African Journal of Agricultural Research Vol. 4 (11), pp. 1189-1198, November, 2009
Available online at http://www.academicjournals.org/AJAR
ISSN 1991-637X © 2009 Academic Journals

Full Length Research Paper

Residual effects of relay-cropped mucuna and lablab on maize and bean yields in northwest Kenya

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Accepted 30 September, 2009

In many areas of the tropics, soil nutrient depletion is a major constraint to food production. Performance of legumes relay cropped with a long-season maize (*Zea mays* L.) hybrid were studied to determine whether subsequent maize grain yield could be increased. Treatments were the factorial (2 × 2 × 3) combinations of two legume cropping systems [based on the legume used; mucuna (*Mucuna pruriens* (L.) DC. var. *Utilis* (Wright) Bruck) and lablab (*Lablab purpureus* (L.) Sweet cv. Rongai)], two levels of legume defoliation (none or herbage above 10 cm from soil surface removed prior to residue incorporation into soil), and three crop sequences (legume in first year only, both years and second year only). There were three controls; (1) 30 kg ha^{-1} inorganic N; (2) natural fallow and; (3) 5 t ha^{-1} cattle manure. Mucuna yielded more herbage in the leaf fraction than lablab (1.6 vs. 0.86 t ha^{-1}), and defoliation resulted in lower (0.76 vs. 0.13 t ha^{-1}) leaf biomass. Lablab accumulated more biomass in the stem than mucuna (1.8 vs. 1.3 t ha^{-1}). Leaf N accumulation for the defoliated mucuna treatment (D-M) averaged 48% that of undefoliated mucuna (UD-M), but for defoliated lablab (D-L), the value was only 4% that of undefoliated lablab (UD-L). When legume residue was applied for two consecutive years, UD-L yielded higher ($p < 0.006$) maize grain than UD-M (6.72 vs. 4.46 t ha^{-1}), and D-M resulted in higher ($p < 0.028$) maize grain yield than D-L (6.08 vs. 3.98 t ha^{-1}). After 2 years of residue application, maize grain yield was greater for D-M than UD-M, but defoliation resulted in a reduction of maize grain yield under lablab treatments. The D-M (6.08 t ha^{-1}) and UD-L (6.72 t ha^{-1}) after 2 years of residue application, yielded higher maize grain yield than the natural fallow control (4.11 t ha^{-1}). Residual nutrients from legume residue incorporation in March 2000 increased maize yield in the 2001 season over that obtained for a natural fallow. It is concluded that single-year or alternate-year intercropping of mucuna and lablab can increase subsequent maize grain yield, even when a portion of top-canopy legume biomass is removed as livestock fodder.

Key words: Residual effects, lablab, mucuna, residue quality, soil fertility, maize, bean.

INTRODUCTION

Agriculture is a very important sector of the Kenyan economy, accounting for 70% of employment, 80% of export earnings, and contributing 25% of the total gross domestic product (Kenya, 2000). Most agricultural production in Kenya is from smallholder farmers, and in north-western Kenya, these farmers practice mixed farming where dairying is integrated with the production of maize (*Zea mays* L.) intercropped with common bean (*Phaseolus* (*vulgaris* L.), in addition to other food crops (Rees et al., 1997). Maize is inter-planted with beans, usually at the beginning of the rainy season in April; some farmers plant a second crop of beans in August. After harvesting maize in November, the land is left fallow during the dry season from November to March.

Due to land limitations, farmers practice continuous

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cropping and grazing with little or no fertilizer application. This has lead to declining soil fertility and productivity of both crops and livestock (Nyambati, 1997; Rees et al., 1997). Although cycling of biomass through livestock and use of manure and urine to fertilize soil have been an important link between livestock and soil fertility (Powell and Valentine, 1998), the quantities of manure available on farm is usually not enough to replenish nutrients harvested in grain and crop residues (Williams et al., 1995). In addition, intercropping of the common bean with maize provides little or no N to concurrent or subsequent maize, as the majority of N fixed by bean is harvested in the grain (Giller et al., 1991, 1994; Amijee and Giller, 1998).

Intercropping of soil-improving legume green manures with cereal crops is a promising, low-cost, ecological means of improving soil fertility (Giller et al., 1997). *Mucuna pruriens* var. *Utilis* (L) DC (Wright) Burck (mucuna or velvet bean) and *Lablab purpureus* L. (Sweet) cv. Rongai (lablab or dolichos) are promising legume green manures that have been successfully intercropped with maize in different parts of the world. They have been shown to increase grain yields of subsequent maize crop compared to continuously grown maize (Ibewiro et al., 2000; Tian et al., 2000). Even incorporation of only the roots of mucuna or lablab had a positive effect on subsequent maize as compared to a control where no residue was applied (Ibewiro et al., 1998).

