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THE ROLE OF GREEN MANURE LEGUMES IN SMALLHOLDER FARMING SYSTEMS IN KENYA: The Legume Research Network Project

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SUMMARY

Low soil fertility is a major constraint hampering the productivity of Kenyan smallholder farms. Green manure (GM) legume technologies were introduced in 1994 by the Legume Research Network Project (LRNP) as an accessible technology to arrest soil degradation and maintain soil fertility. The Network, with diverse members working across the country, has conducted research to identify promising GM legume species for different agro-ecological zones, to determine inoculation and P fertilization needs of the species, to evaluate GM legumes as a component of integrated nutrient management, and to assess the value of the legumes in controlling striga (*Striga hermonthica*), a noxious weed common in western Kenya. An overview of the research results is presented here. Also presented are the potential niches for GM legume technologies and the way forward for the LRNP.

Key words: Maize-based cropping systems, soil fertility improvement, green manure legumes.

INTRODUCTION

The soil fertility problem

As in most of the Sub-Saharan African countries, a major constraint to smallholder farming in Kenya is declining soil fertility (Smaling *et al*., 1997). Smallholder farms, about 2 ha on average, are usually cultivated continuously without adequate replenishment of plant nutrients. Smaling and Braun (1996) reported nutrient mining in smallholder farms in Kisii District in southwest Kenya to be 112 kg nitrogen (N), 3 kg phosphorus (P) and 70 kg potassium (K) ha^{-1} yr^{-1}. Soil erosion on most smallholder farms is severe due to hilly terrain, poor cultivation practices and inadequate soil erosion control. A two-year study conducted in central Kenya in 1991 and 1992 revealed that soil loss ranged from 0.8 to 247.3 t ha^{-1} and that runoff ranged from 1 to 89 mm (Gachene *et al*., 1997). The high cost of inorganic fertilizers coupled with low returns and unreliable markets for agricultural produce have limited the use of fertilizers by the majority of smallholders in Kenya (Hassan *et al*., 1998). The most common method of maintaining soil fertility is the application of farmyard manure, but its quality is usually low because of poor handling and poor quality feeds for livestock (Lekasi *et al*., 1998). Traditional fallows are no longer feasible because of the diminishing size of land holdings.

Legumes can play a major role in improving farm productivity in smallholder agriculture as short-term fallow species (Hudgens, 2000). They can increase plant nutrient supply in the soil (especially N) and improve soil physical characteristics, thereby improving crop yields (Yost and Evans, 1988; Peoples and Craswell, 1992; Muller-Samann and Kotschi, 1994). Legumes can also provide good ground cover, thereby minimizing soil erosion through a reduction of raindrop impact and runoff (Lal *et al*., 1991). Intercropping purple vetch (*Vicia benghalensis*) with maize (*Zea mays*) in central Kenya reduced cumulative soil loss over an eight-month period by three fold compared to bare plots which had 7.1 t ha^{-1} cumulative soil loss (Gachene and Haru, 1997). In addition, grain legumes, being rich in protein, are important as food, while herbaceous and tree legumes are commonly used as livestock feeds (Peoples and Craswell, 1992; Weber, 1996).

Legume Research Network Project

Efforts were undertaken in 1994 to introduce green manure cover crops in Kenya (Dyck, 1997). The Legume Screening Network was formed to primarily evaluate and identify suitable "best-bet" legume species for the different regions (Dyck, 1997). The Network later expanded its activities and, as a result, changed its name in 1998 to the Legume Research Network Project. The LRNP covers eleven sites located in the major agro-ecological zones of Kenya (Figure 1; Table 1). The Network has already provided information on suitable legumes for different regions of Kenya to many non-governmental (NGOs) and government organizations. Preparation of a legume database is at an advanced stage. To ensure that GM legume seeds are available to organizations interested in introducing them to Kenyan farmers, all Network members are bulking seeds of their "best-bet" legumes. The Network is mainly funded by the Rockefeller Foundation (RF) and Kenya Agricultural Research Institute (KARI) and is housed by KARI at the National Agricultural Research Laboratories (NARL).

This paper reports results of six Network studies and highlights the way forward for future Network activities:

1. Screening herbaceous legumes for soil fertility improvement
2. Response of "best-bet" legumes to rhizobia inoculation
3. Response of legume species to phosphorus application
4. Management of legume biomass (i.e. residue) in maize-based cropping systems
5. Green manure legumes as a component of integrated nutrient management strategy
6. Effect of green manure legumes on control of striga (*Striga hermonthica*) weed.

Highlights of research

1. *Screening herbaceous legumes for soil fertility improvement*

Altogether 43 legume species were screened in the 11 Network sites for a period of 2 years (Table 2). Some legume species were obtained locally (e.g., common bean [*Phaseolus vulgaris*], cowpea [*Vigna unguiculata*], and lablab [*Lablab purpureus* cv Rongai]) and others were acquired from outside the region (e.g., USA and Australia). Some temperate species were included in the cooler sites but buck-wheat (*Fagopyrum esculentum*), a temperate species and a non-legume, was tested at each site because of its wide usage for weed control and as a cover crop. The screening was conducted under optimal conditions, which included inoculation of legumes and application of P at the rate of 20 kg P ha^{-1}. The criteria for selection included biomass production, nodulation and nitrogen fixation, ground cover, and pest and disease resistance.

Based on their phenology and cumulative dry matter production, the legumes were classified into two groups: (1) short duration crops with fast emergence and substantial biomass production within 2-3 mo of growth, and (2) long duration legumes with slow establishment and 6-12 mo or longer to yield substantial biomass (Dyck, 1997). Among the legumes that produced the highest amount of biomass after three months were *Vicia dyscarpa* (lana vetch) and *Crotalaria juncea*. *Crotalaria* species performed well in most sites. Buckwheat produced flowers within four weeks and senesced after two months. These short-duration legumes are suitable for short-term fallow systems. The long duration green manure legume included species such as *Desmodium uncinatum*, *Calapogonium mucunoides* (calopo) and *Neonotonia wightii* (glycine). These legumes are suitable for medium to long-term fallow systems.

