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Velvet Bean and Cowpea Residual Effects on Maize Crop in Smallholder Farming Areas of Zimbabwe

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Abstract

On-farm research was conducted in Dendenyore Communal Land and Zana Resettlement areas of Hwedza District, Zimbabwe from 1999 to 2001. The objective of the study was to evaluate the effects of velvet bean and cowpea on growth and yield of maize in legume-maize rotation system. A total of 14 treatments, which consisted of forage legume and maize crops were examined. The experiment was established in a randomized complete block design with 9 replicates. On-farm sites were the replicates. The results show a significant residual effect of velvet bean and cowpea, when grown with single super phosphate fertiliser, on the maize stover and grain yield. They indicate significant phosphorus residual effects on a subsequent maize crop on sandy soils. Forage legumes contribute to residual soil fertility in fallen leaves and roots that increases yield of subsequent crops. The results also reveal that biomass production in perennial leys, grazed during the dry season, would be greater in the second season than in the establishment year. The results also indicate that in the velvet bean systems, especially green manure, nitrogen is lost very early in the season. This may lead to lack of synchrony between nutrient availability and crop uptake. The maize after green manure system had a nitrogen use efficiency of about 11 kg/kg of nitrogen applied. These results show the residual potential of forage legumes in reducing nitrogen fertiliser need for subsequent maize crops in mixed livestock-cropping systems.

Keywords: *Mucuna pruriens*, *Vigna unguiculata*, livestock-cropping systems, residual effect, yield, soil fertility

1. Introduction

In Zimbabwe, for improved fallow (or forage legume ley) management practice to be adopted by crop - livestock farmers, the practice should enhance dry season feed supply for livestock and improve soil fertility for the intended cropping systems. Recently, McCarty *et al.* (2016) indicated that an improvement of existing fallow management systems with sown legumes has the potential to enhance the restoration of soil fertility through the accumulation of organic matter and fixation of atmospheric N₂ thereby improving N availability in the soil as well as improving soil physical properties (McCarty *et al.*, 2016). Suitable crops include legumes with multiple uses (e.g. grain, feed or fodder) with potential to alleviate feed constraints for cattle, especially during the dry season, where crop residues are used to feed cattle (Dubeux *et al.*, 2015). This is because legume crop residues have higher nutritive value compared with most forage materials that would normally be found on natural fallow (Dubeux *et al.*, 2015). Testing of suitable legumes for both livestock production and cropping has been attempted in a few cases in Thailand, Sri Lanka and Syria (IRRI, 2009). However, due to different climatic conditions the technologies may not be easily adapted to Zimbabwe conditions. In sub-humid West Africa, where Annan-Afful *et al* (2004) measured the effects of fodder bank pastures on subsequent crop production, strategic research on improved fallow or ley systems for crop livestock systems started only relatively recently.

This study evaluated the effects of velvet bean and cowpea on growth and the biomass and grain yield of maize in legume - maize rotation system. The results are compared with the response of maize on the same sites to nitrogen fertilisation after natural fallow, and after maize.

2. Materials and Methods

2.1 Sites Description

On-farm research was conducted at selected sites in Dendenyore Communal Land and Zana Resettlement Areas of Hwedza District, Zimbabwe (18°41' S latitude; 31°42' E longitude; 1400 m asl), about 140 km south east of Harare and 70 km from Grasslands Research Station, Marondera, in Natural Regions IIb and III. The research was done over two cropping seasons, 1999/2000 and 2000/2001 seasons. The soils in the district are generally deep brown sands formed from granitic rocks and classified as Ferralic Arenosol (Giller, 2001) with small patches of sandy clays classified as Chromic Luvisols derived from ultramafic lava and intrusion parent material. Mean annual rainfall ranged from 600-1000 mm/annum with most rain falling between November and March. Mid-season droughts were not uncommon during the research period. During the 1999/2000 season, total rainfall recorded for Zana resettlement and Dendenyore communal areas in Hwedza District averaged about 900 mm (Figure 1). This amount was more than the average annual precipitation in the last three years (810 mm). The season was favourable for nearly all crops, though the lack of rain soon after the first effective rainfall in November and December affected the establishment of some of the crops, and the unusually copious rains during the month of February interfered with weeding operations, increased pest incidence and prolonged the days to maturity for most of the crops. However, this allowed late-planted crops to reach normal maturity. Despite some dry spells, all crops made satisfactory growth.

