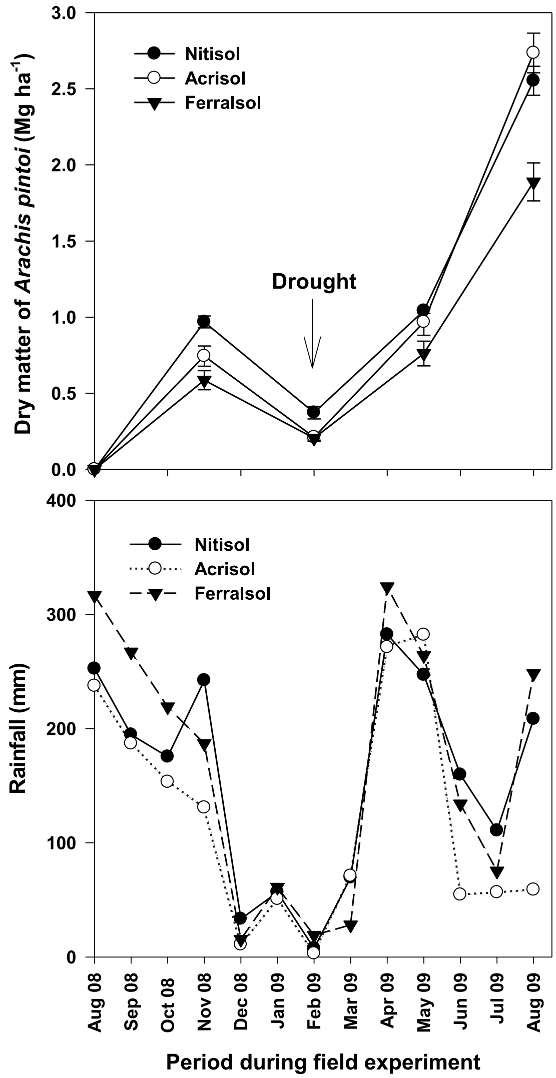

Fig. 1: *Sequential dry matter of Arachis pintoi (CIAT 18744) and rainfall distribution with time after seeding between August 2008 and August 2009 on three contrasting soil types in Kakamega, Kenya. Bars are standard error of means (n = 4).*

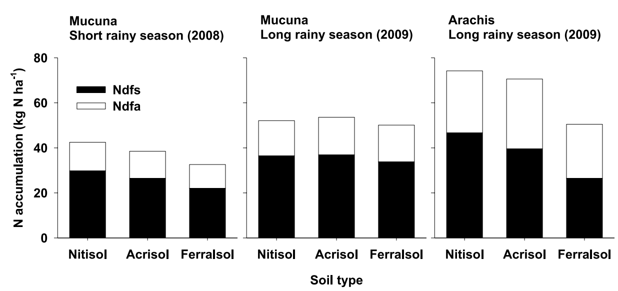

Fig. 2: *Nitrogen accumulation of Mucuna pruriens var. utilis and Arachis pintoi (CIAT 18744) on three contrasting soil types in Kakamega, Kenya. Bars are standard error of means (n = 4). Mucuna pruriens was evaluated at 6 weeks after seeding in the short rainy season (2008) and the long rainy season (2009). Arachis pintoi was evaluated after 12 months at the end of the long rainy season (2009).*

Table 2: *Above-ground dry matter (DM) accumulation and nutrient concentration of six-weeks old Mucuna pruriens var. utilis on three contrasting soil types in Kakamega, Kenya, during the short rainy season (SR) of 2008 and the long rainy (LR) season of 2009.*

	Nitisol		*Acrisol*		*Ferralsol*	
	SR 2008	*LR 2009*	*SR 2008*	*LR 2009*	*SR 2008*	*LR 2009*
DM (Mg ha^{-1})†	1.00±0.11‡	1.20±0.12	1.20±0.01	1.30±0.11	0.90±0.10	1.10±0.11
Nitrogen (%)	4.10±0.30	4.60±0.31	3.30±0.30	4.00±0.21	3.60±0.28	4.30±0.21
Phosphorus (%)	0.33±0.01	0.34±0.01	0.34±0.01	0.34±0.01	0.32±0.01	0.34±0.02
Potassium (%)	0.32±0.01	0.30±0.02	0.26±0.02	0.25±0.05	0.32±0.03	0.29±0.03

† Above-ground dry biomass.
‡ ± "means" standard deviation (n = 4).