The most outstanding legumes across the sites were identified based mainly on biomass accumulation (Table 3). They included *Mucuna pruriens* (velvet bean), *Lablab purpureus, Crotalaria ochroleuca* (sunnhemp), and *Canavalia ensiformis* (jackbean).

Farmers' perception of the green manure legumes was also assessed in all Network sites, as it is key to the adoption of the legumes. In Gatanga, perceptions of 19 farmers were evaluated through informal visits and semi-structured interviews in 1999, two years after the screening trial was concluded (Mureithi *et al*., 2000a). The Gatanga site has a hilly terrain and soil erosion is a major constraint to farming. The farmers identified the following four characteristics as important in green manure legumes:

1. High biomass production, to have plenty available for incorporation into the soil. They considered that velvet bean gave the highest biomass yield.

2. Rapid establishment of ground cover, for effective control of soil erosion and weeds. Velvet bean was preferred because of its fast establishment.

3. Alternative uses, particularly as human food and livestock feed.

4. Legumes with soft stems (e.g., velvet bean and lablab), which are easy to chop prior to incorporation, were preferred over those with hard stems (e.g., sunnhemp).

Table 1. Legume Research Network sites.

Site name	Elevation (masl)	Temperature range (°C)		Annual rainfall (mm)	Cropping seasons		Soil type*
		Min.	Max.		Long rains	Short rains	
Machakos	1600	12	27	750	October-December	March-August	Luvisol
Kabete	1700	11	23	1000	March-August	October-December	Nitisol
Gatanga	1500	13	25	1100	March-August	October-December	Nitisol
Kitale	1890	11	29	1100	April-December	None	Ferrasol
Kisii	1750	15	25	2000	February-July	September-January	Nitisol
Kakamega	1560	14	26	1900	February-July	October-December	Nitisol
Karurina	1280	13	27	1100	March-August	October-December	Nitisol
Gachoka	1070	15	28	950	March-August	October-December	Ferrasol
Matanya	1842	11	29	600	October-December	March-August	Vertisol
Kendu Bay	1190	15	30	1130	March-July	July-December	Vertisol/Ferrasol
Mtwapa	15	20	31	1200	March-August	October-December	Acrisol/Luvisol

*Based on FAO/UNESCO soil classification system.

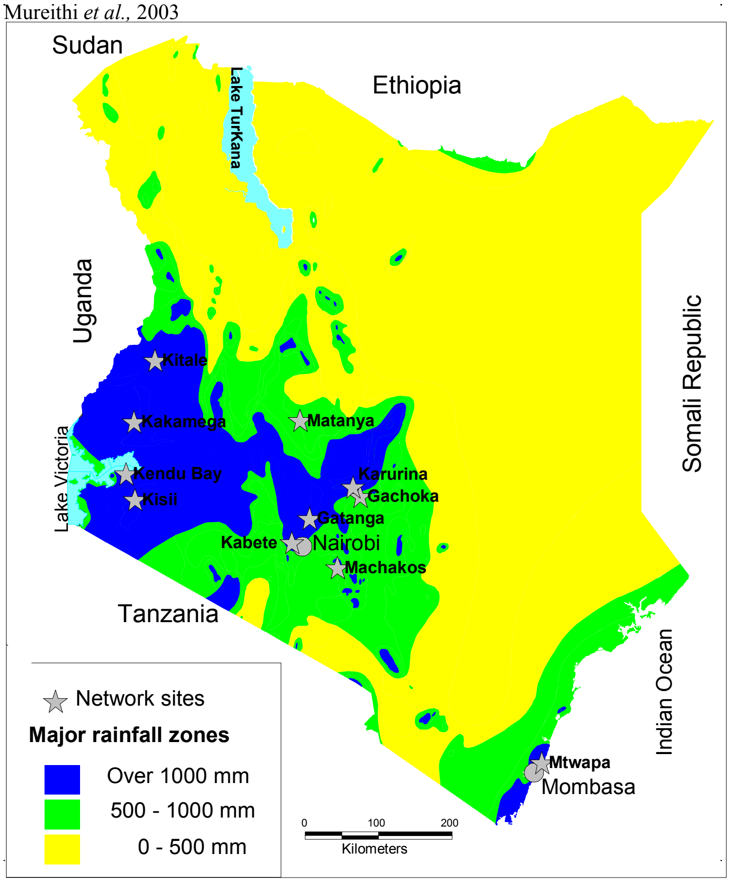

Figure 1. Legume Research Network project sites in Kenya.

2. *Response of "best-bet" legume species to rhizobia inoculation*

Since the majority of farmers in Kenya do not inoculate legume seeds at planting (Woomer *et al*., 1997), a study was initiated to assess the importance of inoculating legume seed with *rhizobia* (Mureithi *et al*., 1998). Eighteen legumes were selected, including those with wide agro-ecological adaptation such as velvet bean, jackbean, lablab and sunnhemp. The study was conducted in all Network sites, except Karurina, Embu, at the beginning of the 1997 long rains. Each legume was inoculated with appropriate *rhizobia* and fertilized with phosphorus (P). Total number and effective nodules per plant were assessed two months and four months after planting.

Significantly, in all the study sites the majority of legumes did not respond to inoculation (Mureithi *et al*., 1998). An obvious factor that can cause such a result is contamination of control plots but this possibility was eliminated through following strict procedures during inoculation, planting, and sampling of nodules. Also, precautions were taken to minimize loss of inoculant viability due to poor storage and handling. Lack of response to inoculation has also been reported in western Kenya by Sustainable Community-Oriented Development Program (SCODP) (Dismas Okello, personal communication) and with common bean in a humic Nitisol at Muguga, central Kenya, and in a ferral chromic Luvisol at Katumani, semi-arid Kenya (Okalebo, 1989).

To test whether the presence of effective native *rhizobia* in the soil may explain the lack of inoculation response, LRNP characterized the indigenous *rhizobia* in the study sites. This study revealed surprisingly low levels of native *rhizobia* (<50 cells g^{-1} soil), a finding not supported by the good performance of the legumes. Also, the *Rhizobium* Ecology Network of East and Southern Africa (RENEASA) found high levels of the cowpea-type promiscuous *rhizobia* in 90% of 40 sites located in eight countries, with population sizes as high as 9275 cells g^{-1} soil in some sites (Woomer *et al*., 1997). These *rhizobia* are capable of inoculating most of the legumes used in this study (Yost and Evans, 1988). Based on the results of this study, inoculation of "best-bet" legumes in the Network sites cannot be recommended. However, further systematic characterization of the native *rhizobia* should be undertaken in all Network sites.