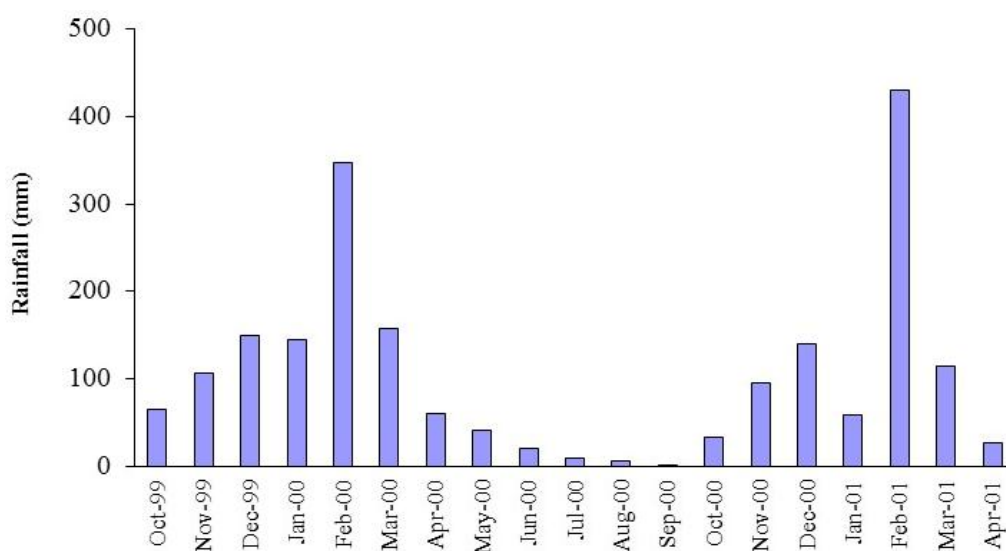


Figure 1. Rainfall data (mm) for the two experimental seasons (1999/00 and 2000/01) for Hwedza district

2.2 Trial Details

The trial to compare legume integration systems was conducted at nine on-farm sites which included two clay and six sandy sites, and one sand loamy site. This variation between the sites enabled the comparison of a large number of treatments over a wide range of soils and management. The trials involved a legume phase as well as weed fallow and sole maize as controls, followed by a maize cropping phase for all annual legume treatments.

2.3 Experimental Design and Number of Replications

The experiment was established in a randomized complete block design with 9 replicates (one replicate per farmer). This was a compromise between the small land areas at the sites and the number of treatments and technologies that were to be explored. Having one replicate per site allowed for comparison of a large number of treatments per given area. It also allowed broader testing of promising treatments across different soil conditions and allowed for the examination of the relationship between soil factors and responses to SSP and lime.

2.4 Treatments List and Descriptions

A comparison was made of forage supply and subsequent rotational benefits of *Mucuna pruriens* var. *utilis* (velvet bean), *Vigna unguiculata* (cowpea) and *Zea mays* (maize) grown as leys, intercrops or green manure. *Macrotyloma axillare* cv. *Archer* (archer) mixed with *Chloris gayana* (Katambora Rhodes grass) was grown as a ley in both seasons to compare its forage production with velvet bean and cowpea. With maize-velvet bean

intercropping, velvet bean was planted two weeks after maize to reduce competition effects. Partial nutrient balances were determined during the trial period.

The experiments commenced with the first effective rainfall. The different forage legume cropping systems were initiated in the 1999/2000 season. During the 2000/2001 season maize yield and soil fertility, under the different season 1 treatments, were monitored. Legumes were inoculated with appropriate rhizobia and received single superphosphate (SSP), which was broadcast and incorporated before planting at the rate of 200 kg/ha (except for the without SSP treatments). Farmers had indicated their willingness to use some fertilizer even on the forages. As per farmer practices, fields were to be accessible to livestock during the dry season. All maize was fertilized with basal (300 kg/ha Compound D) and top dressings (200 kg/ha Ammonium Nitrate) as per the farmer practice.

2.5 Varieties of Forage Legumes, Grass and Maize

The following legumes were used in the trials:

1. *Mucuna pruriens* var. *utilis* (velvet bean): the main crop in this project, obtained from local seed sources
2. *Vigna unguiculata* (cowpea, ex-Matopos variety)
3. *Macrotyloma axillare* cv. Archer (Archer): a perennial legume.

The following grasses were used:

1. *Chloris gayana* (Katambora Rhodes grass): a grass used for grazing and for nematode control.
2. *Zea mays* (maize, a Seed Co-op medium season hybrid variety (SC513) recommended for Hwedza farming area and tolerant to grey leaf spot).

A list of the treatments tested in this experiment are shown in Table 1.

Table 1. List of treatments used in the main trials in 1999/00 and 2000/01 seasons.

