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POTENTIAL OF PASTURE LEGUMES IN LOW-EXTERNAL-INPUT AND SUSTAINABLE AGRICULTURE (LEISA). 1. RESULTS FROM GREEN MANURE RESEARCH IN LUAPULA PROVINCE, ZAMBIA

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SUMMARY

In view of soil fertility problems and financial constraints identified in small-scale farming, on-station investigations on Low-External-Input and Sustainable Agriculture (LEISA) were started by the Farming Systems Research Team Luapula Province (FSRT-LP) in order to assess the potential of three annual and six perennial pasture legume species for green manuring purposes. Rhodes grass (*Chloris gayana* cv NIRS Boma) was used as a control. Over two seasons, a pasture legume-maize rotation trial was established. Different mineral fertilizer amounts were applied to the maize. Of all the species and cultivars tested, the perennial glycine (*Neonotonia wightii* cv Cooper) had the strongest green manure effect when no mineral fertilizer was applied. Of the annual pasture legumes, sunn hemp (*Crotalaria juncea* cv. NIRS 3) and velvet bean (*Mucuna pruriens* cv. NIRS 16) showed the greatest green manure potential at zero mineral fertilizer level. There were strong indications that the carbon:nitrogen ratio influenced the green manure potential of a species more than its ability to produce biomass. The need to assess the economics and sustainability of current mineral fertilizer practices on maize has been identified.

INTRODUCTION

Agricultural production conditions in Zambia have changed over recent years due to the liberalization of markets (Jansen and Rukovo, 1992; Holden, 1997). The removal of subsidies for mineral fertilizers and other external agricultural inputs led to increases in the prices of food staples such as maize (*Zea mays*). Especially in rural areas such as Luapula Province in the north of Zambia, the problems of high prices and limited access to agricultural inputs are more prevalent than in areas closer to the main markets. In order to address these unfavourable conditions for farming and household economies, the Luapula Livelihood and Food Security Programme (LLFSP) was set up through co-operation between the Ministry of Agriculture, Food and Fisheries of Zambia and the Ministry for Foreign Affairs of Finland, Department for International Development Cooperation (MAFF and

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FINNIDA, 1994). LLFSP mainly focused on small-scalefarmer households since they form the largest category of all Luapula households. Within the LLFSP, the Farming Systems Research Team of the Luapula Province (FSRT-LP) implemented the Low-External-Input and Sustainable Agriculture (LEISA) subcomponent. It included co-ordinated on-station and on-farm experiment programmes. All research activities emanated from dialogue with farmers and followed the Participatory Extension and Adaptive Research (PEAR) approach applied by LLFSP. Rather than developing technological packages, FSRT-LP used a 'starter technology' in on-farm experimentation with Farmer Research Groups (FRGs) for further adaptation to farming conditions by the farmers themselves.

The results of these LEISA research programmes on the nutrient potential of pasture legumes (in conjunction with their applicability as green manuring organic fertilizer for open-pollinating maize varieties) are presented in two papers. This first highlights and discusses results from an on-station trial at Mansa Technology Assessment Site (TAS). Adaptation, by farmers, of a starter technology in Luapula Province is presented in the second paper (Steinmaier, 2001).

MATERIALS AND METHODS

Situation and research analysis

FSRT-LP has been operating in Luapula Province since 1982 (Kean, 1988) and has carried out a number of diagnostic surveys and studies over the years. Since farming systems are dynamic rather than static, new information on the current situation and problems of small-scale farmers had to be collected and analysed after the liberalization of the agricultural markets in Zambia. Meetings and discussions realized this with community groups and FRGs, which were constituted in line with the PEAR-approach.

A wide array of problems was revealed during discussions with small-scale subsistence farmers who presented the lack of adequate access to fertilizers and improved maize varieties as their overriding concerns. Based on this feedback, LEISA started to investigate options to improve the situation in maize production. One alternative was seen in cultivating pasture legumes for green manure purposes in arable farming. The intention would be to supplement the N component of mineral fertilization through the fixation of atmospheric N by the promotion of bacteria in the root nodules of pasture legumes. In addition to this chemical aspect of soil fertility, the physical structure of and the microbiological activity in soils would improve with regular applications of green manure. With respect to the supply of maize seed to small-scale farmers, the problems of annual purchasing and high prices of hybrid varieties together with constraints in the timely accessing of such seeds would be tackled by the introduction of open-pollinating varieties. Because they require far simpler multiplication techniques than do hybrid varieties, the open-pollinating varieties were to be multiplied by the small-scale farmers themselves.