Table 2. Legume species screened in the Network sites from 1995 to 1997.

Species name	Common name	Species name	Common name
Arachis hypogaea	Groundnut	*Melilotus alba*	White sweet clover
Arachis pintoi	Wild peanut	*Mucuna pruriens*	Velvet bean
Cajanus cajan	Pigeon pea	*Neontonia wightii*	Glycine
Calopogonium mucunoides	Calopo	*Pisum sativum* (3 var)	Pea, field pea
Canavalia ensiformis	Jackbean	*Phaseolus lunatus*	Lima bean
Cicer arietinum	Chickpea	*Phaseolus vulgaris*	Common bean
Clitoria ternatea	Clitoria	*Pueraria phaseoloides*	Tropical kudzu
Crotalaria juncea	Tanzanian sunnhemp	*Stylosanthes guianensis*	Stylo
Crotalaria ochroleuca	Sunnhemp	*Trifolium alexandrinum*	Berseem clover
Desmodium intortum	Greenleaf desmodium	*Trifolium hirtum*	Rose clover
Desmodium uncinatum	Silverleaf desmodium	*Trifolium incarnatum*	Crimson clover
*Fagopyrum esculentum**	Buckwheat	*Trifolium subterraneum*	Subclover
Glycine max	Soybean	*Trifolium vesiculosum*	Arrowleaf clover
Lablab purpureus cv Rongai	Lablab	*Vicia benghalensis*	Purple vetch
Lupinus albus	Sweet white lupine	*Vicia faba*	Faba bean
Lupinus angustifolius	Blue lupine	*Vicia dasycarpa*	Lana woolly pod vetch
Lupinus luteus	Yellow lupine	*Vigna sativa*	Common vetch
Macroptilium atropurpureum	Siratro	*Vigna villosa*	Hairy vetch
Macrotyloma axillaris	Axillare	*Vigna radiata*	Green gram
Macrotyloma uniflorum	Horse gram	*Vigna unguiculata*	Cowpea
Medicago sativa	Lucerne, alfalfa	*Voandzeia subterranean*	Bambara groundnut
Medicago truncatula	Barrel medic		

* A non-legume included in the screening trial because of its good qualities as a cover crop

3 Response of legume species to phosphorus application

The trials were established at the Kakamega, Kabete and Kisii sites at on-set of the 1998 long rains (Ojiem *et al*., 2000). Three to six legumes were selected for each site. The soil P levels for Kakamega, Kisii and Kabete sites were 2, 2 and 10.5 mg P kg^{-1} soil, respectively. No clear impact of P fertilization was detected in any of the three sites.

In Kakamega, 30 kg P ha^{-1} was applied and performance was assessed at 3 months after planting. Sunnhemp, lablab and soybean had higher biomass accumulation with application of P (2.2, 1.6 and 1.83 t DM ha^{-1}, respectively) than without P (1.7, 1.1 and 1.57 t DM ha^{-1}, respectively. Higher nodulation of all species was recorded with P, but these differences were not statistically significant. Calopo, jackbean and velvet bean did not show any response to P.

At the Kabete site, response of the legumes to three levels of P (0, 20, and 40 kg P ha^{-1}) was assessed 5 months after planting. The response of the legumes to P application was not statistically significant. However, application of P at the rate of 20 kg ha^{-1} substantially increased velvet bean biomass yield from 1.9 to 3.3 t DM ha^{-1}, that of sunnhemp from 0.2 to 0.7 t DM ha^{-1}, and purple vetch from 0.5 to 1.1 t DM ha^{-1}. The legumes did not respond substantially to application of P beyond 20 kg ha^{-1}.

In Kisii, biomass data was collected six months after planting. Like in the other two sites, the legumes did not respond to application of P fertilizer. Biomass accumulation in this site was lowest, averaging 0.5 t DM ha^{-1}. Nodulation data was not taken in both the Kabete and Kisii sites.

The lack of response of green manure legumes to P application can be partly attributed to poor rainfall distribution at the Kabete site and to pest attacks at Kakamega and Kisii sites. In addition, the predominant soil in the three sites is nitisol and has a high P absorption capacity.

Table 3. Some of the "best-bet" green manure legume species for different regions of Kenya

Region	*Mucuna*	*Cana-valia*	*Lab-Lab*	*Phaseo-lus*	*Vigna*	*Neono-tonia*	*Desmo-dium*	*Crota-laria*	*Glycine*	*Clito-ria*	*Macro-ptilium*
Semi-arid eastern Kenya (Machakos)	X	X		X	X	X					
Central highland (Kabete and Gatanga)	X		X	X			X	X			
North Rift Valley (Kitale)	X	X	X				X	X			
Southwest Kenya-Nyanza highlands (Kisii)	X	X	X					X			
Western Kenya (Kakamega)	X	X	X					X	X		
Eastern highland (Embu -Karurina)	X		X			X	X				
Lower Embu (Gachoka)	X		X		X			X			
Mt Kenya rain shadow (Matanya)	X		X	X		X					
Lake Victoria Basin (Kendu Bay)	X	X	X					X	X		
Coastal lowlands (Mtwapa)	X	X	X							X	X

Note: Full names of the "best-bet"species are: *Mucuna pruriens, Canavalia ensiformis, Lablab purpureus, Phaseolus lunatus, Vigna unguiculata, Neonotonia wightii, Desmodium uncinatum, Crotalaria ochroleuca, Glycine max.*

A study found that nitisols in Kakamega and Otomba in Kisii required 310 and 360 kg P ha^{-1}, respectively, to raise equilibrium solution P level to 0.5 mg L^{-1} (Gikonyo *et al*., 1994). This may suggest that the levels of P used in the studies reported here were too low.

4. *Management of legume biomass (i.e., residue) in maize-based cropping systems*

Research results. The study was conducted over two years (1997-99) at five Network sites where maize production is important: Machakos, Kabete, Gatanga, Kitale, and Kisii. Research was conducted on station, except in Gatanga, where it was conducted on 19 farms.