Table 3: *Above-ground dry matter accumulation and nutrient concentration of Arachis pintoi at the end of the long rainy season of 2009 (after 12 months) on three contrasting soil types in Kakamega, Kenya.*

	Nitisol	*Acrisol*	*Ferralsol*
Dry matter (Mg ha^{-1})	2.60±0.40	2.70±0.31	1.90±0.30
Nitrogen (%)	2.90±0.12	2.60±0.14	2.70±0.16
Phosphorus (%)	0.32±0.04	0.35±0.02	0.32±0.01
Potassium (%)	0.38±0.05	0.30±0.08	0.40±0.03

± "means" standard deviation (n = 4).

Table 4: *Percentage of N derived from the atmosphere (%Ndfa) and from the soil (%Ndfs) by Mucuna pruriens var. utilis and Arachis pintoi CIAT 18744 on three contrasting soil types in Kakamega, Kenya, during the short rainy season (2008) and the long rainy season (2009).*

Crop and season	*Soil type*	*N derived from atmosphere (%Ndfa)* *	*N derived from soil (%Ndfs)*
Mucuna† Short rainy season	Nitisol	70.0±3.3	30.0
	Acrisol	68.9±2.7	31.1
	Ferralsol	67.5±0.4	32.5
Mucuna Long rainy season	Nitisol	70.1±3.2	29.9
	Acrisol	68.8±2.7	31.2
	Ferralsol	68.0±0.5	32.0
Arachis‡ Long rainy season	Nitisol	63.0±5.4	37.0
	Acrisol	56.4±6.8	43.6
	Ferralsol	51.9±3.3	48.1

* ± "means" standard deviation from the mean (n = 4).
† Mucuna was evaluated at 6 weeks after seeding in both seasons.
‡ Arachis was evaluated at the end of the long rainy season (after 12 months).

3.2 *Effect of cover crops on soil carbon and nitrogen stocks*

Total C ranged from 4.00% to 4.14% (Nitisol), 2.79% to 2.95% (Ferralsol) and 1.19% to 1.32% (Acrisol). Total N was 0.30–0.34%, 0.23–0.28% and 0.10–0.14% in the Nitisol, Ferralsol and Acrisol, respectively. Bulk density was 1.11–1.13 (Nitisol), 1.11–1.13 (Ferralsol) and 1.22–1.25 (Acrisol). *Mucuna* green manure did not significantly increase soil C or N stocks across soils (Figure 3). *Arachis* significantly ($p < 0.01$) enhanced soil carbon stock on the Acrisol but not on the Nitisol and the Ferralsol, possibly because of the high inherent C on the Nitisol and the Ferralsol. Approximately 2 to 4 Mg ha^{-1} C were added by the leguminous cover crops, regardless of sites. Unlike C, N stock was significantly ($p < 0.01$) increased by *Arachis* at all three sites, ranging between 0.3 to 1.0 Mg ha^{-1} over the control treatment.

3.3 *Effect of cover crops on maize yields*

Maize grain yield was significantly increased with both *Mucuna* and *Arachis* across sites and seasons (Figure 4). In the short rainy season, *Arachis* showed the strongest effect on maize grain yield (> 1 Mg ha^{-1} over control) across sites. Irrespective of the treatment, highest maize grain yield was noted on the Nitisol and lowest on the Acrisol. In the long rainy season, maize grain yield was generally higher than in the short rainy season with the best responses observed on the Nitisol. However, response of maize grain yield under *Arachis* on the Acrisol in the long rainy season was 30% lower than previously observed in the short rainy season and 0.5 Mg ha^{-1} less than maize yield under *Mucuna*. Similarly, maize grain yield under control on the Ferralsol decreased by > 40 % in the long rainy season compared with the short rainy season.