Against this background, a secondary data and literature review on pasture legumes and open-pollinating maize varieties was carried out at Mansa TAS, Mount Makulu National Research Centre in Chilanga, and at Misamfu Regional Research Centre in Kasama. It was found that research on pasture legumes and grasses in Zambia has a sound history (Craufurd, 1979) especially on their use as fodder crops (van Rensburg, 1967; 1969). Intensive breeding programmes that had been carried out were reviewed by Craufurd (1978) and Sarmezey (1979). Studies on nutritional values of pasture legumes were made by Gihad (1976) and valuable research efforts concerning animal feeding and pasture management are compiled in a Zambian handbook of pasture and fodder crops (Thorp, 1979). Kulich (1993; 1995a; b) investigated the seed production potential of pasture legume species.

A few institutions and programmes in Zambia have started to investigate the green manuring of soils by the application of pasture legumes. They include the Adaptive Research Planning Teams of the Luapula and Eastern Provinces located in Mansa and Chipata respectively, the Pasture Legume Team situated at Golden Valley Agricultural Research Trust (MAFF/GART) in Chisamba, and the Soil Productivity Research Programme (SPRP) based at Misamfu Regional Research Centre in Kasama. FSRT-LP collaborated closely with the National Commodity Research Team Maize (CRT-Maize) on open-pollinating maize varieties. Through consultations with all these teams, valuable information and ideas have been exchanged with and shared by FSRT-LP.

On-station trial

A two-year (1995–96) green manure × mineral fertilizer trial was established at Mansa-TAS in the Luapula Province (lat. 11° 12' S; long. 28° 53' E; alt. 1181 m asl). The period of the growing season is 188–195 d (Veldkamp, 1987) and the location is not prone to drought or frost. Sunshine hours during the rainy season are between 700 and 850 h. Details of rainfall and temperature ranges are given in Table 1.

Natural environment and soil

The natural vegetation at Mansa TAS is Brachystegia woodland (Miombo) belonging to the *Brachystegia-Julbernadia-Isoberlina* group (Anon., 1977). While *Julbernandia peniculata* and *Combretum ghasalense* occur in shallow soils, major species in deep soils are *Brachystegia speciformis* and *Isoberlinia angolensis* (Yager *et al.*, 1968).

The soil of the trial site was classified by Yager *et al.* (1968) as Ultisol and described as Mufulira sandy loam. It is a well-drained upland soil with moderate permeability on parent granite material. Before the trial, a representative soil sampling was done to a depth of 20 cm. The soil was analysed in Lusaka at the Soil Science Department, School of Agriculture, University of Zambia, according to standard methods for soil analysis. Physical soil analysis revealed a sandy loam texture with fractions of 78% sand, 10% silt and 12% clay. Chemical character-

Table 1. Rainfall and temperature recorded at Mansa TAS for the long-term average (30 years) and for the 1995–96 and the 1996–97 rainy seasons.

	Month											
	J	A	S	O	N	D	J	F	M	A	M	J
						Rainfall (mm)						
1995–96	0	0	0	21	197	249	305	161	222	65	36	0
1996–97	0	0	0	†	48	185	243	338	98	77	0	0
30-year long-term average	0	0	0	30	135	229	229	214	200	56	0	0
						Temperature (°C)						
Mean daily temperature 1995–96	18	21	23	25	24	23	22	23	23	21	20	16
Mean daily temperature 1996–97	17	20	24	24	25	24	23	23	24	22	19	18
30-year long-term average mean temperature	16	18	22	23	22	21	21	21	21	21	19	16

† Trace precipitation: less than 0.1 mm was recorded.

istics are: pH 5.6 (KCl), 0.05% total N concentration (Kjeldahl), 1.0% C concentration, 9.4 ppm available P (Bray I), cation exchange capacity (CEC) = 5.4 me 100 g^{-1} composed of 3.1 me 100 g^{-1} Ca, 1.7 me 100 g^{-1} Mg, 0.2 me 100 g^{-1} K, 0.3 me 100 g^{-1} Na and 0.1 me 100 g^{-1} Al + H.