The GM legumes used were among the "best-bets" of each site. In all sites but Kitale, two maize crops are planted in a year, the first one at the beginning of the long rains (March) and the second at the beginning of the short rainy season (September/October). The legumes were intercropped with each maize crop one to two weeks after planting maize to reduce competition. In Kitale, which has one long maize-growing season from April until December, the legumes were planted in August. Lower maize leaves were pruned to allow light penetration. In all sites, the legumes were left growing after maize harvest as short-term fallow until land preparation for the following maize crop. The legume biomass was then harvested and applied in maize plots according to the following treatments: (1) incorporated (burying), (2) left as mulch, and (3) removed (to assess the value of below ground biomass on maize yields). Control treatments were maize plots planted in pure stands with and without fertilizer. Data was collected on maize and legume performance and, importantly, on labor inputs. The following results were obtained:

- Semi-arid eastern Kenya (Machakos): The biomass yield of lima bean, sunnhemp and velvet bean averaged 6, 19, and 20 t DM ha^{-1}, respectively. Although the effect of legume residue management treatments was not statistically significant, mulching with legume biomass gave the highest maize grain yield (2.8 t ha^{-1}) followed by incorporation of the legume biomass into the soil (2.3 t ha^{-1}). Removal of legume residue from the maize plot gave the lowest maize yield (1.4 t ha^{-1}). On average the legume treatments increased maize yields by 120% over the no-fertilizer control (1.05 t ha^{-1}). Mulching with velvet bean increased maize yield from the no-fertilizer control by 300% ($P<0.01$), and with lima bean and sunnhemp by 66 and 170%, respectively, but these were not statistically different.

- Central highlands (Kabete and Gatanga): In Kabete, average biomass production was 2 and 11 t DM ha^{-1} for purple vetch and velvet bean, respectively. Maize grain yield was highest ($P<0.05$) where the residue was incorporated and lowest where it was removed. Incorporating sunnhemp increased grain yield by more than 100% (3.6 t ha^{-1}) compared to the control (1.8 t ha^{-1}). This experiment was repeated during the 1998 short rainy season but failed due to low rainfall. In Gatanga the mean legume biomass was 2.3 for sunnhemp and 2.5 t DM ha^{-1} for velvet bean. Maize grain yields in plots where sunnhemp and velvet bean were incorporated in the long rainy season of 1998 were 2.5 and 2.0 t ha^{-1}, respectively. These yields were 66 and 120% higher ($P<0.05$) than in plots with surface mulch. Maize yields from plots where legume biomass was removed were, as as in the no-fertilizer control plots, low (about 1 t ha^{-1}). The effect of the treatments on maize yield during the 1999 long rains was not significant, but maize grain yield after incorporation was 44 and 50% higher for sunnhemp and velvet bean, respectively. Soil samples taken at the end of 1999 long rains did not reveal any significant treatment effects. In plots where residues had been incorporated, the contents of P was 28.7 mg kg^{-1} soil and of K 0.43%. These levels were 17 and 19% greater than in the soil from the no input treatment. Organic carbon was 1.46% in the mulched and 1.11% in the no-fertilizer treatment.

- North Rift Valley: The work in Kitale involved the use of velvet bean and maize stover. The legume DM yield was 6.4 t DM ha^{-1}. Incorporating legume biomass and maize stover residues gave 40% higher ($P<0.001$) maize grain yield (5.7 t ha^{-1}), than plots where biomass was removed. The presence of maize stover in the residues did not significantly affect maize yields. Yield of maize in plots with surface mulch (4.8 t ha^{-1}) was similar to those where incorporation had been done (5.1 t ha^{-1}). This study was repeated in 1999 but without the mulching treatment that did not conform to the cropping practices of the area. The low biomass of velvet bean (1.9 t DM ha^{-1}) was attributed to an unidentified disease that caused stunted growth and bronzing of velvet bean leaves. As in 1998, incorporation resulted in a greater ($P<0.05$) yield (4.4 t ha^{-1}) than the removal of residues (3.8 t ha^{-1}).

- Southwest Kenya-Nyanza highlands: The study in Kisii, conducted only over one season, did not show significant differences between the residue management treatments. Maize yield with incorporation was 6.1 t ha^{-1} and in plots where residues had been removed was 5.6 t ha^{-1}. However, on the whole, the legume treatments gave 65% higher maize yield than the control treatment where maize was planted without inputs.

Observations of the data. Although great variability in performance often resulted in yield differences that were not statistically different, when results across the sites are compared, certain trends are clear:

- Greater crop yields with incorporation at most sites, presumably due to increased N supply to the soil and reduced loss of N by volatilization (Hudgens, 2000), as evidenced in a study conducted in a Brazilian Oxisol where incorporation resulted in 60% higher net inorganic N accumulation than mulching (Costa *et al*., 1990).

- In semi-arid regions, mulching resulted in superior maize yields due to moisture conservation, rather than to improved soil fertility effect (Gachene *et al*., 2000). It is known that mulching promotes water infiltration and reduces water loss by evaporation (Muller-Samann and Kotschi, 1994).

- Returns to labor were higher with incorporation than with mulching, even with the higher labor required for incorporation (Muller-Sämann and Kotschi, 1994; Hudgens, 2000). This effect was analyzed in Gatanga (Mureithi *et al*., 2000b) and also confirmed by farmers in Kisii and Gatanga who reported that the additional labor for incorporation is minimal because it is done together with land preparation (Table 4).

- Contribution by below-ground biomass was negligible or nil, in contrast to studies by Ibewiro *et al*. (1997), who found in Ibadan, Nigeria, that velvet bean and lablab root bio-mass increased maize yields by 46 and 130 %, respectively, by M. Bekunda (personal communication) in Kabale, Uganda where purple vetch and sunhemp below ground biomass gave 24 % better yields than the no-input control (0.5 t ha^{-1}), and by Kullaya *et al*. (1998) in Tanzania where sunnhemp stubble incorporation resulted in 50% greater maize yields than without inputs.

These findings highlight the importance of developing a GM legume decision guide to assist farmers in making informed decisions.