One reason for the success of mucuna and lablab is that they have shown a greater competitive ability than many herbaceous forage and grain legumes under the shade of long-season maize cultivars when planted after maize (Maasdorp and Titterton, 1997). Although information on the contribution of whole-plant biomass incorporation on subsequent maize yields is available, information on the contribution of roots or roots plus stem stubble, after removing some shoot biomass for livestock feed, is still limited. The objectives of this research were to; (1) determine the effect of number of years of legume residue incorporation on soil fertility as measured through a subsequent test maize-bean intercrop; (2) determine the extent to which harvesting top-growth of legumes for fodder reduces the impact of legume intercrop use on subsequent maize and bean yields and; (3) evaluate the long-term residual effects of residue application.

MATERIALS AND METHODS

Experimental site

The research was conducted from 1999 to 2001 at the National Agricultural Research Center (NARC) at Kitale in northwestern Kenya (1° 01'N and 35° 00'E; 1860 m). The center is in the agro-ecological zone Upper Midlands 4, as described by Jaetzold and Schmidt (1983). The experimental site was a field that has been under continuous cultivation of maize for at least the last 10 years. The soils are classified as humic ferrolsols based on FAO/UNESCO system (FAO - UNESCO, 1994) equivalent to kandiudalfic eutaudox in the USDA soil taxonomy system (Soil Survey Staff, 1994). The top soil (0 - 20 cm) had the following properties; pH (1:2.5 H_2O) 5.4; organic C, 14.2 g kg^{-1}; total N, 1.3 g kg^{-1}; extractable P (modified Olsen), 9.7 mg kg^{-1}; and its clay loam with 39% clay, 41% sand, and 20% silt. Both N and P are limiting for crop growth (Smaling et al., 1997). Rainfall is distributed in one growing season with an annual total (30-year average) of 1143 mm. The growing season is from mid-March to mid-November, and the dry season is from December to March.

Experimental treatments and layout

There were 15 treatments, including three controls, replicated three times in a randomized complete block design. Twelve treatments originated from a 2 × 3 × 2 factorial that included two legume cropping systems, three crop sequences (number of years of residue application), and two legume defoliation treatments. The two legume cropping systems were; (1) maize + bean (both planted in April) + mucuna (planted in August) and; (2) maize + bean (both planted in April) + lablab (planted in August). The three crop sequences were defined based on whether the legume was planted in the first production cycle only (1999/2000), in the second production cycle only (2000/2001), or in both the first and second cycles (Table 1). Plots planted to mucuna or lablab only in the first production cycle, were planted to the maize-common bean intercrop in cycle 2. Plots planted to mucuna or lablab in cycle 2 only were planted to maize-common bean intercrop in cycle 1. The two legume defoliation treatments were; (1) herbage above 10 cm removed at season end and; (2) undefoliated. The three control treatments were; (1) inorganic N fertilizer (30 kg N ha^{-1}); (2) no N fertilization and; (3) 5 t ha^{-1} cattle manure (supplying approximately 65 kg N and 18 kg P ha^{-1}). No inorganic N was applied to any plots other than the inorganic control. At maize planting, 13 kg P ha^{-1} was applied to all plots, except the cattle manure treatment. In the third production cycle of the experiment (2001 growing season), all plots were planted to a maize-bean intercrop.

Experimental plots were 4.5 by 6 m with a 1 m border on all sides. The experiment was planted at the beginning of the rainy season in April 1999. The maize was planted at an inter- and intra-row spacing of 75 × 30 cm, respectively, using two hybrid 614D maize seeds per hill. The maize seedlings were thinned to one plant per hill 4 weeks after planting (WAP) to give a plant population of 44,440 plants ha^{-1}. An improved bean cultivar (GLP2; Rose coco), commonly planted by farmers in the region, was used. The common bean was planted simultaneously with maize at the onset of rains in April. Before planting the legume intercrop (after harvesting the first crop of beans), the maize was weeded and all leaves below the ear were removed to minimize shading. The common bean, mucuna, and lablab were planted in between the maize rows at an intra-row spacing of 30 cm using three seeds per hill, which were thinned to two plants per hill 4 WAP. All the plots were hand weeded twice before harvesting the first crop of beans. The plots were manually weeded once after the August planting of legumes. Stalk borer (*Chilo* spp.), a common pest of maize, was controlled by application of Beta-cyfluthrin (Bulldock), a synthetic pyrethroid insecticide in granular form into the whorl of each plant, at the rate of 7 kg ha^{-1} at 4 and 8 weeks after germination.