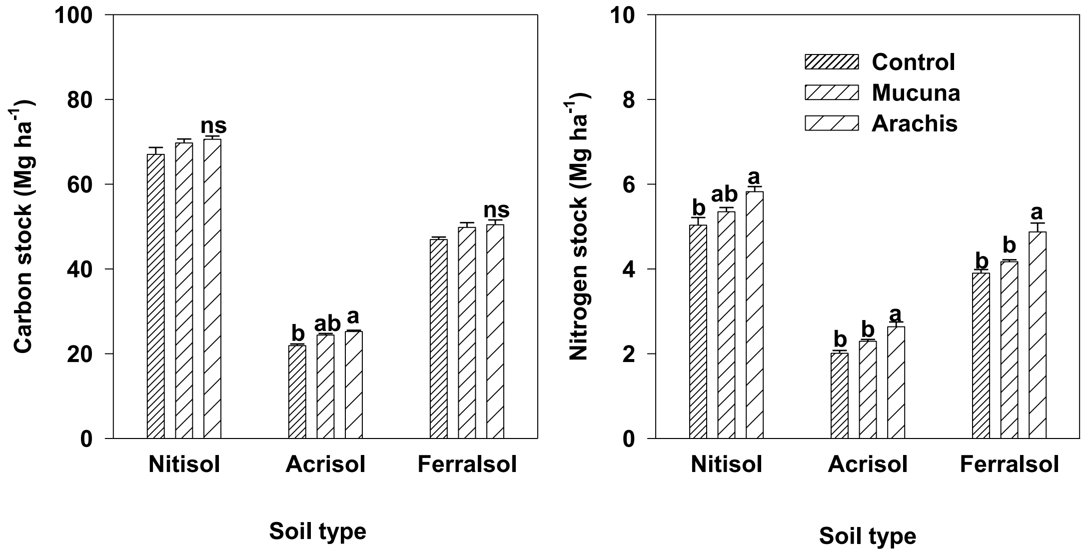

Fig. 3: *Effect of leguminous cover crops (Mucuna pruriens and Arachis pintoi) on carbon and nitrogen stocks on three contrasting soil types in Kakamega, Kenya, after two seasons of treatment application. Farmers' practice (FP) was the control. Treatments with the same letter on a soil type are not significantly different by Tukey ($P < 0.05$). ns = non significant.*

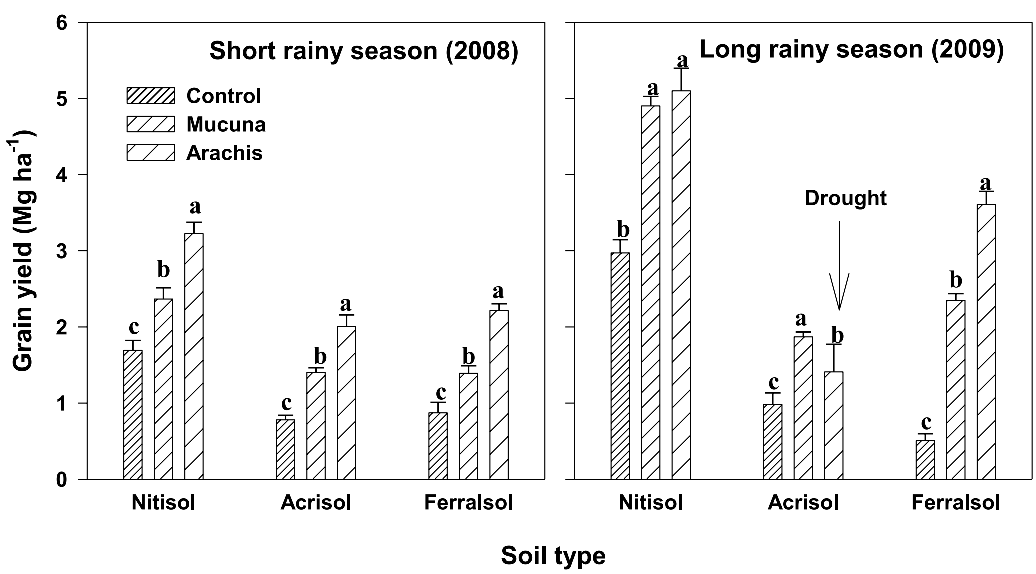

Fig. 4: *Response of maize grain yield to Mucuna pruriens var. utilis and Arachis pintoi (CIAT 18744) on three contrasting soil types in Kakamega, Kenya. Farmers' practice (FP) was the control. Trials were conducted in the short rainy season (2008) and in the long rainy season (2009). Mucuna was evaluated until 6 weeks after seeding. Arachis pintoi was evaluated from seeding to the end of the long rainy season of 2009 (after 12 months). Bars are standard error of the means ($n = 4$). Treatments with the same letter are not significantly different by Tukey ($P < 0.05$).*