5. *Green manure legumes as a component of integrated nutrient management*

Research results. Integrated nutrient management (INM) emphasizes judicious use of inorganic and organic sources of nutrients to maintain ecologically sound and economically viable farming systems (Franzluebbers *et al*., 1998). The combined use of the two sources of nutrients can be a sustainable way of maintaining soil nutrient base to improve crop productivity in smallholder farms (Smaling *et al*., 1992; Smaling and Braun, 1996; Kullaya *et al*., 1998).

Table 4. Returns to labor used in different treatments of legume residue management of Gatanga, Central Kenya.

Treatment	Maize grain yield kg ha^{-1}	Person days ha^{-1}	Returns per US$ spent on labor
Incorporation	2400	19	11.5
Mulch	1200	15	7.3
Removal	1000	10	9
Maize fertilizer	800	8	9
Maize with no input	700	8	8

Note: Maize costs US$ 146 / metric ton; - Labor costs US$ 1.6 / person day. ‘Person day’ is equivalent to eight hours work of an adult per day in the field.

The INM study was conducted in three Network sites: Kakamega, Karurina and Mtwapa from October 1997 to August 1999. The general treatments included:

1. Green manure legume: a. none, b. velvet bean, c. sunnhemp (in Mtwapa: lablab)

2. Farm yard manure: a. none, b. 50% of recommended (2.5 t ha^{-1})

3. N fertilizer: a. none, b. 25% of recommended (in Embu: 12.5 kg ha^{-1}, in Kakamega and Mtwapa: 15 kg ha^{-1}), and c. 50% of recommended (25 and 30 kg ha^{-1}, respectively).

The design of the trial was a randomized complete block design with factorial combinations. The test crop was maize.

During the 1997 short rainy season, legumes were planted as a sole-crop in Kakamega (where second-season maize cultivation is uncommon) or, in Karurina and Mtwapa, as an intercrop with maize and after maize harvest, as a sole crop for one month. They were slashed and incorporated in the end of the dry season and planting of maize and legume (two weeks after maize planting) was done in the beginning of the 1998 long rains. The trial was repeated in the 1998/99 cropping seasons. Highlights of the results include:

- Western Kenya (Kakamega): Legume dry matter accumulation ranged from 2.6 to 5.4 t ha^{-1}. Biomass yield in 1999 was half that of 1998 due to poor rainfall distribution during the short rainy season. Out of the three factors investigated, only legume treatments produced significant effects ($P<0.05$) on maize grain yield. Averaged over two years, GM increased grain yield by 30%, from 5.1 to 6.6 t ha^{-1}. Although the treatment interactions were not significant, the GM and FYM seemingly responded differently to N fertilizer applied at the rate of 15 and 30 kg ha^{-1} (Figure 2). Application of 15 kg N ha^{-1} to the GM treatment increased maize yields by 38%, but doubling the N rate only increased yields by an additional 3%. On the other hand, maize grain yield in FYM treatments only increased by 4% after application of 15 kg N ha^{-1}, while doubling the N rate to 30 kg ha^{-1} increased yield by 23%. These results suggest that maize grain yield can be greatly improved by integrating GM, FYM, and inorganic nitrogen.

- Eastern highlands (Embu): Exceptionally high rainfall during the short rains of 1997 (probably due to El Niño) resulted in high legume biomass accumulation of 8.1 and 6.3 t DM ha^{-1} for velvet bean and *Crotalaria*, respectively. In the subsequent two cropping seasons, the poor rainfall (probably due to La Niña) resulted in average biomass of only about 1 t DM ha^{-1}. In the first and second cropping seasons, differences between treatments were not significant. During the third cropping season, the organic and inorganic treatments gave, at 8.8 t ha^{-1}, 25% greater maize yields ($P<0.05$) than the no-input control. There was no advantage in combining the different nutrient sources.

- Coastal lowlands (Mtwapa): Data on legume biomass were not taken during the 1998 long rainy season for the legumes planted at the onset of the short rains in 1997. However, the biomass yield of velvet bean and lablab planted during the long rains in 1998 were 2.5 and 1.3 t DM ha^{-1}. The 1998 short rains maize and legumes failed due to poor rainfall. During the long rains in 1999, the legumes were planted again and biomass produced was 4.4 t DM ha^{-1} for velvet bean and 3.5 t DM ha^{-1} for the lablab. The maize yield results are for the 1999 long and 1999 short rainy seasons. The organic sources of N did not show any significant effects on grain yield during the 1998 long rainy season. In contrast, application of 15 kg N ha^{-1} in the form of calcium ammonium nitrate fertilizer increased maize grain yield by 27 % ($P<0.01$) compared to maize without N fertilizer (3.0 t ha^{-1}). Applying N fertilizer at 30 kg N ha^{-1} did not result in additional maize grain yield. The interaction between N fertilizer treatments and organic N sources was significant ($P<0.05$) for maize stover yield in the 1999 long rains season (Table 5). Application of N at the rate of 15 kg ha^{-1} to the FYM treatment increased stover yield by 120%, but doubling the rate did not result in increased maize yield. Stover yield in the lablab plots responded linearly to N fertilizer. Surprisingly, applying 15 kg N ha^{-1} to maize in velvet bean treatments reduced stover yield by 50% and even doubling the fertilizer rate did not offset the reduction (Table 5).

Observations on the data. In Kakamega and Karurina, but not in Mtwapa, legumes were able to increase maize yield. The differences between the sites could be attributed partly to differences in inherent soil fertility. The soil in the Karurina site was the most fertile (N, P, and organic C levels of 0.5%, 14 mg kg^{-1} soil, and 2.3%, respectively) which could have masked treatment effects. In Kakamega and Mtwapa, soil fertility was lower (N below 2%, P below 10 mg kg^{-1} soil and organic carbon about 2%). However, the soil in Mtwapa is 90% sand. Given the high ambient and soil temperatures in the site (Table 1), most of the nutrients from the organic sources could have been lost by leaching and/or volatilization. N fertilizer in Mtwapa was applied in two splits to minimize leaching losses. Other factors contributing to differences in response may have been legume DM production (highest in the Karurina site), the cropping systems (in Kakamega, rotational system was used while in Mtwapa and Karurina, intercropping system).