The objective of the trial was to screen pasture legume species and cultivars for their biomass nutrient potential and to assess their potential as green manure crops for maize. A split-plot design was chosen with three mineral fertilizer levels as the main factor and 11 green manure species as the sub-factor. The treatments were replicated in three blocks with 4 × 5 m plots. Pasture legume species and planting details are presented in Table 2.

The legumes were sown in the 1995–96 growing season and their biomass

Table 2. Seed rates, spacing and planting methods of pasture legume species and Rhodes grass used in the establishment of a two-year green manure × mineral fertilizer trial in the rainy season, 1995–96.

Species and cultivars	Seed rate	Spacing (row width × plant-width)	Planting method
Sunn hemp NIRS (*Crotalaria juncea* cv NIRS 3)†	40 kg ha^{-1}	60 cm × 15 cm	2 seeds per station
Sesbania (*Sesbania macrantha*)‡	1 $plant^{-2}$	100 cm × 100 cm	seedling
Velvet beans (*Mucuna pruriens* cv NIRS 16)†	50 kg ha^{-1}	100 cm × 30 cm	1 seed per station
Sunn hemp Marejea (*Crotalaria zanzibarica* cv Marejea)†	40 kg ha^{-1}	60 cm × 15 cm	2 seeds per station
Stylo (*Stylosanthes guianensis* cv Graham)‡	3 kg ha^{-1}	100 cm	drilling in line
Lablab (*Lablab purpureus* cv Highworth)†	20 kg ha^{-1}	50 cm × 50 cm	1 seed per station
Siratro (*Macroptilium atropurpureum* cv Siratro)‡	3 kg ha^{-1}	100 cm	drilling in line
Glycine (*Neonotonia wightii* cv Cooper)‡	4 kg ha^{-1}	100 cm	drilling in line
Centro (*Centrosema pubescens*)‡	6 kg ha^{-1}	100 cm	drilling in line
Teramnus (*Teramnus uncinatus*)‡	5 kg ha^{-1}	100 cm	drilling in line
Rhodes grass (*Chloris gayana* cv NIRS Boma)†	5 kg ha^{-1}	50 cm	drilling in line

†Annual species; ‡perennial species

incorporated into the soil in 1996–97 four weeks before an open-pollinating and early-maturing maize variety was planted. In addition, mineral fertilizers were applied to the maize. Rhodes grass was chosen as the control treatment to check the green manure effects of legumes against grasses. It was assumed that Rhodes grass would bind at least the same amount of nutrients in its biomass as would natural re-growth on abandoned fields.

The trial commenced on 13 December 1995. The site selected had received no fertilizer applications in the previous four years during which cassava (*Manihot esculenta*) and finger millet (*Eleusine coracana*) had been cultivated. On 8 May 1996 plant samples were taken from areas of one square metre in all plots. The weight of the total plant dry matter biomass and the concentrations of N, P, K and C were estimated. Only leaf samples were taken from *Sesbania macrantha*, (woody parts were not included). Using hand hoes, the most common method practised by small-scale farmers in the Luapula Province, the biomass of all pasture legumes and Rhodes grass plots was incorporated into the soil on 22 November 1996.

The maize variety chosen was 'Pool 16'. It takes about 95 d to mature. FRGs had appreciated its early-maturing character in on-farm experiments in the rainy season 1995–96 (Steinmaier, 2001). The maize was sown on 20 December 1996 at a seed rate of 20 kg ha^{-1} with spacings of 75 cm between rows and 30 cm within rows and with one seed per station. In line with local practice the maize was sown on ridges. The fertilizer treatments shown in Table 3 represent the most common fertilizer types (Compound D and Ammonium Nitrate, AN) and the most common application rates and methods (200 kg D ha^{-1} for base dressing and 200 kg AN ha^{-1} for top-dressing.) in the Luapula Province and are recommended by the agricultural extension services. Basal and top-dressing fertilizer applications were given on 8 January 1997 and 24 February 1997 respectively and applied by hand to the plant stations. Weeding was done once on 20 February 1997. Harvesting was completed on 11 April 1997. The maize residue dry matter biomass from all 99 plots was estimated in June 1997 after an adequate period of six weeks of sun drying. Analyses of N, P and K concentrations were done separately for maize grain and the maize cob residue. For both, dry matter biomass was also estimated.