Herbage yield and chemical composition

The production of legume residue biomass was assessed in terms of litter fall, above-ground biomass (leaf and stem), and root mass from two 0.5 m^2 quadrats per plot at 30 WAP (mid-March). To measure root mass, soil from the 0.5-m^2 areas was removed to a depth of 20 cm. All visible roots were separated from the soil, washed with water on top of a 0.5-mm sieve to remove the remaining soil, and rinsed with distilled water. The samples of shoots and roots were

Table 1. Outline of treatment arrangement showing crop combinations, cropping system sequences, and legume defoliation regime.

1999		2000		2001
Cropping system[†]	Legume defoliation[‡]	Cropping system	Legume defoliation	Cropping system
Z/B/M	No	Z/B/M	No	Z/B
Z/B/M	Yes	Z/B/M	Yes	Z/B
Z/B/B	-	Z/B/M	No	Z/B
Z/B/B	-	Z/B/M	Yes	Z/B
Z/B/M	No	Z	-	Z/B
Z/B/M	Yes	Z	-	Z/B
Z/B/L	No	Z/B/L	No	Z/B
Z/B/L	Yes	Z/B/L	Yes	Z/B
Z/B/B	-	Z/B/L	No	Z/B
Z/B/B	-	Z/B/L	Yes	Z/B
Z/B/L	No	Z	-	Z/B
Z/B/L	Yes	Z	-	Z/B
Z/B/B (IN)[§]	-	Z/B/B (IN)	-	Z/B
Z/B/B (No IN)[§]	-	Z/B/B (No IN)	-	Z/B
Z/B/B (CM)[§]	-	Z/B/B (CM)	-	Z/B

[†] Crops are represented as Z = maize, B = common bean, M = mucuna, and L = lablab; [‡] Defoliation regime indicated as no = no defoliation occurring and yes = mucuna or lablab herbage above 10 cm removed at season end as fodder, and a dash (-) indicates absence of forage legume; [§] Control treatments abbreviated as maize and beans IN = Inorganic N fertilized, No IN = No inorganic N applied, and CM = cattle manure applied.

oven dried at 60°C for 48 h, weighed, and grounded for the determination of N concentration. Nitrogen concentration of the plant samples was determined using the Kjeldahl digestion with concentrated sulphuric acid followed by calorimetric determination of N (Anderson and Ingram, 1993). Nitrogen accumulated in the harvested biomass and litter fall was calculated by multiplying biomass N concentration by quantity.

Grain and stover/straw dry matter yield of maize and beans

The common bean was harvested at the end of July (all treatments) and the maize was harvested in mid-November. Maize grain yield at 135 g kg^{-1} moisture concentration and stover dry matter (DM) yield were recorded. Common bean grain and straw DM yields were also measured from the same sampling unit. The comparison of 1 year versus two consecutive years of residue application was made using 2001 maize (November) and bean (August) data from plots where legume residue was incorporated only in the second production cycle (2000/2001) and plots where legume residue was incorporated in both cycles (1999/2000 and 2000/2001). The long-term residual effects of residue application on common bean and maize yields were evaluated using 2001 maize (November) and bean (August) data from plots where legume residue was incurporated in March 2000 (1999/2000 production cycle), but not March 2001 (2000/2001 cycle).

Statistical analyses

To assess the effect of legume cropping system, defoliation regime, and cropping sequence (number of years of residue application), and their interactions on biomass yield, legume N concentration and accumulation, the above and below-ground legume fraction data were analyzed using the general linear model procedure of SAS (SAS, 2001). The maize and bean data were also analyzed using the same procedure. Single degree of freedom contrasts were used to compare controls with green manure treatments. Treatments were considered differently at $p \leq 0.10$.

RESULTS AND DISCUSSION

Effect of one versus two years of consecutive residue application

Legume biomass

The three-way interaction of legume × defoliation × cropping sequence was significant ($p = 0.062$) for leaf mass (Table 2). Undefoliated mucuna had a higher leaf mass than lablab on the one-year residue plots ($p = 0.002$) and tended to have more ($p = 0.105$) on the two-year residue plots. Defoliated mucuna had a higher ($p < 0.001$) leaf mass than D-L in both sequences. Defoliation reduced ($p < 0.01$) leaf mass of both legumes in both one- and two-year residue plots.