Table 5. Effect of legume and fertiliser N on maize grain yield (t ha^{-1}) during short rains of 1999 in Mtwapa, Coastal Kenya.

Nitrogen rate (kg N ha^{-1})	Legume			Mean
	None	*Lablab*	*Mucuna*	
0	1.731	1.273	1.057	1.353 [a]
15	2.478	1.066	0.802	1.449 [a]
30	2.647	1.428	0.908	1.661 [a]
Mean	2.286 [a]	1.256 [b]	0.922 [c]	

Column or row means followed by the same letter are not significantly different (P> 0.01).

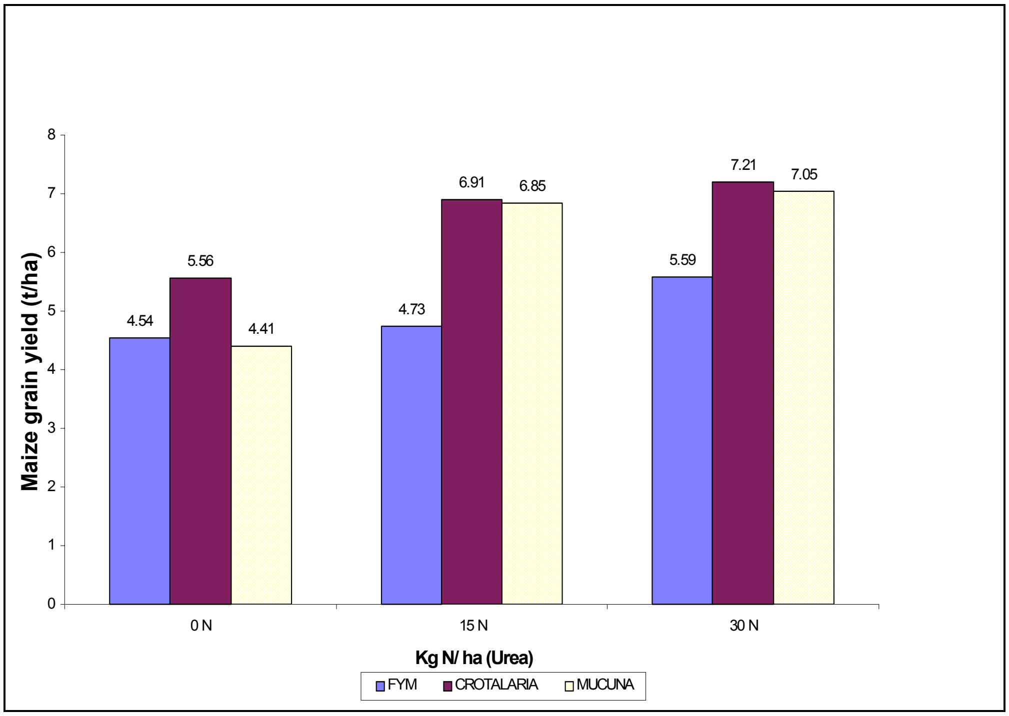

Figure 2. Effect of inorganic N on maize grain yield response to farm yard manure (FYM), *Crotalaria ochroleuca* (sunnhemp) and *Mucuna pruriens* (velvet bean) green manures at Kakamega, Western Kenya.

The promising response of maize to the GM legumes was clear in Kakamega where N applied at the rate of 15 kg ha^{-1} with GM resulted in maize grain yields similar to the yields where only N was applied at 30 kg ha^{-1} (Figure 2).

6. Effect of green manure legumes on control of striga

This study, conducted in Kendu Bay site in the Lake Victoria basin, evaluated the effectiveness of three GM legumes (sunnhemp, lablab, and velvet bean) to control striga *(Striga hermonthica*) and to improve soil fertility. A rotational system was practiced where the legumes were sole-cropped in the short rainy season and their biomass incorporated into the soil at the onset of the long rainy season before maize planting. Striga infestation was monitored by counting striga seeds that germinated in the experimental plots. Results from 1996 and 1997 revealed that the legumes had deterrent effect on striga germination. The plots with legumes had on average 10 striga counts m^{-2} while the control had 32 striga counts m^{-2}. Maize grain yield was higher in legume plots (2.4 t ha^{-1}) than in the control plots (1.4 t ha^{-1}).

Way forward

Emerging technologies

Three systems have emerged from the studies discussed above:

- Intercropping green manure legumes with maize: This is feasible in the regions receiving bimodal rainfall where farmers plant two maize crops in a year. Green manure legumes are planted in each of the two maize crops either at the same time or one to two weeks after maize. A single row of legumes is typically planted between single maize rows, although preliminary results from the Gatanga and Kitale sites indicate that double rows of legumes result in higher biomass without affecting the yield of maize drastically. After the maize harvest, the legume continues growing during the short fallow period preceding land preparation for the following crop, before planting the next maize crop legume biomass is incorporated into the soil. This system has been found to work well in such sites as Mtwapa, Gatanga, and Kisii.

- Late intercropped legumes in maize: In the regions receiving unimodal rainfall, such as Kitale, the only maize crop of the year is usually planted in April. In these regions, legumes need to be planted in August between maize rows after lower maize leaves have been pruned to reduce competition for light (Kirungu *et al*., 2000). The maize is harvested in November/December and the legume is left growing in the field as a short-term fallow until land preparation for the long rainy season maize crop.

- Rotational short-term fallow with green manure legumes: Regions that receive bimodal rainfall but have an unreliable second season are suited for a rotational system. The maize crop is planted as a pure stand during the long rains (February-August). Green manure legumes are planted in September as a short-term fallow crop and incorporated during land preparation in January/February of the following year. This system is practiced in areas like Kakamega.

Additional farmer-identified niches

As farmers get more familiar with green manure legumes, they are able to creatively identify niches within their farming systems for green manure technologies, as became evident during an informal study in Gatanga (Mureithi *et al*., 2000b):

- Under coffee trees: Five farmers said they did not always have enough farmyard manure to apply to the coffee fields and that green manure legumes could be used as an alternative. Velvet bean was preferred because of its quick establishment.

- Intercropped with vegetables: Some farmers indicated that legumes could be intercropped with vegetables like kale. Sunnhemp was most preferred because it grows upright and does not coil on the kale plants.

