The Potential of Green Manures to Increase Soil Fertility and Maize Yields in Malawi

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Abstract

The effect of sole maize and green manures (*Mucuna pruriens*, *Crotalaria juncea* and *Lablab purpureus*) on maize for two successive cropping seasons was determined in an on-farm experiment at five locations in Malawi, from 1996 to 1999. Legume residues were incorporated in two different manners; “early” at peak biomass and “late” when the plants started to senesce.

After growing and incorporating the green manures after the end of the 1996/97 growing season, maize was planted in 1997/98 and 1998/99 to test the effect of the legumes on maize yields compared with continuous maize. Biomass production from “early” incorporated legume residues were 6.7 t ha^{-1} for Mucuna, 4.9 t ha^{-1} for Crotalaria, and 4.9 t ha^{-1} for *Lablab purpureus*; and for “late” incorporated legume residues were 5.9, 5.2 and 4.1 t ha^{-1} for the same legumes, respectively. Of the three legumes *Lablab purpureus* produced less biomass (averaged 4.2 t ha^{-1}), compared with the other two green manures and Mucuna produced the highest seed yield. Over the two seasons and across the five sites, the application of inorganic fertiliser (35 or 69 kg N ha^{-1}) to maize significantly increased maize yields in all the sites. Maize yields following green manures without inorganic fertiliser additions were much higher than yields from continuous maize with no fertiliser addition. Addition of inorganic fertiliser to legume crop residues resulted in increased maize yields at all the sites, but the highest fertilizer use efficiency was obtained from the addition of 35 kg N ha^{-1}. There were no significant maize yield differences when maize followed early or late incorporated green manures across season and sites for all the three legumes. Results indicate that all the three green manures have potential to increase maize yields when used as sole green manures or in combination with inorganic fertilizers compared to sole maize alone, following each other.

Introduction

Smallholder farmers in Malawi are confronting a difficult set of conditions that threaten not only their livelihoods, but also their abilities to feed themselves and their families. Over the past twenty-four years, Malawi has experienced a series of periodic drought that requires food relief by international agencies. Structural reforms imposed, as a condition for development aid, required the removal of subsidies for farm inputs, which in turn reduced farmers access to materials required to modernise agriculture. Continuous cropping and soil erosion has led to soil degradation. But despite these setbacks, several promising new technologies have emerged that offer promise to better manage agricultural resources. One such technology is the use of nitrogen-fixing green manure legumes (Giller and Wilson, 1991). A green manure legume is one that is grown specifically for use as organic manure and maximises the amount of N from the legume that is available for a subsequent crop.

Apart from periodic drought and effects of structural adjustments in Southern Africa, and in particular Malawi, some of the major causes of low maize yields are declining soil fertility and insufficient use of fertilisers resulting in severe nutrient depletion of soils (Buresh *et al.*, 1997). Inorganic fertilizers are unaffordable by most smallholder farmers in Malawi (Kumwenda *et al.*, 1997). Use of green manures in combination with inorganic fertilizers is a less expensive way of increasing soil fertility and consequently maize yields compared with the use of inorganic fertilizers alone. Although the use of green manures in Malawi was first initiated more than 70 years ago (Sakala, 2000), intensive research on green manures gained momentum in the 1990s.

Large increases in growth and yield of crops sown after incorporation of green manures have been reported, for example, maize yields have more than doubled by incorporation of a 3-month-old green manure of *Mucuna pruriens var. utilis* or *Crotalaria juncea* grown in alluvial soil on the island of Java, Indonesia (Hairiah and van Noordwijk, 1989). Simple decision aids based on chemical and physical characteristics of the green manures have been developed to guide scientists, as well as farmers, in choosing the legumes which are suitable for improving soil fertility (Palm *et al.*, 1997). This paper summarises the results of an experiment which was initiated to:

(i) determine biomass production of early and late incorporated legume manures
(ii) determine the effects of legume manures on the subsequent maize yields, and
(iii) test the effect of combining organic and inorganic fertilisers on maize yield.