The interaction of legume, defoliation regime, and cropping sequence on stem herbage mass was also significant ($P = 0.018$). Stem mass of UD-L was higher ($p = 0.003$) than UD-M on the two-year residue plots but not ($p = 0.551$) on the one-year residue plots (Table 2). Stem mass of D-M was higher ($p = 0.012$) than D-L on the two-year residue plots and tended to be higher ($p = 0.140$) on the one-year residue plots. Thus, unlike leaf mass, which was consistently greater for mucuna, stem mass tended to favor lablab for undefoliated plots and mucuna for defoliated plots. Defoliation of mucuna reduced ($p = 0.003$)

Table 2. Effects of cropping sequence (1 year versus 2 consecutive years of legume), legume species, and defoliation on residue biomass of mucuna and lablab relay cropped in maize during the 2000/2001 season.

Treatments	Leaf	Stem	Litter	Roots	Total legume residue
	t ha^{-1}				
1 year legume					
UD-M†	1.69	1.52	1.53	0.27	5.01
D-M	0.73	0.88	1.33	0.27	3.21
UD-L	0.76	1.74	0.20	0.30	2.89
D-L	0.13	0.68	0.21	0.25	1.15
2 years legume					
UD-M	1.41	1.17	1.99	0.24	4.81
D-M	0.78	1.41	2.23	0.32	4.74
UD-L	0.96	1.94	0.06	0.34	3.31
D-L	0.12	0.57	0.15	0.22	0.96
Effects	**P values**				
Legume (L)	< 0.001	0.919	< 0.001	0.898	< 0.001
Defoliation regime (D)	< 0.001	< 0.001	0.897	0.525	< 0.001
L × D	0.669	< 0.001	0.961	0.131	0.095
Cropping sequence (CS)	0.900	0.552	0.331	0.898	0.233
L × CS	0.128	0.850	0.197	0.898	0.388
D × CS	0.669	0.227	0.657	0.898	0.382
L × D × CS	0.062	0.018	0.763	0.335	0.081
SE	0.11	0.11	0.15	0.02	0.33

† UD-M = Undefoliated mucuna; D-M = defoliated mucuna; UD-L = undefoliated lablab; D-L = defoliated lablab.

stem mass on the one-year residue plots but not ($p = 0.267$) on the two-year residue plots; however, defoliation of lablab reduced stem mass in both one- ($p = 0.036$) and two- ($p < 0.001$) year residue plots.

In agreement with the literature (Van Noordwijk and Purnomisidi, 1992) mucuna had a greater litter biomass than lablab ($p < 0.001$; Table 2). Root mass was not affected by treatments, but lablab root comprised a higher percentage of total biomass (10%) than mucuna (5%), in agreement with Tian and Kang (1998).

The three-way interaction of legume by defoliation by cropping sequence for total residue mass was significant ($p = 0.081$). Undefoliated mucuna had a higher ($p = 0.058$) total residue mass than UD-L on the one-year plots and tended to yield more ($p = 0.103$) on the two-year plots. Defoliated mucuna had a higher residue mass than D-L on both the one- ($p = 0.011$) and two- ($p < 0.001$) year residue plots. Defoliation of mucuna decreased ($p = 0.073$) residue mass on one-year residue plots, but did not ($p = 0.918$) affect residue mass on two-year plots. Defoliation of lablab decreased residue mass on both one- ($p = 0.033$) and two- ($p = 0.004$) year plots.

Generally mucuna total residue biomass was greater than for lablab, and defoliation reduced residue mass, except for D-M on the two-year residue plots which yielded as much as UD-M. The generally higher residue biomass for mucuna vs. lablab plots was due to the greater leaf and litter biomass for mucuna treatments.

The greater amounts of mucuna biomass suggest that it was more adapted to growth under shading by maize and to the dry conditions following maize harvest than lablab. Legume biomass under the intercrop were in the lower end of the range reported by Wortmann et al. (2000) from the highlands of East Africa when mucuna and lablab were grown in rotation with maize.

Legume N concentration

Legume and defoliation regime effects on leaf N concentration were significant (Table 3). Undefoliated legumes contained higher ($p = 0.036$) leaf N than defoliated treatments. Lablab leaf N concentration was greater ($P = 0.003$) than for mucuna.