1999/00 treatments	2000/01 treatments
Weed fallow	Maize (30 kg N ha ⁻¹ applied as AN)
Sole maize (full rate inorganic fertiliser ¹ i.e. 93 kg N/ha: 18 kg P/ha: 18 kg K/ha and 19.5 kg S/ha)	Maize (full rate inorganic fertiliser i.e. 93 kg N/ha: 18 kg P/ha: 18 kg K/ha and 19.5 kg S/ha)
Maize-velvet intercrop (full fertiliser rate)	Maize (full fertilizer rate)
Ley velvet bean with SSP ²	Maize (30 kgNha ⁻¹ applied as AN)
Ley velvet bean without SSP	Maize (30 kgNha ⁻¹ applied as AN)
Ley velvet bean with SSP	Ley velvet bean without SSP
Ley velvet bean without SSP	Ley velvet bean with SSP
Ley cowpea with SSP	Maize (30 kgNha ⁻¹ applied as AN)
Ley cowpea without SSP	Maize (30 kgNha ⁻¹ applied as AN)
Perennial ley with SSP	Perennial ley without SSP
Perennial ley without SSP	Perennial ley with SSP
Green manure velvet bean with SSP	Maize (30 kgNha ⁻¹ applied as AN)
Green manure velvet bean without SSP	Maize (30 kgNha ⁻¹ applied as AN)
Ley velvet bean with SSP and lime ³	Maize (30 kgNha ⁻¹ applied as AN)

¹Applied as 300 kg/ha Compound D (8%N, 6%P, 6%K, 6.5%S) and 200 kg/ha ammonium nitrate (34.5%N)

²Applied as 200 kg/ha Single superphosphate (SSP) (9% P, 11% S, 20% Ca and 0.5% Mg)

³Dolomitic lime was applied at 500 kg/ha

The trailing cowpea (ex Matopos) was included as a traditional variety with a unique characteristic of being able to grow well on less fertile soils. Archer was included as a perennial forage legume that has been shown to be among the forage legumes best adapted to the soil and climatic conditions such as are found in Hwedza (Muza, 1998). Velvet bean is a promising green manure and forage legume (Muza, 1998; Vissoh *et al.*, 1998). Katambora Rhodes grass helps in the control of nematodes, which are common in continuous maize cropping systems.

There were nine farmers participating in the area. Gross plot size was 9 x 8 m, with a net plot of 7 x 6 m.

2.6 Field Management

All fields were ox-ploughed. Maize was overplanted at two seeds per station and thinned to one plant per station

at the three emerged leaf stage. Legumes were planted at two seeds per station and thinned to one plant per station during first weeding. Planting was done at 90 cm x 30 cm, inter-row and in-row spacing, respectively, for maize, velvet bean and cowpea. Maize and velvet bean were intercropped in-row. Weeding was done manually at two and five weeks after crop emergence (WACE). Dolloping of fertilizer to maize, at 300 kg/ha Compound D and 200 kg/ha AN, was done at planting and at five WACE, respectively, to sole and intercropped maize in season 1, and to the maize following these crops in season 2. Ammonium nitrate was split applied to maize at 3 and 6 WACE in season 2. Single superphosphate (SSP) and lime, in season 1, were applied at the rate of 200 kg/ha and 500 kg/ha, respectively. Spraying was done against leaf eaters and aphids in legumes using a combination of carbaryl 85% WP and dimethoate to reduce pest and disease effects on crop performance and yield.

2.7 Seasonal Characteristics

One distinct feature in the 2000/2001 season was the long mid-season drought that occurred soon after the first effective rainfall. This led to most of the crops not attaining their maximum potential in terms of growth and yield. The average rainfall for Hwedza District was about 864 mm. The mid-season drought in December and January negatively affected crop growth and the unusually copious rains during the month of February interfered with weeding operations, increased pest incidence and prolonged the days to maturity for most of the crops.

2.8 Pests and Diseases

No major pests were encountered despite the long dry spell that induced rapid aphid (species of Aphididae) infestation on velvet bean and cowpea. The velvet bean variety used, however, showed less susceptibility to pests and diseases compared to the other legumes. Dipterex was used for stalk borer control on maize. No pests were identified on Archer and Katambora Rhodes grass.

2.9 Harvesting Procedures and Measurements

Harvesting was done 130 days after planting from an area measuring 42 m². The border area (1 m) was excluded from the harvested area. The maize and the legume components of the intercrop were harvested separately. The maize ear was removed from the stalk, dehusked and the kernels extracted. The legumes were cut at ground level and weighed immediately after cutting. Archer and Katambora Rhodes grass were cut at about 10 cm above the ground to facilitate regrowth. Sub-samples were taken from freshly harvested materials, weighed, dried at 60°C for 48 hours and then re-weighed for dry matter (DM) content determination and estimation of DM yield. The dry samples were used for N and P analysis. Maize grain and stover sub-samples were also collected from the bulk sample and weighed immediately to enable maize stover and grain DM yield determination.