Materials and Methods

An experiment with three legumes that were to be incorporated late (after seed was harvested) was started in the 1995/96 cropping season. The experiment was sited both on station and on-farm. During this season all the on-farm sites were not successful because animals ate all the legume crops as incorporation was scheduled after maize harvest. This led to a new experiment, which included an early incorporation treatment (before seed harvest) in 1996/1997 cropping season. This trial was initiated at Bembeke, Mathambi, Mbawa, Chitedze and Kamwendo. The site location characteristics are presented in Table 26.1.

A split plot design was used and seven treatments were arranged in randomised complete block, with 3 replications. Each plot was 18 rows, 10 m long. The treatments for the 1996/97 seasons were: Sole Mucuna (*Mucuna pruriens*), with early incorporation at maximum flowering and pod initiation incorporation, sole Mucuna, with late incorporation after harvest of Mucuna seed or grain, sole Crotalaria (*Crotalaria juncea*), with early incorporation as in I, Sole Crotalaria with late incorporation as in II, sole *Lablab purpureus* with early incorporation as in I, sole *Lablab purpureus* with late incorporation as in II and sole Maize crop (NSCM 51). In the 1997/98 and 1998/99 cropping season, maize a hybrid maize NCM51 was planted on the 7 main-plots following Mucuna, Crotalaria *or Lablab purpureus* legume crop residue, each incorporated early or late,

Table 26.1: Experimental site location characteristics where the experiment was conducted between 1996 to 1999

Trial site location	Evaluation (masl)	Lati-tude	Longi-tude	Soils	Rainfall range (mm)	Rainfall variabilty
Bembeke	1219-1585	34° 25’	14° 21’	Ferallitic Latosols	800-1,270	Low
Mathambi	1200-1810	35° 21’	16° 01’	Ferallitic Latosols	2,000-2,400	Low
Mbawa	1219-1250	33° 25’	12° 07’	Weakly Ferallitic Lotosols,	700-1,200	Medium
Chitedze	1097-1372	33° 38’	13° 59’	Ferruginous Latosols	700-1,200	Medium
Kamwendo	1067 – 1158	38’ 02’	13° 50’	Weakly Ferallitic Latosols	700-1,100	Medium

and a pure continuous maize crop. Each main-plot had 3 sub-plots consisting of inorganic fertilisers which were added as packages as follows: 1) no fertiliser, 2) 35:10:0:+2S kg ha^{-1}, and 3) 69:21:0+4S kg ha^{-1} (N:P_2O_5:0+S). A split plot design was used and these treatments were arranged in a randomised complete block design with three replications. Each main plot had 18 rows while each sub-plot had 6 rows, each 10 m long. In plots, which had fertilizer, the basal fertiliser was applied at planting and the source was 23:21:0+4S and the top-dressing source was urea (46%N) that was applied three weeks after planting. Maize was planted at a rate of 44,000 plants per hectare. Maize yield was determined by harvesting 4 middle rows of each sub-plot, 9.1 m long each and the yield was adjusted to 12.5% moisture content. Mucuna and *Lablab purpureus* were planted at 74,407 seeds per hectare (90 cm x 15 cm x 1 plant). Crotalaria was drilled on the ridge, double row per ridge, at 45 kg of seed per hectare. Maize seed was planted at 44,000 seeds per ha^{-1} (0.9 m x 0.75 m x 3 plants). The pure crop of maize received 35:10:0+2S (N:P_2O_5+S) per hectare of fertiliser from 23:21:4S as a basal fertiliser and from urea as a top dressing fertiliser. The aboveground biomass was measured at each incorporation time, early or late (after seed harvest). Legume seed or grain yield of late incorporated legume manures was also determined. Seed yield of legume manures was determined by harvesting 18 rows x 10 m long each. Legume seed yields are reported for Mucuna and Crotalaria only because *Lablab purpureus* started flowering late and therefore seed was not harvested.

Maize yield was determined by harvesting 16 middle rows, 9.1 m long each, and adjusted to 12.5% moisture content. Maize and green manure yields were analysed by use of general statistical program

(GENSTAT), developed at Rothamsted experimental station (Payne, 1978). Analysis of variance was the main procedure used for testing significances of differences between means.