Stem N concentration was affected by both legume ($p < 0.001$) and the interaction of defoliation regime × cropping sequence ($p = 0.049$). Mucuna stem had a higher N concentration than lablab ($p < 0.001$). Defoliation × sequence interaction effects occurred because defoliation tended to reduced stem N concentration on the

Table 3. Effects of cropping sequence (1 year versus 2 consecutive years of legume), legume species, and defoliation on residue N concentration of mucuna and lablab relay cropped in maize.

Treatments	Leaf	Stem	Litter	Roots	Total legume residue
	g kg^{-1}				
1 year legume					
UD-M†	36.8	18.9	8.0	17.5	21.8
D-M	35.7	17.4	8.1	18.4	18.9
UD-L	43.2	15.0	13.0	13.7	22.6
D-L	39.1	11.0	15.4	12.4	15.4
2 years legume					
UD-M	34.8	17.7	8.0	16.7	19.1
D-M	33.7	17.3	7.8	15.6	15.4
UD-L	45.4	13.0	15.1	13.2	22.3
D-L	36.9	12.8	12.6	11.2	13.4
Effects	**P values**				
Legume (L)	0.003	< 0.001	0.003	< 0.001	0.823
Defoliation regime (D)	0.036	0.018	0.964	0.104	0.008
L × D	0.114	0.328	0.990	0.146	0.203
Cropping sequence (CS)	0.520	0.586	0.904	0.021	0.235
L × CS	0.560	0.618	0.983	0.304	0.335
D × CS	0.577	0.049	0.399	0.191	0.717
L × D × CS	0.557	0.263	0.441	0.578	0.894
SE	1.10	0.63	0.74	0.54	0.93

† UD-M = Undefoliated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab.

one-year residue plots (p = 0.118), but there was no effect (P = 0.870) on the two-year plots.

Mucuna litter contained lower (p < 0.003) N concentration than lablab, due likely to the greater initial N concentration in lablab leaf. Lower N concentration in the litter fraction than in the leaf was likely due to nutrient resorption during senescence when leaf proteins and other nitrogenous compounds are hydrolyzed and the products are transported into perennial tissues before leaf fall (Norby and Contrufo, 1998). Nitrogen concentration in mucuna roots was higher (p < 0.001) than in lablab concurring with Tian and Kang (1998). The N concentration in the total legume residue was not affected by legume (p = 0.823) and cropping sequence (p = 0.235), but defoliation reduced (p = 0.008) N concentration in the residue.

Legume N content

The three-way interaction of legume × defoliation × cropping sequence for leaf N content (kg N ha^{-1}) was significant (p = 0.045) (Table 4). By virtue of greater leaf mass, undefoliated mucuna had greater (p = 0.003) N content in the leaf fraction than UD-L on one-year plots, but there was no difference (p = 0.628) on two-year plots. Defoliated mucuna had a greater (p = 0.03) leaf N content than D-L on both the one- and two-year plots. Defoliation reduced (p = 0.042) leaf N content of both legumes on both plots. The N content of the leaf fraction of D-M was on the average 48% as great as that from UD-M, but the contribution from D-L was only 4% that of UD-L. Thus the impact of removing top canopy herbage for fodder on amount of residue N incorporated was much greater for lablab than mucuna.

The interaction of legume × defoliation × cropping sequence for stem N content was significant (p = 0.027). There was no difference (p > 0.127) in stem N content between UD-M and UD-L, but D-M had a greater (p < 0.009) stem N content than D-L on both the one- and two-year plots. Defoliation of mucuna decreased (p = 0.004) stem N content on one-year plots, but it did not affect (p = 0.349) stem N content on the two-year plots. Defoliation of lablab decreased (p < 0.055) stem N content on both plots. Mucuna accumulated more N in the litter than lablab (p = 0.001), but defoliation did not affect (P = 0.906) N content in the litter fraction.

The three-way interaction of legume x defoliation x cropping sequence for total residue N content was significant (P = 0.054). Undefoliated mucuna had a higher

Table 4. Effects of cropping sequence (1 year versus 2 consecutive years of legume), legume species and defoliation on residue N content of mucuna and lablab relay cropped in maize.