4 Discussion

4.1 Effects of rainfall and soil type on cover legumes

This study demonstrated that *Mucuna pruriens* and *Arachis pintoi* can accumulate a reasonable amount of biomass in Western Kenya. The differences in biomass accumulation between sites were probably due to seasonal differences in rainfall and soil types (Carsky *et al.*, 2001; Giller, 2001). Moisture availability is an important determinant for growth in leguminous cover crops. In situations where rainfall is erratic with frequent dry spells within the cropping season, the amount of biomass accumulated by leguminous cover crops may reduce as observe in the current study. Although *Arachis* is persistent and known to tolerate drought conditions (Jones, 1993), growth of the legume in Western Kenya is likely to be retarded when cumulative monthly rainfall is consistently less than 100 mm. In addition to rainfall, soil type affected the amount of biomass accumulated by the cover legumes. Thus, a generally higher biomass was accumulated on the Acrisol and Nitisol than on the Ferralsol, possibly because the Ferralsol was highly acidic with the possibility of fixing phosphorus and a poor aeration (George *et al.*, 2002). In an earlier study in West Africa, Carsky *et al.* (2001) observed that *Mucuna* does not grow very well on clayey and highly acidic soils. Similarly, Baruch & Fisher (1996) reported an enhanced growth of *Arachis* on sandy as opposed to clay soils in Colombia.

Soil types also affected the nutrient concentrations in the biomass of the cover legumes. Thus, N and K concentrations tended to be higher on the Nitisol and the Ferralsol than on the Acrisol while P concentrations tended to be highest on the Acrisol and lowest on the Ferralsol, irrespective of the season. Nevertheless, the N, P and K concentrations of *Mucuna* and *Arachis* in the current study were similar to those reported elsewhere (Castillo, 2003) and for other forage crops (Adjolohoun *et al.*, 2008). As such, these legumes could be suitable for use as forage in Kenya.

This study also demonstrated that *Mucuna* and *Arachis* are likely to improve soil N balances through nitrogen fixation as observed elsewhere (Becker, 1999; Thomas *et al.*, 1997). But this will depend on inherent soil characteristics such as soil P, soil pH and soil moisture availability (Becker *et al.*, 1995). Given the low level of inherent soil P (< 6 mg P kg^{-1}) at all three study sites, it would be necessary to apply mineral or organic P to the cover legumes to stimulate nitrogen fixation and enhance growth (Somado *et al.*, 2003). P is essential in nitrogen fixation and the application of P is widely reported to have a significant positive effect on nodulation and nitrogen fixation in legumes (Becker *et al.*, 1991). Although P is generally applied to legumes to stimulate BNF, it is likely that the P applied will be recycled together with the fixed N during incorporation of the legumes which can be used by the following crop (Giller, 2001), thus stimulating the systems' productivity (Somado *et al.*, 2003).

4.2 Effects of cover legumes on soil attributes

Soil N, soil organic matter (SOM) and available soil P are major determinants of the productivity and sustainability of agricultural production systems (Blair *et al.*, 1995; Kifuko *et al.*, 2007). In permanently cropped fields, soil organic C and N stocks can be enhanced by management practices including reduced tillage and green manuring (Jarecki & Lal, 2003). In the current study, the introduction of *Arachis* significantly enhanced soil C and N stocks, which was consistent with earlier reports on cover legumes (Armstrong *et al.*, 1999; Diekow *et al.*, 2005). In contrast, *Mucuna* green manure did not significantly influence soil C, which was similar to the observation made by Whitbread *et al.* (2004) in the sub-humid region of Zimbabwe. The observed increase in C stock could be attributed not only to legume above-ground biomass, but presumably to legume below-ground biomass, maize residues and weed biomass. This may explain the apparently large increase in soil C, not entirely explained by the legume above-ground C input. Generally, the effect of the leguminous cover crops was largest on the sandy-textured Acrisol than on the clay-textured soils due possibly to the low inherent C and N content in the Acrisol.