2.10 Soil and Plant Analyses

Composite soil samples were collected in season 1 from each replication, i.e. samples were collected from each plot and mixed for each replicate (thus 18 samples: 9 replicates x 2 depths of 0-15 cm and 15-30 cm). After this first sampling all other samplings (at harvesting in year 1 and at planting in year 2) were done per plot. Soil sampling in all the plots was done at Year 1 harvest. Soil samples were analysed for available P, total N, K, C, Mg, Ca and pH_(CaCl2). The soils were analysed for total soil N by acid digestion (Bruce, 1997), total organic carbon by combustion, P using the Bray II method, while K, Ca and Mg were done by analyzing leachate using spectroscopy and pH was determined by the calcium method (Bruce, 1997). In the second season, soil sampling in the weed fallow, green manure velvet bean (with P) and velvet bean hay (with lime and P) plots was done at selected sites, representing different soil conditions, to determine N leaching. This sampling was done at pre-planting, planting, 1 week after crop emergence (WACE), 2 and 4 WACE. The samples were analyzed for mineral N and carbon. This decision to reduced analysis in year 2 was based to cost and known behaviour of certain nutrients within short time periods.

2.11 Maize Harvesting

Harvesting was done 132 days after planting in the net plots after removing a 1 m border row on the gross plot size. The maize cobs were then removed from the stalk and de-husked. The legumes and maize stover (maize crop residue without kernels) were cut at ground level and weighed immediately after cutting. Six samples for dry matter (DM) determination and chemical analysis were collected per plot. They were weighed at the same time as the bulk weighing and taken to the laboratory and dried at 60°C for 48 hours and then reweighed for DM content determination as well as estimation of the respective DM yields.

2.12 Statistical Analysis

Minitab statistical package was used to analyse the data. Treatment differences were tested in an Analysis of

Variance and least significant difference was used to calculate mean separation. Significance in treatment differences was declared at $P \leq 0.05$.

3. Results and Discussion

3.1 Soil Chemical Properties

The samples taken at the time of harvesting in Year 1 (April 2000), to trace the effects of the different systems on soil chemical properties, indicated a similar pattern in the levels of the nutrient irrespective of the system examined. The light clay soils still had relatively higher concentrations of N, C, Ca and Mg, and low P levels (Table 2). The other soils maintained low levels of all the nutrients. There was, however, a noticeable increase in the percentage of C in the velvet bean plots at some sites. The light clay soils averaged a C content of 1% while the sandy soil sites ranged from 0.2 to 0.5%.

Overall, mineral N concentrations were lower at pre-planting sampling than at planting (after rainfall). This could be because mineralization had been slow before the rains but had accelerated with moisture availability. The lowest pre-planting mineral N concentrations were obtained in the weed fallow system. This could be due to the lack of purely leguminous species in the weed composition, which differed from site to site. Mineral N pre-planting tended to be higher with green manure incorporation. The biggest difference between the mineral N concentration at pre-planting and at planting was observed in the weed fallow system. There was more mineral N in the green manure treatments at planting at the sandy and clay soil sites as compared to the velvet bean hay (with P and lime) and weed fallow treatments. The reason for the similarities in mineral N concentrations between the weedy fallow and green manure velvet bean systems at planting could be due to rapid release and leaching of nitrate N at the time when the rains came and before samples were collected (Giller, 2001).

Table 2. Soil chemical properties at the different sites before planting in the 1999/2000 season, Dendenyore and Zana, Zimbabwe

Site	Soil Type	Soil Depth (cm)	pH	K	Mg	Ca	avai. P	Total N	C	C/N ratio
				(cmol./kg) ¹			(µg/g) ²	%		
Mbavha	Sand	0-15	4.28	0.12	0.06	0.32	17	0.06	0.32	5.3
		15-30	4.02	0.06	0.03	0.12	6	0.05	0.25	5
Ruzane	Sand	0-15	4.32	0.08	0.04	0.19	24	0.03	0.29	9.7
		15-30	4.20	0.10	0.03	0.12	16	0.04	0.24	6
Mumvana	Sand	0-15	4.42	0.12	0.06	0.29	11	0.04	0.34	8.5
		15-30	3.97	0.10	0.04	0.23	3	0.04	0.20	5
Mapira C	Sandy loam	0-15	4.53	0.22	0.11	0.41	10	0.04	0.40	10
		15-30	4.28	0.13	0.14	0.59	4	0.04	0.27	6.8
Mapira A	Sand	0-15	4.35	0.13	0.09	0.17	8	0.05	0.44	8.8
		15-30	4.27	0.08	0.04	0.15	3	0.04	0.28	7
Chikumbirike	Sand	0-15	4.27	0.11	0.06	0.06	4	0.03	0.40	13.3
		15-30	4.21	0.11	0.06	0.07	3	0.04	0.32	8
Dzuna	Blackish clay	0-15	5.20	0.26	2.67	3.74	1	0.11	1.24	11.3
		15-30	5.14	0.20	3.54	4.36	1	0.10	1.19	11.9
Gunzvenzve	Red clay	0-15	4.42	0.20	1.69	2.89	1	0.09	1.03	11.4
		15-30	5.22	0.12	2.70	4.78	1	0.08	0.89	11.1
Munamati	Sand	0-15	4.23	0.12	0.06	0.26	11	0.05	0.33	6.6
		15-30	4.15	0.10	0.08	0.31	4	0.04	0.25	6.3