Results

The soils from the experimental sites were slightly acidic and pH ranged from 5.8 to 6.2 (Table 26.2). Bembeke was more acidic compared to the other sites. All sites had low organic carbon, which is a common characteristic of most soils from farmer's fields in Malawi. The exchangeable cations were also on the low side.

Table 26.2: Soil chemical characteristics for some experimental sites

Sites	pH	Total N ppm	OC %	P mg kg^{-1}	Ca mg kg^{-1}	K mg kg^{-1}	Mg mg kg^{-1}
Bembeke	5.9	45.1	1.8	5.7	1.8	0.7	0.3
Kamwendo	5.8	18.5	1.0	0.4	0.8	0.3	0.2
Mathambi	5.3	43.7	1.8	8.8	1.4	0.4	0.3
Chitedze	6.2	19.5	2.1	1.5	3.3	0.3	0.2

Crotalaria took a shorter time than the other legumes to attain maximum flowering stage, which ranged from 64 to 85 days after planting, followed by Mucuna, which ranged from 122 to 142 days after planting. Mucuna and Crotalaria were incorporated when the soil was still wet because they reached maximum flowering while the rainy season was still in progress. *Lablab purpureus* flowered very late, hence, early incorporation was thus done before flowering. At the date of early incorporation, Mucuna had accumulated the highest dry matter (5 to 11 t ha^{-1} and averaged 6.7 t ha^{-1}) followed by Crotalaria, which averaged 4.9 t ha^{-1} (Figure 26.1).

The biomass for late incorporated Mucuna ranged from 3.8 to 7.9 and averaged 5.9 t ha^{-1}, Crotalaria biomass ranged from 3.8 to 8.6 and averaged 5.2 t ha^{-1} and Lablab ranged from 0 to 8.9 and averaged 4.0 t ha^{-1}. Total nitrogen contribution to the soil ranged from 164 kg N ha^{-1} for late incorporated Lablab to 367 kg N ha^{-1} for early-incorporated Mucuna.

The highest maize grain yield 2.1 t ha^{-1} and seed yield of Crotalaria 1.7 t ha^{-1} were obtained at Chitedze in 1997/98 season (Table 26.3). The highest seed yields of Mucuna were obtained at Chitedze (1.8 t ha^{1}). Mucuna seed yield was also higher than for maize or Crotalaria at Kamwendo, Bembeke, and Mbawa. This shows that Mucuna like other legume crops can grow well even on poor soils.

Figure 26.1: Mean dry matter (t ha^{-1}) yields of early and late incorporated legume green manures at five sites in 1996/97 cropping season

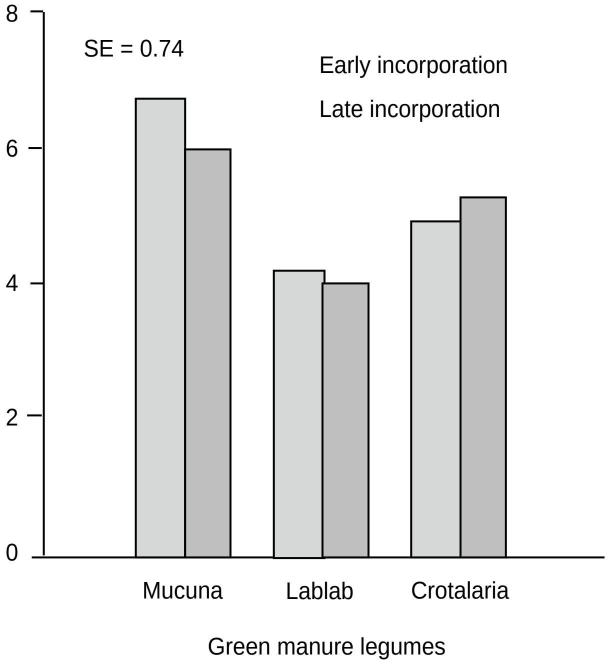

Table 26.3: Seed and grain yield (t ha^{-1}) of legume crops and maize at test sites, 1996/97 cropping season

Site	Maize	Mucuna	Crotalaria
Chitedze	2.1	1.8	1.7
Kamwendo	0.1	1.2	0.5
Bembeke	0.6	-	0.5
Mbawa	0.9	1.1	0.1
Mathambi	-	2.5	0.5
Mean	0.9*	1.7**	0.7

* Mean from 4 sites only; the farmer harvested the maize.