Besides improving soil C and N stocks, cover legumes may enhance soil P content in the long-term. P-acquisition from fertilizer application and/or from subsoil by deeper rooting legumes will stimulate C accumulation and N addition by nitrogen fixation that can subsequently be made available to the associated crop upon incorporation and organic matter mineralization (Becker, 1999). However, in the short-term under very low soil P conditions the capacity of these legumes to recycle P may be limited because of high translocation rates to meet the internal P demand for nitrogen fixation (Kimaro *et al.*, 2009). Furthermore, legumes will compete for soil moisture (and nutrients) with associated crops (Akanvou *et al.*, 2002). In exchange, in the long-term they may increase soil organic matter and thus water-holding capacity (Becker *et al.*, 1995). This is of particularly relevance on the sandy Acrisol site with relatively less rainfall. But under more humid and poorly-drained soil conditions such as the case with the clay-textured Ferralsol, the cover legumes may cause water-logged conditions (Giller *et al.*, 2009).

4.3 *Effects of cover legumes on maize yield*

This current study supports earlier findings that increased maize production in smallholder farming systems can be achieved using leguminous cover crops (Kaizzi *et al.*, 2006) and mineral fertilizer use (Kifuko *et al.*, 2007; Okalebo *et al.*, 2006). The study further demonstrated the possibility of growing *Mucuna* and maize simultaneously in the same piece of land before the *Mucuna* is incorporated between maize rows. Previously, scientists recommended planting of leguminoucs cover crops like *Mucuna* solely during the short rainy season and incorporate them before planting maize in the following long rainy season (Carsky *et al.*, 2001). However, most farmers in Kenya are very reluctant to implement this technology because the practice requires a sacrifice of one season maize crop (Rao & Mathuva, 2000). This finding is therefore important for smallholder farming systems in areas of Kenya where rainfall is sufficiently available and farmers grow maize continuously on the same piece of land. Additionally, this study illustrated that the magnitude of the effect of leguminous cover crops on maize yields is likely to depend on soil type and seasonal rainfall patterns. In cropping seasons with frequent dry spells, maize yields may reduce due to competition from leguminous cover crops (Mathuva *et al.*, 1998). This is compounded on sandy soils where legumes such as *Arachis* root deep (Baruch & Fisher, 1996) and where the water-holding capacity is low (Brady & Weil, 2002). Thus, the generally lower maize yields observed in the *Arachis* treatment plots particularly on the Acrisol could be ascribed to acute competition for soil moisture from the legume. This is in line with Salako & Tian (2003) who noted soil water depletion under leguminous cover crops in parts of West Africa. Plants take up nutrients in solution. Hence, moisture availability can influence the N content of crop roots and shoots residues that reportedly has the greatest sensitivity when simulating maize grain yield response to green manuring using APSIM (Robertson *et al.*, 2005). In addition to moisture availability, mineral fertilizer use largely improved maize yields particularly on the Nitisol and Ferralsol. This explains why the *Arachis* treatment, with additional fertilizer input, had the highest maize yields on the Nitisol and Ferralsol than the *Mucuna* or Farmer practice. N and P are the most limiting nutrients in Western Kenya and their application in maize fields is well known to improve maize productivity (Kifuko *et al.*, 2007; Odendo *et al.*, 2006).

Finally, the marked reduction in maize grain yield observed with the control treatment on the Ferralsol could be ascribed to weed infestation. Weeds are one of the major constraints to crop production in Western Kenya and their effects are reportedly most severe on the Ferralsol than on the Acrisol or Nitisol (Ngome, 2006).

We can conclude that *Mucuna* and *Arachis* have the potential to increase maize yields in Western Kenya, although this may depend largely on inherent soil conditions particularly soil P, pH and texture, and seasonal rainfall availability. Additional studies on the social economic implications of introducing *Mucuna* and *Arachis* into the smallholder farming systems of Western Kenya are underway.

Acknowledgements

This study was financed by the German Federal Ministry of Education and Research (BMBF) through the 'Biodiversity Monitoring Transect Analysis in Africa' (BIOTA) Project and the German Catholic Exchange Service (KAAD). The institutional support from KARI Kakamega of Kenya, IRAD of Cameroon, University of Bonn and University of Dar es Salaam is acknowledged.

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