- On steep land: Farmers explained that green manure legumes could be planted on the steep land to control soil erosion. Velvet bean was again preferred because of its ability to cover the ground quickly.

- Under avocado trees: Some farmers are already planting legumes such as *Desmodium* under avocado trees to control soil erosion and to produce fodder for livestock.

Future research

Research on legumes needs to continue to improve the effectiveness and efficiency of these technologies. The following areas merit attention:

- Nitrogen fixing potential of “best-bet" legumes: During the screening, amount of N fixed was not quantified and it is therefore not known how much those legumes were adding N to the soil and how much they were scavenging and recycling available N. Studies are proposed to determine the amount of N fixed by the legumes. Moreover, although the initial studies did not support positive impact of *rhizobia* inoculation on nodulation and N fixation, it is recommended that this subject be pursued further. Finally, because of the importance of P in the biological nitrogen fixation process, it is recommended that P response studies to be conducted at all the Network sites.

- Legume residue mineralization: Detailed decom-position and mineralization studies should be conducted in order to improve crop nutrient demand-supply synchrony. Methods of incorporation of legume residue by hand, tractor, and oxen plough should be evaluated. Time of residue incorporation in relation to time of planting the companion crop should be ascertained. The fertilizer equivalency values and residual effects of incorporated green manure legumes, including effects on soil physical properties, should be established.

- Management of green manure cover crops in plantation crops: Legumes such as velvet bean and jack bean have great potential as a green manure and for weed control in plantation crops like coffee and avocado. However, it is important to develop management practices that minimize competition, especially for light and moisture with plantation crops.

- Use of legume forage and seed for human and livestock feed: Apart from conventional legumes such as cowpeas and lablab, little is known about the appropriate processing methods to process most of the studied GM legumes into livestock feed and human food. Studies are necessary to develop cost-effective methods to eliminate anti-nutritional factors.

- Intercropping with food crops: Research on resource use in green manure-food crop intercropping systems should be conducted, including studies on plant densities and planting time of legumes to minimize competition.

- Socio-economics: Profitability of green manure technologies, their returns to labor, farmers' perceptions on them, and their potential for adoption need further assessment. Detailed studies to characterize green manure niches will be undertaken.

- Screening of legumes tolerant to abiotic stresses: The "best-bet" species for different agroecological zones were screened under optimal conditions. It is important to screen these legume species and their cultivars, as well as other ones to widen legumes available for Kenyan farmers, under stress conditions typical of smallholder farming systems (e.g., acidic and low P soils, competition with companion crops and prolonged drought).

- Seed bulking: This will be done at sites where the performance of the legumes is highest. Quality control in production and storage is to be guaranteed and issuance of minimum data to accompany seed exchanges in the region will be made routine. The Network will discourage provision of free seeds to farmers or potential collaborators and will charge a nominal fee that will ensure recovery of the production cost of the seeds. Farmers and farmer groups will be encouraged to produce their own seed locally to save on seed costs.

CONCLUSIONS

The LRNP has identified suitable GM legumes with potential for soil fertility improvement in major agroecological zones of Kenya. Studies conducted to date have shown that the GM legumes do not respond to *rhizobia* inoculation and effects of P fertilizer on the performance of the legumes is variable. Application of GM biomass as a mulch was more beneficial in dry areas where moisture availability is critical. The LRNP will continue to undertake research to mainly test the value of the GM in soil fertility improvement, to diversify niches for their incorporation in smallholder farming systems and to evaluate the profitability of GM technologies.

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REFERENCES

Costa, FJSA, Bouldin, DR, Suhet, AR. 1990. Evaluation of N recovery from mucuna placed on the surface or incorporated in a Brazilian Oxisol. Plant and Soil 124: 91-96.

Dyck, E. 1997. Screening legumes for potential for soil productivity improvement in Kenya. Poster presented at the Green Manure and Cover Crop Systems for Smallholders in Tropical and Subtropical Regions Conference in Santa Catarina, Brazil, 6-12 April 1997.

Franzluebbers, K, Hossner, LR, Juo, ASR. 1998. Integrated Nutrient Management for sustained crop production in Sub-Saharan Africa (A review). Soil Management CRSP. TropSoils/TAMU Technical Bulletin 98-03. Department of Soil Science and Crop Sciences, Texas A&M University. 50 pp.

Gachene, CKK, Jarvis, NJ, Linner, H, Mbuvi, JP. 1997. Soil erosion efforts on soil properties in a highland area of central Kenya. Soil Science Society of America Journal 61: 559-564.

Gachene, CKK, Haru, R. 1997. Controlling seasonal soil loss using purple vetch (*Vicia benghalensis*). African Crop Science Conference Proceedings 3: 369-373.

Gachene, CKK, Mureithi, JG, Makau, M. 2000. Incorporation of green manure crops in maize based cropping system in a semi-arid environment, Kenya. Proceedings of the 2nd Scientific Conference of the Soil Management and Legume Research Network Projects, 26-30 June 2000. Kenya Agricultural Research Institute. Pp. 145-151.

Gethin-Jones, GH. 1942. The effect of a leguminous cover crop in building up soil fertility. East African Agricultural Journal 8: 48-52.

Gikonyo, EW, Keter, JKA., Oduor, POS. 1994. Effect of manure and phosphate fertilizer application on phosphorus sorption by some Kenya soils. In: Rwakaikara-Silver, M.C., Bekunda, MA, Tenywa, JS. (Eds.), Enhancing Farmers Efforts to Combat Soil Degradation: A Challenge to Soil Science Technology. Proceedings of the 14th Conference of the Soil Science Society of East Africa. Makerere University, Kampala, Uganda. Pp. 101-107.

Gitari, JN, Dyck, E, Maina, P. 2000. Legume screening for soil fertility improvement, food and fodder utilisation in medium altitude areas of Mount Kenya region. In: Mureithi, JG, Mwendia, CW, Muyekho, FN, Onyango, M, Maobe, SN. (Eds.). Participatory Technology Development for Soil Management by Smallholders in Kenya. Special publication of Soil Management and Legume Research Network Projects. Kenya Agricultural Research Institute, Nairobi, Kenya. Pp. 121-131.