¹equivalent to meq/100g ²Bray P

3.2 Biomass Yield Assessment

Sole maize stover yield increased significantly ($P < 0.05$) in year 2 when compared with year 1 maize stover yield (3.9 and 4.3 t DM/ha respectively), probably due to differences in seasonal rainfall temporal distribution. Maize stover yield was lowest in the maize following weed fallow plot (2.9 t ha⁻¹) and the highest maize stover yield was in the maize following velvet bean with SSP application. Compared with maize following the weed fallow, maize stover yield was significantly increased following velvet bean with SSP (with or without lime), cowpea with SSP and green manure velvet bean with or without SSP (Table 3). Maize stover yield was higher when maize was grown after velvet bean with SSP than after velvet bean without SSP (Table 3).

Table 1 shows the yields (maize stover and grain, velvet bean and perennial ley DM) obtained in year 2 after the

various year 1 treatments. Yields from clay and sandy loam soils were generally higher than yields from sandy soils. This could be due to generally higher inherent soil fertility in clay and loam soils compared to sandy soils (Bationo, 2007).

When velvet bean with SSP was grown after velvet bean (biomass removed) without SSP an 8% increase in the total DM yield was effected (comparing years 1 and 2) (Table 4). However, when velvet bean (biomass removed) was grown without SSP after velvet bean with SSP, the total DM yield was reduced by 39%. There was no response to P in year 1, which could imply that factors other than P might be limiting DM yield (Bationo, 2007).

The Archer and Katambora Rhodes grass plots gave interesting results. There were significant increases in total DM ($P < 0.05$) in the Archer and Katambora Rhodes plots in the second season as compared to the first season (Table 4). There was a three-fold increase in the DM yield of the perennial plot in the second year, with no significant differences between plots fertilized with P in the first or second year.

Table 3. Hay, maize stover and grain yield (t/ha DM) in the different cropping systems at different sites in season 2

Treatment	Mbavha (Sandy)	Mumvana (Sandy)	Mapira A (Sandy)	Chikumbirike (Sandy)	Mapira C (Sandy Loam)	Gunzvenzve (Clay)	Dzuna (Clay)	Treatment means
Maize (full rate) after sole	1.3	2.1	4.8	2.4	7.3	7.8	5.2	4.3
maize (full rate): stover								
maize grain	0.9	1.8	4.2	1.8	5.7	4.6	4.3	3.3
Maize (+ 30 N) after	0.9	1.8	5.3	2.7	4.5	4.1	3.5	2.9
weed fallow: stover								
maize grain	0.6	1.0	1.9	1.2	2.3	3.2	2.0	2.1
Velvet bean after	3.7	6.9	8.9	6.0	9.8	9.4	8.8	7.6
velvet bean (SSP)								
Velvet bean (SSP) after	2.3	2.0	4.4	2.7	5.6	6.2	6.3	4.2
velvet bean								
Maize (+ 30 N) after velvet	3.2	2.8	3.2	2.6	3.8	3.8	3.1	3.2
bean: stover								
maize grain	2.9	1.1	0.7	1.1	1.3	2.8	3.2	1.8
Maize (+ 30 N) after velvet	4.2	9.0	9.4	6.9	9.1	9.8	8.9	8.1
bean (SSP): stover								
maize grain	3.9	3.1	2.3	2.6	3.7	3.1	2.9	3.1
Maize (+ 30 N) after velvet	3.2	3.1	4.9	4.8	4.5	6.5	6.7	4.8
bean (SSP + lime): stover								
maize grain	3.0	2.6	3.6	2.7	2.8	4.9	5.6	3.6
Perennial ley after	7.4	11.0	14.6	4.6	15.7	15.6	14.4	11.9
perennial ley (SSP)								
Perennial ley (SSP) after	7.2	12.5	14.1	5.6	10.4	14.6	9.8	10.6
perennial ley								
Maize (+ 30 N) after	1.4	2.1	5.3	2.6	6.2	5.6	3.9	3.8
cowpea: stover								
maize grain	1.0	1.5	2.3	2.0	4.2	3.9	2.6	2.5
Maize (+ 30 N) after	4.2	4.8	5.8	3.7	6.9	5.8	5.5	5.2
cowpea (SSP): stover								
maize grain	2.8	2.9	3.5	2.8	3.2	4.1	4.4	3.4
Maize (+ 30 N) after green	2.9	2.2	5.9	4.0	4.1	6.5	7.6	4.7
manure velvet bean: stover								
maize grain	1.4	1.9	2.8	1.3	3.8	3.5	4.5	2.8
Maize (+ 30 N) after green	4.9	2.6	6.5	4.2	6.4	7.1	6.8	5.5
manure velvet bean (SSP):								
stover								
maize grain	3.2	2.2	3.2	1.9	3.6	4.1	3.7	3.1
Maize (full rate) after maize	3.9	1.6	6.7	1.2	5.4	5.1	4.7	4.0
velvet intercrop (full rate)								
maize grain	0.3	0.9	3.6	0.9	3.7	3.7	3.6	2.4
Site means: Maize stover	3.0^a	3.2^a	5.8^b	3.5^a	5.9^b	6.2^b	5.6^b	
Maize grain	2.0^a	1.9^a	2.8^b	1.9^a	3.5^b	3.8^b	3.7^b	