** Mean from 4 sites only. Mucuna did not flower at Chitala and Bembeke.

All the three green manures used in this experiment had a high N content at flowering time (4%) (Table 26.4). The N content for the three legumes were within the ranges of these green manures, which were extracted from the organic resource database compiled by the Tropical Soil Biology and fertility programme indicated in (Table 26.4).

Table 26.4: Chemical quality characteristics of Mucuna, Crotalaria and Lablab at flowering time

Legume	%N	C:N ratio	Lignin (%)	Lignin: N ratio
Mucuna	(5.5) 1.4-6.5	9.8-30.8	5.5-16.8	1.3-8.3
Crotalaria	(5.3) 1.6-5.7	8.0-32.1	3.8-9.8	1.0-6.3
Lablab	(4.1) 1.7-6.3	7.4-29.1	2.6-11.5	0.4-9.8

Source: Organic Resource Database Manual

( ) %N measured from the experiment.

When maize was planted following the three legumes and sole maize for two successive seasons at five sites, maize grain yield differed with maize following green manures having similar yields which were significantly higher (P 0.05) than maize yield from plots where maize was being grown continuously (Table 26.5). There were no significant maize yield differences for each legume due to time of green manure incorporation. Bembeke site had the least average maize yields during the two seasons and Chitedze had the largest average maize yield when grown after the green manures.

Table 26.5: Average maize grain yield following three legumes incorporated early or late at five sites in 1997/98 and 1998/1999 seasons

Legume incorporation	Bembeke	Mathambi	Mbawa ($t\ ha^{-1}$)	Chitedze	Kamwendo	Legume Mean
Mucuna early	1.3	2.4	3.1	4.4	1.7	2.7
Mucuna late	1.8	2.3	3.4	3.5	1.9	2.9
Crotaralia early	1.9	2.8	3.7	4.2	1.9	3.0
Crotaralia late	0.9	2.6	3.5	3.6	2.0	2.8
Lablab early	2.0	1.4	3.4	4.2	2.0	2.7
Lablab Late	1.3	1.8	3.1	4.0	1.9	2.7
Maize	1.1	1.9	2.6	2.5	15	2.1
Site Mean	1.5	2.2	3.3	3.8	1.8	

	Legume	Site	Interaction
Significance	0.001	0.001	0.001
SED	0.09	0.09	0.02
CV (%)	6.1	36	36

Cross season and cross sites analysis showed that at all the five sites, the application of inorganic fertilisers increased maize yield (Table 26.6). An increase in fertilizer application resulted in greater maize yield increases in plots where maize had followed a legume compared with plots where maize was grown continuously. Legume residue incorporation resulted in large maize yield increases for the two seasons that maize followed the green manure planted in the first year at all the five sites compared with continuous maize with no fertiliser additions. Again larger responses were obtained when fertilizer was combined with inorganic fertilizer. There were no significant differences in maize yields due to different types of legumes that were planted in the first season. The mean for two seasons showed no significant yield differences between maize yield following their incorporation. The effect of time of incorporating legume residue was not evident across the five sites for the two seasons.

Table 26.6: The effect of three different rates of inorganic fertilizer following legumes or sole maize on the grain yield of maize across five sites for two seasons 1997-1999

Legume time incorporation	0	35:10:0+2S	69:21:0+4S	Legume Mean
		(t ha^{-1})		
Mucuna early	2.1	2.6	3.5	2.7
Mucuna late	2.2	2.6	3.5	2.8
Crotaralia early	2.2	3.1	3.7	3.0
Crotaralia late	1.8	2.9	3.6	2.8
Lablab early	2.0	2.8	3.4	2.7
Lablab late	1.7	2.9	3.4	2.7
Maize (Control)	1.2	2.2	2.7	2.0
Fertiliser Mean	1.9	2.7	3.4	2.7
	Legume	Fertilizer	Interaction	
Significance	0.001	0.001	Ns	
SED	0.09	0.07	0.02	
CV (%)	6.1	8.7	8.7	