Treatments	Leaf	Stem	Litter	Roots	Total legume residue
	kg ha^{-1}				
1 year legume					
UD-M†	61.6	28.7	12.2	4.8	107.3
D-M	26.2	15.3	11.1	5.0	57.5
UD-L	31.1	25.2	1.5	4.3	62.0
D-L	5.9	7.4	2.2	3.1	18.7
2 year legume					
UD-M	49.2	20.7	16.2	3.9	89.9
D-M	26.2	24.4	17.4	5.0	73.0
UD-L	43.8	25.4	0.6	4.6	74.5
D-L	4.4	7.3	1.1	2.5	15.3
Effects	**P values**				
Legume (L)	< 0.001	0.005	0.001	0.086	< 0.001
Defoliation regime (D)	< 0.001	< 0.001	0.906	0.403	< 0.001
L × D	0.318	0.004	0.919	0.070	0.119
Cropping sequence (CS)	0.763	0.806	0.475	0.630	0.806
L × CS	0.109	0.961	0.290	0.867	0.696
D × CS	0.846	0.044	0.852	0.994	0.583
L × D × CS	0.045	0.027	0.826	0.404	0.054
SE	4.37	1.82	1.12	0.29	6.93

† UD-M = Undefoliated mucuna; D-M = defoliated mucuna; UD-L = undefoliated lablab; D-L = defoliated lablab.

(p = 0.033) N content in total residue than UD-L in one-year plots, but there were no differences (p = 0.317) in the two-year plots. Defoliated mucuna had a greater N content than D-L on both one- (p = 0.023) and two- (p = 0.002) year plots. Defoliation of mucuna decreased residue N content relative to UD-M on one- (p = 0.005) and two- (p = 0.083) year plots. Defoliation of lablab also reduced residue N content compared to UD-L on one- (P = 0.094) and two- (p = 0.028) year plots. In agreement with previous reports (Tian et al., 2000), mucuna generally accumulated more N in the total biomass than lablab.

Bean grain and straw yield

Mucuna treatments resulted in higher (p= 0.004) subsequent bean grain yield than lablab (Table 5), but defoliation regime had no effect (p = 0.435) on bean grain yield. Mean bean grain yield on plots after 1 year of residue application (437 kg ha^{-1}) was not different (p > 0.830) from those where the residue had been applied for 2 years (446), suggesting that there was no apparent advantage of 2 versus 1 year of residue application. Single degree of freedom comparisons showed that mucuna treatments tended (p = 0.158) to yield higher bean grain yield than the natural fallow, and the yields under mucuna treatments were similar to those from inorganic N (P = 0.847) and cattle manure (p = 0.720).

Legume species affected (p = 0.069) bean straw DM yield (Table 5), with mucuna plots out yielding lablab plots. Defoliation did not affect (p = 0.892) straw DM yield and neither did residue application for 2 versus 1 year (p = 0.764). The yields of bean grain and straw showed that mucuna residue application resulted in higher yields than lablab. The D-M treatment performed particularly well after 2 years of incorporation suggesting that it may have more residual effects than the other treatments. Overall, there was no apparent advantage to applying residue for two consecutive years compared to 1 year.

Bean yield in this study was affected by both low fertility and root rot disease caused by a complex of fungal pathogens (*Fusarium solani*, *Rhizoctonia solani*, and *Pythium spp.*), which have been observed to be severe in western Kenya where bean production is intensive (Otsyula et al., 1998). The beans yields were higher, however than those reported from the highlands of East Africa (Wortmann et al., 2000) when maize-bean intercrops were preceded by mucuna and lablab green manures.

Maize grain and stover yield

There was interaction among legume, defoliation, and

Table 5. Effects of cropping sequence (1 year versus 2 consecutive years), legume species, and defoliation of mucuna and lablab grain and straw yield of common bean intercropped in succeeding maize.

Treatments	Grain	Straw
	kg ha^{-1}	
After 1 year residue		
UD-M†	527	379
D-M	499	357
UD-L	342	299
D-L	380	297
After 2 years residue		
UD-M	428	318
D-M	589	397
UD-L	403	359
D-L	362	290
Controls		
N fertilizer	493	338
Natural fallow	379	310
Cattle manure	544	328
Effects	**P values**	
Legume (L)	0.004	0.069
Defoliation regime (D)	0.435	0.892
L × D	0.408	0.247
Cropping sequence (CS)	0.830	0.764
L × CS	0.752	0.495
D × CS	0.501	0.757
L× D × CS	0.116	0.132
SE	25.74	13.91

† UD-M = Undefoliated mucuna; D-M = defoliated mucuna; UD-L = undefoliated lablab; D-L = defoliated lablab.

Table 6. Effects of cropping sequence (1 year versus 2 consecutive years), legume species, and defoliation of mucuna and lablab on grain and Stover yield of succeeding maize.