Table 3. Mineral fertilizer treatments and amounts of nutrients applied as basal and top dressings to maize

Fertilizer treatment	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Sulphur (kg ha^{-1})
Half rate				
Basal: 100 kg D ha^{-1}	10	20	10	9
Top: 100 kg AN ha^{-1}	34	–	–	–
Full rate†				
Basal: 200 kg D ha^{-1}	20	40	20	18
Top: 200 kg AN ha^{-1}	68	–	–	–

†Fertilizer recommendation of the agricultural extension service in the Luapula Province.

Statistical analysis

Normal distribution of data was examined by the Kolmogorow-Smirnow test with a Lilliefors significance level for testing normality. Homogeneity of variances was analysed by the Levene test. Analyses of variances were done using ONEWAY and ANOVA procedures. Differences of means were tested by the Student-Newman-Keuls test. Where data had ordinal measurement, the Mann-Whitney test and Kruskal-Wallis one-way analysis of variance were applied to test two or more independent samples. All statistical analyses were carried out at Mansa TAS and used the SPSS for Windows™ statistical software package for personal computers.

RESULTS

NPK nutrient contents

The amount of dry matter biomass produced by the tested species and cultivars and their concentrations of C, N, P and K are presented in Table 4. With respect to the total amounts of N, P and K bound in the dry matter biomass, the annual species sunn hemp Marejea (329 kg N ha^{-1}, 79 kg P ha^{-1}, 280 kg K ha^{-1}), sunn hemp NIRS (232 kg N ha^{-1}, 66 kg P ha^{-1}, 162 kg ha^{-1}) and velvet beans (183 kg N ha^{-1}, 41 kg P ha^{-1}, 112 kg K ha^{-1}) showed the highest values.

On average, annual pasture legumes bind 213 kg N ha^{-1}, 55 kg P ha^{-1} and 163 kg K ha^{-1}. Perennial pasture legumes obtained average N,P and K values of 68 kg ha^{-1}, 20 kg ha^{-1} and 73 kg ha^{-1} respectively. Rhodes grass bound nutrient amounts similar to those bound by annual pasture legumes, but with lower N and higher K values, 165 kg N ha^{-1}, 58 kg P ha^{-1} and 273 kg K ha^{-1}.

Table 4. Amounts of dry matter biomass produced by pasture legume species and Rhodes grass, and their concentrations of C, N, P and K.

Species	Plant biomass (kg DM ha^{-1})	Concentrations (% of plant DM)			
		C	N	P	K
Sunn hemp NIRS	12134	21.0	1.87	0.50	1.34
Sesbania	7092	20.6	1.75	0.60	2.29
Velvet beans	9281	19.8	1.97	0.43	1.19
Sunn hemp Marejea	14639	21.3	2.24	0.56	1.88
Stylo	4300	18.4	2.05	0.57	1.93
Lablab	5786	22.5	1.98	0.60	1.74
Siratro	2398	19.7	2.59	0.56	2.23
Glycine	937	22.4	2.22	0.57	2.30
Centro	1214	21.8	2.24	0.56	1.61
Teramnus	3848	21.9	2.08	0.57	2.28
Rhodes grass	14041	22.2	1.19	0.40	1.95