A combination of organic and inorganic fertilizer increased fertilizer use efficiency at both rates of inorganic fertilizer (35 and 69 kgNha^{-1}) that were applied together with the green manures that were incorporated during the first season compared to where inorganic fertilizers were applied alone. Although fertilizer use efficiency was increased by combining organic and inorganic fertilizer, the fertilizer use efficiency was much higher when lower rates of 35 kgNha^{-1} were applied for both year one (when the green manures had just been incorporated) and year two (when the fertilizer was added after one season from the time when green manures were incorporated). There were no marked differences in fertilizer use efficiency due to combination of organic and inorganic between year one and year two at each level of fertilizer added to incorporated green manure, except for early Mucuna incorporation which had a significantly reduced fertilizer use efficiency in the second year when 35 kgN ha^{-1} of inorganic fertilizer were added. On the other hand, late incorporated Mucuna had a slightly increased fertilizer use efficiency in the second season at both rates of inorganic fertilizer added to the green manures. Highest fertilizer use efficiency was realised from early-incorporated Crotalaria at both rates of fertilizer combination over the two season combined compared with the other two green manures that were used. For *Lablab purpureus* both early and late incorporation had similar fertilizer use efficiency (in the first and second season for each rate of fertilizer combined with the green manure).

Discussion

Dry matter accumulation of the green manures and their effect on maize yield

Dry matter accumulation varied among legume species because sampling for dry matter and incorporation was done when each legume had reached its maximum flowering stage. Late incorporation tended to have lower biomass because biomass was measured after seed had been harvested and during this time most leaves had senesced and started falling down This affected the final biomass yield. Again, aphids severely infested*Lablab purpureus* at Kamwendo and Mbawa and consequently resulted in reduced dry matter yield at these sites (averaged 4.2 t ha^{-1}). *Lablab purpureus* had the lowest total nitrogen contribution to the soil due to low biomass yield as well as low nitrogen content compared to the other legumes. Mucuna seed yield was also highest compared with*Lablab purpureus* and Crotalaria at Kamwendo, Bembeke, and Mbawa. This suggests that Mucuna unlike other green manure crops can grow well even on poor soils.

Significance of high N content on the three green manures

All the three green manures had N content of more than 4% N, which is an indication of better quality (Palm *et al.*, 1991). Nitrogen release from crop residues can be slow or rapid, depending on the quality of the residues. With the high N content, it is likely that these legumes will be able to release nitrogen for use by the plant when incorporated into the field. Both slow and rapid release of nutrients from organic fertilisers can have positive effects on nitrogen management in the soil (Sakala *et al.*, 2000). Rapid release enhances early nitrogen uptake by the crop but may lead to nitrogen loss through leaching if crop demand is less than the amount of nitrogen being released. Slow release would guarantee a continuous supply of nitrogen during most of the growing period of the crop, although, if the amount of nitrogen released is small its contribution to crop growth may not significantly boost crop performance

Nitrogen use efficiency

Maize yields increased with the application of green manures and inorganic fertilizers separately or in combination. However, the combination of 35 kg N ha^{-1} and any of the three green manures produced the highest efficiency in the first year of green manure application as well as in the second year, when residual effects of the green manures were being tested.

Conclusion

Results from this study have shown that early-incorporated Mucuna produced the largest biomass, which averaged 6.7 t ha^{-1}, followed by Crotalaria, which produced 4.9 t ha^{-1}. Biomass from late incorporated legume manures were lower than from early incorporated legume manures, due to the loss of leaves by harvest time. Application of organic and inorganic fertilisers separately or in combination, increased maize yields at all sites, but higher fertilizer use efficiency was obtained when the green manures were combined with 35 kg N ha^{-1}. Growing maize after legume residues resulted in increased maize yields compared with growing maize after maize. There was no difference between early and late incorporation of legume residues, when the data were pulled for two seasons. These results show that these three legume residues can be potential alternative sources of fertilisers for a following maize crop.

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