Means followed by the same letter are statistically similar ($P \leq 0.05$)

Table 4. Dry matter yield (t/ha) for legumes grown following legumes with or without P fertilization and with biomass removal

Year 1 treatment	Year 1 DM yield (t/ha)	Year 2 treatment	Year 2 DM yield (t/ha)	Year 1 + Year 2 DM (t/ha)
Velvet bean (-P)	7.1 ^b	Velvet bean (+P)	7.7 ^b	14.8 ^y
Velvet bean (+P)	6.9 ^b	Velvet bean (-P)	4.3 ^a	11.1 ^x
Archer + Katambora Rhodes grass (-P)	2.8 ^a	Archer + Katambora Rhodes grass (+P)	11.9 ^c	14.6 ^y
Archer + Katambora Rhodes grass (+P)	3.2 ^a	Archer + Katambora Rhodes grass (-P)	10.6 ^c	13.8 ^y

Year 1: CV = 42.72%; S.E of treatment means = 764.5

Year 2: CV = 32.85%; S.E of treatment means = 1247.37

Means followed by the same letter are statistically similar ($P \leq 0.05$)

3.3 Grain Yield

Due to the mid-season drought in the second year, sole maize grain yields in the first and second years were similar (stover yields in year 2 were greater than year 1). There were significant differences ($P < 0.05$) between the maize grain yields following the different season 1 treatments. The highest grain yields were obtained in the fully fertilised maize after sole and intercropped maize plots ($3.1 - 4.3 \text{ t ha}^{-1}$) and maize with low N following velvet bean with SSP and lime (Table 3). Cowpea with SSP resulted in a significantly higher ($P < 0.05$) maize grain yield as compared to the cowpea without SSP. Velvet bean without SSP also led to significantly lower ($P < 0.05$) yields as compared with velvet bean with SSP irrespective of whether the velvet bean was incorporated or not. The lowest was obtained in the maize following velvet bean without SSP plot (1.6 t ha^{-1}). Presence of legume in the intercrop did not apparently benefit the following maize crop. Thus, there were no apparent soil fertility benefits to the following maize crop.

The amount of green manure biomass incorporated was strongly related to the maize grain yield obtained. Overall, there was an increase of more than 300kg in maize grain yield for every tonne of green manure incorporated (Figure 2). This was a nitrogen use efficiency of about 11 kg grain/kg N applied (Figure 3).

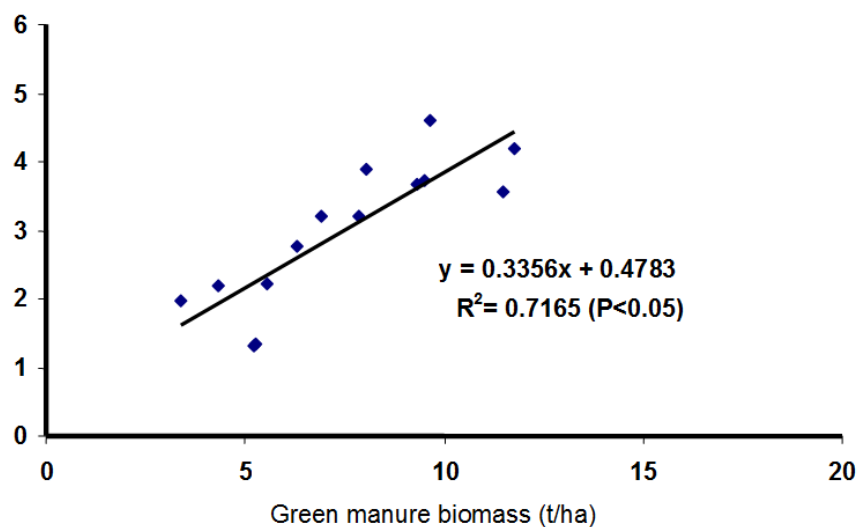


Figure 2. Response of maize grain yield to previous velvet bean green manure biomass yield