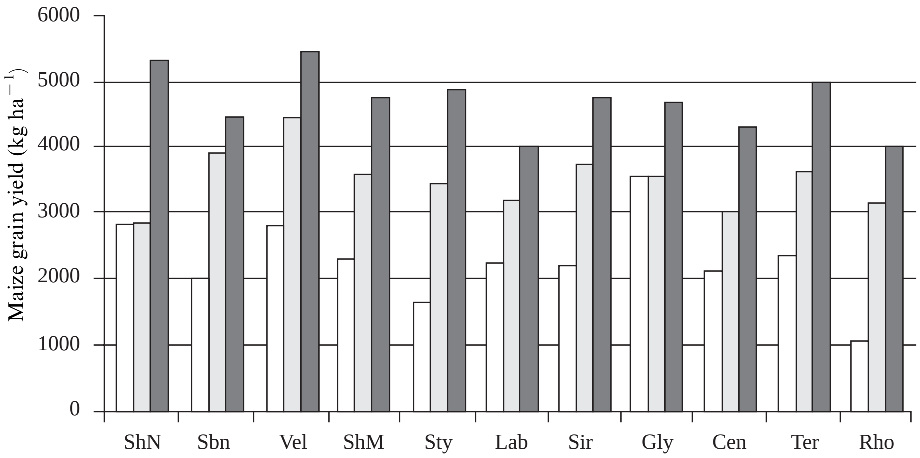

Fig. 1. Grain yields of the open-pollinating maize variety 'Pool 16' at different green manure plus zero (□), half (▒) and full (■) mineral fertilizer application rates. Green manure species and cultivars: sunn hemp NIRS (ShN), sesbania (Sbn), velvet bean (Vel), sunn hemp Marejea (ShM), stylo (Sty), lablab (Lab), siratro (Sir), glycine (Gly), centro (Cen), teramnus (Ter) and Rhodes grass (Rho).

Carbon:nitrogen ratios

The rapidity with which the biomass of green manure plants decomposes after incorporation, depends not only on soil-related factors but also on the C:N ratio of the plant biomass. Table 4 shows that C concentrations did not differ much among the species and cultivars, while N concentrations differed widely. The C:N ratios were calculated and ranged between 7.6 for siratro and 18.8 with Rhodes grass. The average C:N ratios of annual and perennial species were 11.1 and 9.8 respectively.

Green manure effects

The green manure effects of different pasture legumes on the grain yield of maize at different fertilizer levels are presented in Fig. 1. The mean grain yields across mineral fertilizer treatments differed significantly in a range of 2766 kg ha^{-1} for Rhodes grass to 4250 kg ha^{-1} for velvet beans. The latter was followed by glycine 3950 kg ha^{-1}, teramnus 3688 kg ha^{-1}, sunn hemp NIRS 3666 kg ha^{-1}, siratro 3596 kg ha^{-1}, sunn hemp Marejea 3552 kg ha^{-1}, sesbania 3450 kg ha^{-1}, stylo 3338 kg ha^{-1}, centro 3180 kg ha^{-1} and lablab 3147 kg ha^{-1}.

Mineral fertilizer effects

Across all green manure treatments the effects of different mineral fertilizer application rates on the grain yield, cob residue biomass, stover dry matter biomass and the net nutrient export of NPK are presented in Table 5. Grain yields and stover dry matter biomass differed considerably with all three fertilizer application rates. The cob residue dry matter biomass at full fertilizer rate was significantly higher than at the zero fertilizer rate. From the maize net nutrient exports presented in Table 5 and from the nutrient import through mineral

Table 5. Effects of different mineral fertilizer application rates on maize with respect to the grain yield, cob residue biomass, stover dry matter biomass and the net nutrient export of N, P and K.

Fertilizer level	Grain yield ($kg\ ha^{-1}$)	Cob residue biomass ($kg\ DM\ ha^{-1}$)	Stover biomass ($kg\ DM\ ha^{-1}$)	Net nutrient export ($kg\ ha^{-1}$)†		
				N	P	K
Zero rate	2307	586	4220	45	15	20
Half rate	3516	641	6821	68	23	30
Full rate	4700	851	7953	90	31	40
s.e.	133	24	221			

†Grain plus cob residues: Nutrient analysis from maize samples fertilized at half rate. Grain: 1.83 % N, 0.62 % P, 0.76 % K. Cob residue: 0.50 % N, 0.17 % P, 0.46 % K

fertilizers, negative balances (nutrient import minus nutrient export) were calculated for N, P and K at the full fertilizer application rate. While 98% of N export was replaced, P and K replacements reached only 56% and 42% respectively.

Green manure × mineral fertilizer effects

No significant interactions between the green manure treatments and the mineral fertilizer treatments were found. With all green manure species, grain yields of maize increased with increasing amounts of added mineral fertilizer. The highest Pool 16 grain yield (5466 $kg\ ha^{-1}$) was obtained with full fertilizer application rate after the incorporation of velvet beans. The incorporation of Rhodes grass with no mineral fertilizer resulted in the lowest maize grain yield of 1091 $kg\ ha^{-1}$. At the zero mineral fertilizer level, all pasture legume species treatments resulted in higher maize grain yields than the Rhodes grass (control) treatment. The greatest difference between legumes and non-legumes was observed with glycine (+2475 $kg\ ha^{-1}$).