Hassan, RM, Murithi, FM, Kamau, G. 1998. Determinants of fertilizer use and gap between farmers' maize yields and potential yields in Kenya. In: Hassan, RM. (Ed.). Maize Technology Development and Transfer: A GIS Application for Research Planning in Kenya. CAB International, Wallingford, UK. Pp. 137-161.

Hudgens, RE. 2000. Sustaining soil fertility in Africa: the potential for legume green manures. Soil technologies for sustainable smallholder farming systems in East Africa. Proceedings of the 15th Conference of the Soil Science Society of East Africa, Nanyuki, Kenya. Pp. 63-78.

Ibewiro, B, Vanlauwe, B, Sanginga, N, Merck, R. 1997. Nitrogen contributions of roots to succeeding maize in herbaceous legume cover cropping in a tropical derived savanna. In: Renard, AN, Becker, K, von Oppen, M. (Eds). Soil Fertility Management in West African Land Use Systems. Proceedings of the Regional Workshop on Soil Fertility Management in West African Land Use Systems, Niamey, Nigeria, 4-8 March 1997. Margraf Verlag, Weikersheim, Germany. Pp. 123-127.

Kullaya, IK, Kilisara, M, Aune, JB. 1998. The potential of marejea (*Crotalaria ochroleuca*) as green manure in maize production in the Kilimanjaro region of Tanzania. Soil Use Management 14: 117-118.

Kirungu, BAM. 2000. Factors affecting the productivity of the green manure legume, *Lablab purpureus*, in Trans Nzoia district, Kenya. Legume Research Network Project Newsletter, Issue No. 2.

Lal, R, Reignier, E, Edwards, WM, Hammond, R. 1991. Expectations of cover crops for sustainable agriculture. In: Hargrove, WL. (Ed.). Proceedings, Cover Crops for Clean Water: an International Conference, West Tennessee Experiment Station, 9-11 Apr, Jackson, TN, USA. Soil and Water Conservation Society, Ankeny, IA, USA. Pp. 1-11.

Lekasi, JK, Tanner, JC, Kimani, SK, Harris, PJC. 1998. Manure management in the Kenya Highlands: practices and potential. Kenya Agricultural Research Institute (KARI), Nairobi, Kenya; ILRI, Nairobi, Kenya; The Henry Doubleday Research Association (HDRA), Coventry, UK. Pp. 1–35.

Muller-Samann, KM, Kotschi, J. 1994. Sustaining Growth: Soil fertility management in tropical smallholdings. ICTA; GTZ. Transl.: Christine Ernsting and Simon Chaterj. Margraf, Weikersheim, Germany. 486 pp.

Mureithi, JG, Maobe, SN, Dyck, E, Gachene, CKK, Gitari, N, Kirungu, B, Muli, BM, Ojiem, J, Saha, HM, Tana, P. 1998. Screening of legume germplasm in Kenya: effect of *rhizobia* inoculation on performance of "best-bet" legumes. Proceedings of the 16th Conference of the Soil Science Society of East Africa, 13-19 December 1998. Pp. 130-143

Mureithi, JG, Mwaura, P, Kamande, T. 2000a. Introduction of Green Manure Legumes to Smallholders in Gatanga Division, Thika District. Legume Research Network Project Newsletter, Issue No. 3.

Mureithi, JG, Mwaura, P, Nekesa, C. 2000b. Introduction of legume cover crops to smallholder farms in Gatanga central Kenya. Proceedings of the 2nd Scientific Conference of the Soil Management and Legume Research Network Projects, 26-30 June 2000. Kenya Agricultural Research Institute. Pp. 153-164.

Ojiem, JO, Mureithi, JG, Maobe, SN, Okwuosa, EA, Nekesa, CO. 2000. The effect of phosphorus on legume green manure species dry matter yield and nodulation in the sub-humid highlands of Kenya. Proceedings of the 2nd Scientific Conference of the Soil Management and Legume Research Network

Projects, 26-30 June 2000. Kenya Agricultural Research Institute. Pp. 97-102.

Okalebo, JR. 1989. The effect of inoculation with rhizobia and forms of phosphate fertilizer on the growth of beans at Muguga and Katumani, Kenya. In: Mochoge, BO, Njihia, CM, Qureshi, JN, Ayaga, GO (Eds.). Appropriate Soil and Water Resources Management in Agricultural Production. Proceedings of the 9th Annual conference of the Soil Science Society of East Africa. Pp. 153-161.

Peoples, BM, Craswell, ET. 1992. Biological nitrogen fixation: investments, expectations and actual contributions to agriculture. Plant and Soil 141: 13-39.

Smaling, EMA, Nandwa, SM, Prestele, H, Roetter, R, Muchena, FN. 1992. Yield response of maize to fertilizers and manure under different agro-ecological conditions in Kenya. Agricultural Ecosystems and Environment 41: 241-252.

Smaling, EMA, Braun, AR. 1996. Soil fertility research in sub-Saharan Africa: new dimensions, new challenges. Communications in Soil Science and Plant Analysis 27: 365–386.

Smaling, EMA, Nandwa, SM, Janssen, BH. 1997. Soil fertility in Africa is at stake. In: Buresh, RJ, Sanchez, PA, Calhoun, F. (Eds.). Replenishing Soil Fertility in Africa. SSSA Special Publication No. 51. Soil Science Society of America, Madison, WI. Pp. 47-61.

Weber, G. 1996. Legume-based technologies for African Savannas: challenges for research and development. Biological Agriculture and Horticulture 13: 309-332.

Woomer, PL, Karanja, NK, Mekki, EI, Mwakalombe, B, Tembo, M, Nyika, M, Silver, M, Nkwine, C, Ndakidemi, P, Msumali, G, 1997. Indigenous populations of *rhizobia*, legume response to inoculation and farmer awareness of inoculants in east and southern Africa. African Crop Science Conference Proceedings 3: 297–308.

Yost, R, Evans, D. 1988. Green manure and legume covers in the tropics. Research series - Hawaii Agricultural Experimental Station, HITAHR, College of Tropical Agriculture and Human Resources, University of Hawaii. Sept. 1988 (055). 44 pp.

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