Treatments	Grain	Stover
	t ha^{-1}	
After 1 year residue		
UD-M†	5.18	8.04
D-M	4.81	8.93
UD-L	5.59	8.29
D-L	4.69	8.23
After 2 years residue		
UD-M	4.46	8.15
D-M	6.08	11.33
UD-L	6.72	11.05
D-L	3.98	7.12
Controls		
N fertilizer	7.18	11.63
Natural fallow	4.11	9.34
Cattle manure	6.48	9.85
Effects	**P values**	
Legume (L)	0.756	0.616
Defoliation regime (D)	0.030	0.396
L × D	< 0.001	0.012
Cropping sequence (CS)	0.500	0.202
L × CS	0.740	0.403
D × CS	0.976	0.771
L × D × CS	0.002	0.035
SE	0.21	0.48

† UD-M = Undefoliated mucuna; D-M = defoliated mucuna; UD-L = undefoliated lablab; D-L = defoliated lablab.

cropping sequence for maize grain yield ($p = 0.002$) (Table 6). After 1 year of residue application, there were no differences ($P > 0.553$) between mucuna and lablab in maize grain yield. When the legume residue was applied for two consecutive years, D-M resulted in higher ($p = 0.028$) maize grain yield than D-L, but UD-L attained higher ($p < 0.006$) grain yield than UD-M, suggesting that residual effects may be greatest with D-M and UD-L.

Defoliation of both mucuna and lablab tended ($p = 0.123$) to decrease maize grain yield after 1 yr of residue application, but after 2 yr of residue application, defoliation of mucuna increased ($p = 0.053$) the grain yield compared to UD-M, but D-L resulted in a reduction ($p < 0.001$) in maize grain yield compared to UD-L. For maize grain yield, there tended to be an advantage of applying the residue for 2 compared to 1 year for D-M ($P = 0.134$) and UD-L ($P = 0.059$) but not for UD-M and D-L.

Single degree of freedom comparisons showed that the average legume treatment after 2 years of incorporation resulted in higher ($p < 0.055$) maize grain yield than the natural fallow control. The differences were greater ($p < 0.026$) when only the undefoliated treatments were compared to the natural fallow. Defoliated mucuna and UD-L out yielded ($p = 0.033$ and $P = 0.005$, respectively) the natural fallow, but UD-M and D-L did not. Also the inorganic N and cattle manure treatments out yielded ($p < 0.001$, and $p = 0.002$, respectively) the natural fallow. The yields from UD-L plots were similar ($p = 0.444$) to those from cattle manure, but both UD-L and D-M, which yielded the highest maize grain yields among the legume residue treatments, were lower ($p = 0.048$ and $P = 0.007$, respectively) yielding than the inorganic N control.

There was interaction of legume type × defoliation regime × cropping sequence on maize stover yield ($p = 0.035$) (Table 6). After 2 years of residue application, D-M resulted in higher ($p < 0.001$) stover yield than D-L, and there was a trend ($p = 0.131$) for UD-L to out yield UD-M. Also, D-L had a lower ($p = 0.017$) stover yield compared to UD-L, whereas D-M had a greater ($p = 0.095$) stover

Table 7. Residual effects of mucuna and lablab residue application in March 2000 on grain and straw yield of common bean intercropped in succeeding maize in 2001.

Treatments	Grain	Straw
	kg ha^{-1}	
UD-M[†]	437	376
D-M	433	310
UD-L	553	365
D-L	268	267
Controls		
N fertilizer	493	338
Natural fallow	379	310
Cattle manure	544	328
Effects	**P values**	
Legume (L)	0.766	0.593
Defoliation regime (D)	0.112	0.123
L × D	0.120	0.753
SE	22.7	12.1

[†] UD-M = Undefoliated mucuna; D-M = defoliated mucuna; UD-L = undefoliated lablab; D-L = defoliated lablab.

yield relative to UD-M. There was no apparent advantage of applying residue for two consecutive years on maize stover yield, except for UD-L which achieved higher (p = 0.032) yield than after 1 year of residue application. Stover yields of D-M and UD-L treatments were not different than the inorganic N and cattle manure controls.

Both residue quality and total residue N incorporated seem to be important in subsequent maize response. Undefoliated lablab residue consisted of a higher proportion of stem than UD-M and the stem was of lower N and higher lignin concentrations (Palm et al., 2001) than that of mucuna. Defoliation of mucuna reduced the proportion of leaves and increased the proportion of stems (Table 2), which contained lower N and higher lignin concentrations. These differences suggest that residues of both UD-L and D-M were of intermediate quality relative to UD-M (high) and D-L (low). The data on maize grain and stover yields suggest that UD-M may have released nutrients rapidly, and some may have been lost before they were taken up by the long maturity maize hybrid, whereas UD-L and D-M likely released nutrients in greater synchrony with crop demand. Defoliation of lablab resulted in such a large biomass reduction that the beneficial effects of lowered residue quality could not be realized in the first year.