Economic considerations

The economic considerations regarding the use of mineral fertilizer in this trial are presented in Table 6. Calculations based on the results in Table 5 showed that the marginal production of maize grain at half and full mineral fertilizer application rates resulted in a similar value:cost ratio, slightly above 2.0.

DISCUSSION

The experiment showed that the sunn hemp cultivars Marejea and NIRS have the highest nutrient potentials in terms of N, P and K bound in the dry matter biomass. They are followed by velvet beans and Rhodes grass. To what extent this nutrient potential of the dry matter biomass becomes effective after incorporation into the soil, depends on various factors. The results indicate that the biomass potential alone insufficiently explains the green manure effects. Although Rhodes

Table 6. Economic characteristics of mineral fertilization with open-pollinating maize in Luapula Province.

Fertilizer level	Marginal production of maize grain (kg ha^{-1})	Marginal production value† (Kwacha)	Marginal cost value‡ (Kwacha)	Gross benefit	Value : cost ratio
Half	1209	295 533	140 000	155 533	2.11
Full	1184	289 422	140 000	149 422	2.09

†90 kg maize grain = 22 000 ZK (Mansa, June 1997, 1 US$ = 1 290 Kwacha), ‡ 50 kg D = 35 000 K, 50 kg AN = 35 000 ZK (Mansa, December 1996, 1 US$ = 1 360 Kwacha).

grass developed quite a bulky biomass, the green manure effect on the subsequent maize crop was the lowest of all species and cultivars tested. There could be various reasons for that finding, one being the lack in Rhodes grass of atmospheric N fixation as occurs in the root nodules of pasture legumes. Another reason could be the very wide C:N ratio in the Rhodes grass dry matter biomass. More N is required by soil microorganisms for the decomposition of Rhodes grass than is needed for the decomposition of annual and perennial pasture legume biomass. In support of this, Figure 1 shows that when soil microorganisms were supported by mineral fertilization the decomposition of the Rhodes grass dry matter biomass resulted in a substantial marginal increase in maize grain yield. This indicates strongly that, to achieve the intended fertilization effects especially in soils with low fertility status as in the type chosen for this study, a narrow C:N ratio of a green manure crop is more important than its ability to produce large amounts of dry matter biomass. In this context it should be noted that the green manuring effects of perennial pasture legume species on maize grain yields at zero fertilization level were stronger than could be expected from their dry matter biomass production (Figure 1; Table 4). What might also have contributed to this green manure effectiveness of perennial pasture legumes is their continued growth after the end of the rainy season in 1995–96, especially with siratro and glycine. According to Skerman *et al.* (1988) perennial pasture legumes develop deep root systems. In this respect their green manuring effects might be influenced more by the root zone than by the above ground parts.

Under the conditions of this study, the selection of a suitable green manure crop for small-scale farming should be based on two major criteria: firstly, a narrow C:N ratio and secondly, a high biomass nutrient potential. This applies especially to those farmer households where no financial resources are available for acquiring mineral fertilizer. As zero fertilization becomes more and more common in small-scale farming in the Luapula Province, the cultivation of pasture legume species for green manuring purposes is strongly supported by this study. At the current stage of research where all tested species have been compared at zero fertilizer level, the most recommendable annual species are sunn hemp and velvet bean, and glycine is the most promising perennial species.

With respect to mineral fertilizer applications, the results of this study revealed that the P and K nutrient export by maize cobs (grain + cob residue) is higher than the nutrient import. While the N concentration of the soils can be supported by cultivation of pasture legumes (N fixation), based on the findings of this research the P and K resources have to be maintained by higher external nutrient imports. It is recommended strongly, therefore, that research activities should be intensified on (i) whether this can be achieved by the application of plant biomass from outside the fields (cut and carry systems), (ii) how an optimized combination of organic and mineral fertilization could be developed and (iii) how the effectiveness of mineral fertilizer applications could be increased by improved application techniques. This is necessary because a simple recommendation to increase mineral P and K applications would further aggravate the financial situation of small-scale farmers. In this respect, the economic considerations presented in Table 6 (in particular the low value:cost ratio) show that farmers in Luapula Province already take a high financial risk by using mineral fertilizers for maize production.

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