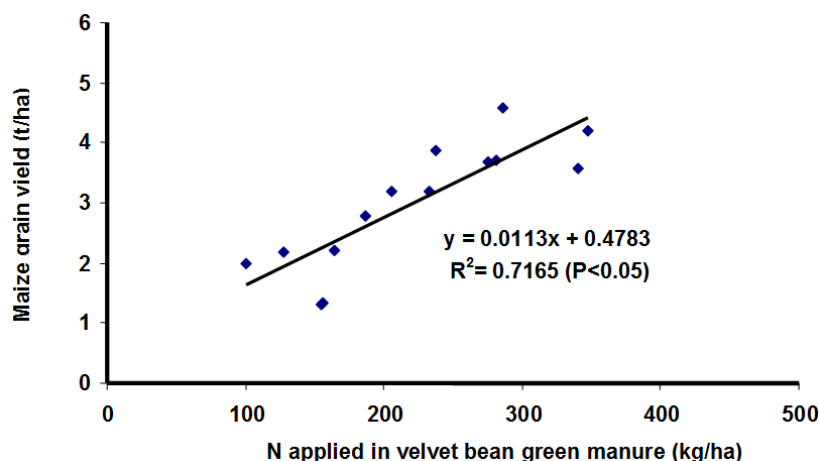


Figure 3. Response of maize grain yield to the amount of N in previous velvet bean green manure

Comparison was also made of the maize grain yield responses after cowpea hay, velvet bean hay (i.e. above ground biomass was removed to simulate a farmer who would make hay from cowpea and velvet bean) and velvet bean green manure (all without SSP) relative to maize grain yield after weed fallow (Figure 4). Removal of velvet bean above-ground biomass led to low (negative or just positive) relative maize grain yield in the following maize crop, while removal of cowpea above-ground biomass (for hay) or incorporating velvet bean biomass led to positive relative maize grain yield over maize after weed fallow (Figure 4). It was not possible to compare the legume systems with SSP to weed fallow, as there was no weed fallow with SSP. Relative maize grain yield was most positive after green manure velvet bean without SSP on the sandy soils, indicating possible P residual effects on these soils. On the clay soils, the just-positive value indicates that there may be no residual P effect on these soils (Figure 4).

A comparison of the maize grain yield responses after cowpea hay, velvet bean hay (i.e. above-ground biomass removed) and velvet bean green manure (all without SSP) relative to maize grain yield after weed fallow indicated that removal of velvet bean above-ground biomass led to low relative maize grain yield in the following maize crop. This was because in the second season, the only source of nutrient before application of top dressing N were decomposed roots and fallen leaves as well as from N_2 fixation.

Although there was a strong correlation between maize grain yield in season 2 and the amount of green manure biomass applied in season 1 (Figure 2), enhancements in grain yield would have been expected but the mid-season drought resulted in poorer yields than anticipated from early crop growth. Until the mid-season drought, large differences in maize growth were observed. Velvet bean green manure led to variable but generally positive increases in the grain yield when compared with situations where the above ground biomass was removed (Figure 4). However, the N use efficiency was only about 11 kg/kg N applied. This was probably due to lack of synchrony between release of the nitrogen and crop uptake since the biomass was incorporated in April 2000 and the crops were planted end November 2000. Velvet bean green manure was incorporated soon after harvesting (mid-April 2000) to avoid being eaten by stray livestock. At that time of the year the soils will still be moist and some decomposition of the plant residues will occur before the onset of the hot dry months of August to November. Some of the mineralized nitrogen could have been lost through leaching, erosion, volatilization and denitrification, while some of it becomes part of the recalcitrant organic matter (Giller, 2001; Mapfumo *et al.*, 2013). There was some significant leaching in the weed fallow, velvet bean with SSP and in velvet bean with lime systems. This is supported by findings from Whitbread *et al.*, (2004).

Removal of above ground biomass led to variable but generally positive increases in the grain yields as the green manure systems. This response means the significant contribution of roots and fallen leaves (already decomposed) by the time of harvest. Although there were no measurements taken to ascertain the contribution of the below ground biomass, these results show that the root biomass has more incremental effect on maize stover and grain yield in velvet bean systems when left intact than when the above ground biomass is incorporated and roots ploughed up. This could possibly be due to slower decomposition of hay crop roots compared with green manure, enhancing synchrony in cases where the above ground biomass was removed. At some sites there were no significant differences in those plots where the above ground biomass was removed and those where it was

incorporated, pointing to the fact that it may not be economic to use the above ground biomass for green manure. It can be used for livestock feed, for instance, and the remaining below ground biomass would still contribute significantly to soil fertility. Of course, there could be long term benefits of the above ground biomass such as increase in organic matter, but this was beyond the scope of this project.