Long-term residual effects of residue application

Bean grain and straw yield

The residual effect of mucuna and lablab residue applied prior to the year 2000 growing season (March) on the year 2001 bean and grain yield is reported in Table 7. The interaction of legume and defoliation approached significance (p = 0.120) because defoliation had no effect (p = 0.966) on mucuna plots but tended to affect (p = 0.107) lablab plots. Single degree of freedom contrasts showed that the yields under UD-M were comparable (p = 0.254) to D-M, but UD-L yielded higher (p = 0.098) bean grain yield than D-L. The bean yields from legume residue treatments were not different (p > 0.10) than those from the three controls.

Maize grain and stover yield

The effect of legume and defoliation on maize grain and stover yield from plots where the legume residue was applied the previous season were not significant (Table 8). Single degree of freedom contrasts showed that yields were higher under D-M (p = 0.052), UDL (p = 0.085), and D-L (p = 0.005) plots than the natural fallow, but yields under UD-M only tended (p = 0.144) to be higher. Also inorganic N and cattle manure treatment yields were higher (p < 0.001, and p = 0.004, respectively) than the natural fallow. The yields on D-L plots were comparable (p = 0.450) to inorganic N plots, but on D-M (p = 0.024) and UD-L (p = 0.013) plots, they were lower than inorganic N. The yields of maize grain suggest that D-M, UD-L, and especially D-L likely had greater residual effects, possibly because of the lower residue quality of these treatments (Palm et al., 2001). The response to D-L may have occurred because after defoliating lablab, which has an upright growth habit, the stubble left behind comprises mainly the stem fraction, which contains low N and high lignin concentration. Thus this low quality resi-due results in slower decomposition and nutrient release (Handayanto et al., 1997; Vanlauwe et al., 1997; Palm et al., 2001), reducing losses and enhancing nutrient use efficiency and residual effects. The residual effects from legume residues is in agreement with previous reports (Ramos et al., 2001) and suggests that farmers could intercrop legumes in alternating years and still realize some benefit from residue application in the year following no application, especially for residues having low leaf: stem ratio, low N concentration and high lignin concentration.

Conclusions

Inclusion of green manure legumes as relay intercrop into the current maize-bean system increased subsequent maize yields. Defoliation of mucuna reduced the residue quality but apparently enhanced the efficiency of nutrient use and in some cases resulted in higher maize yields. In contrast, defoliation of lablab, the residue of which is of lower quality than mucuna, resulted in lower maize grain yield in the year of incorporation due to a greater proportion of biomass and N being removed when clipped to a 10 cm stubble (because of its upright growth habit).

Table 8. Residual effects of mucuna and lablab residue application in March 2000 on grain and stover yield of succeeding maize in November 2001.

Treatments	Grain	Stover
	t ha^{-1}	
UD-M†	5.2	9.0
D-M	5.6	8.9
UD-L	5.5	9.1
D-L	6.6	9.5
Controls		
N fertilizer	7.2	11.6
Natural fallow	4.1	8.8
Cattle manure	6.5	9.9
Effects	**P values**	
Legume (L)	0.349	0.675
Defoliation regime (D)	0.229	0.824
L × D	0.541	0.738
SE	0.17	0.36

† UD-M = Undefoliated mucuna; D-M = defoliated mucuna; UD-L = undefoliated lablab; D-L = defoliated lablab.

These results suggest that incorporating residues from the legume intercrop for 2 compared to 1 year may result in increased maize grain when residues contain a higher stem proportion and lignin concentration and a lower N concentration (UD-L and D-M). For higher quality residue (UD-M), there may be no benefit. Also, these data suggest that carryover effects on maize yield following a year with no residue incorporation is significant and likely to be greater for residues of moderate (UD-L and D-M) to low quality (D-L). The results indicate that farmers have flexibility in the use of these legumes in intercropping systems. They may not need to use legumes every year to achieve a maize yield response, and defoliation of top-canopy biomass for use as livestock fodder appears to be a viable option, especially for mucuna.

ACKNOWLEDGEMENTS

The logistical support provided by the Center Director, Kenya Agricultural Research Institute, Kitale and the assistance of other staff, particularly David Shitandi is highly appreciated. We are grateful for the financial support provided by the Rockefeller Foundation.

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