Green manure velvet bean with P led to similar maize stover yields to green manure without P. Cowpea with P led to a 34% stover yield increment compared with cowpea without P. The velvet bean hay systems without P did not seem to have any positive effects on the following maize stover DM yields compared with maize after weed fallow. These results indicate the importance of P application to the legume prior to a subsequent maize crop on sandy soils. They precisely show that P has significant residual effects on sandy soils. Although maize grain yield was grossly affected by the mid-season drought that occurred, a comparison of the maize grain yield from the different systems reveals that the velvet bean without P systems led to the least yields. The P-fertilized legume systems (green manure, velvet and cowpea) resulted in similar grain yields. This shows the great residual effect P-fertilized legumes had on the following maize crop on sandy soils. However, there would be no residual benefit in applying SSP to a previous legume crop on the clay soils as of the P would be fixed and unavailable for crop use. However, applying P to the legume would generally promote legume growth and, therefore, subsequent maize growth. Furthermore, the application of P to legumes may stimulate nitrogen fixation and may have carry-over effects in terms of C, N and P on the main crop (Olsen *et al.*, 2015).

There were large increases in Archer and Katambora Rhodes grass mixture in the second year (Table 4). The DM yield levels averaged 11.2 t ha⁻¹ in the second season. This shows the potential of this system for forage production. It also supports the argument that biomass production in this system would be higher from the second season onwards as the perennial Archer and Katambora Rhodes grass would then be growing more vigorously. Farmers can apply P to the first year Archer and Katambora Rhodes grass and the residual P would be enough for the second season.

Better fallow and residue management can help accelerate soil restoration and improve traditional cropping systems (Waddington, 2003). An improved fallow, if properly managed, would add substantial amounts of fixed N and organic matter to the soil, recycle nutrients from the subsoil, provide an effective cover against soil erosion, suppress weeds and pests, and improve soil physical conditions (Vanlauwe *et al.*, 2013).

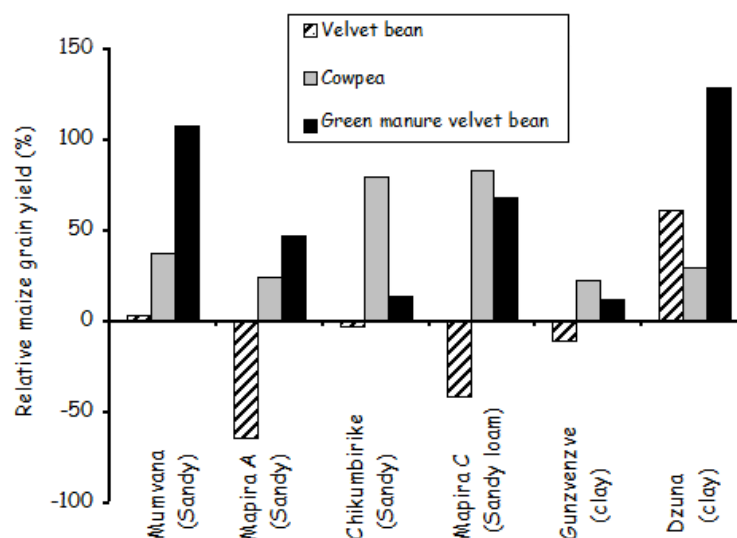


Figure 4. Relative maize grain yield following velvet bean (biomass removed), velvet bean (green manured) and cowpea (biomass removed), all without SSP (maize grain yield after weed fallow as the control)

4. Conclusion

These results show a significant residual effect of velvet bean and cowpea, when grown with SSP, on the maize stover and grain yield. They indicate significant P residual effects on a subsequent maize crop on sandy soils. Farmers would need to apply P every season on clay soils. Forage legumes contribute much to residual soil fertility in fallen leaves and roots that increases yield of subsequent crops. The results also indicate that in the velvet bean systems, especially green manure, N is lost very early in the season. This leads to lack of synchrony

between nutrient availability and crop uptake. From these results, however, farmers would benefit, in terms of maize grain yields, from adopting the velvet bean green manure systems than systems where the above ground biomass was removed. The maize after green manure system had a nitrogen use efficiency of about 11 kg/kg N applied. However, the mid-season drought may have overruled treatment differences due to reduced overall N demand due to decreased growth potential. The results also reveal that biomass production in perennial leys, grazed during the dry season, would be greater in the second season than in the establishment year. Good growth of the perennial leys indicates that the plants survived the grazing well.

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