Chapter 8
Comparative Analysis of the Current and Potential Role of Legumes in Integrated Soil Fertility Management in Southern Africa

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Abstract Food insecurity, arising from low and non-sustainable agricultural production systems under increasing climate variability is one of the major livelihood threats for the majority of households in Southern Africa. Nitrogen (N) is the most limiting nutrient in the predominantly smallholder maize-based cropping systems, with N inputs almost invariably constituting the largest cost of crop production. Traditional methods of soil fertility management are critically short of matching the increasing food demands of a growing human population against the rising cost of living. Limited access to affordable mineral fertilizers by farmers exacerbates inherent problems of a low soil nutrient capital. This paper explores the current and potential contribution of legume biological N_2-fixation (BNF) to the N economy of cropping systems in southern African countries in the context of integrated soil fertility management (ISFM) approaches. There is potential for BNF to generate 200–300 kg N ha^{-1} under farmer management conditions, reducing N fertilizer inputs for subsequent maize by 50–100 kg ha^{-1} in a single cropping season. Legumes derive 50–90% of their N requirements from N-fixation, nearly eliminating the need for external N fertilization. However, current N inputs from BNF on smallholder farms remain as low as 5 kg N ha^{-1} $year^{-1}$ due to factors that include poor choices of legume types/varieties, small areas allocated for legume production, and poor soil fertility (particularly phosphorus [P] deficiency) and rainfall variability that lead to poor biomass accumulation. Application of P containing fertilizers was found to increase legume yields by 20–100% across dominant soils, while combinations of livestock manure and mineral fertilizer increased yields of grain legumes by 50–150% even poor sandy soils. Although legume green manures and agroforestry tree systems resulted in the highest maize yield responses of up to 400%, their lack

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of short-term food and income benefits severely limits their preference and adoption by farmers. In contrast, grain legumes showed the highest potential in farming systems in Malawi, Mozambique, Zambia and Zimbabwe where they are used in rotations and/or intercrops depending on rainfall conditions. Grain legumes increased yields of subsequent cereals by 60% to >200% over non fertilized controls following addition of mineral fertilizer in modest amounts. There are, however, significant technical knowledge gaps among farmers, agro-input suppliers and extension agencies on management options for optimizing BNF. The study identified lack of suitable mechanisms to deliver smallholder communities out of an existing '*maize poverty trap*' as an overaching challenge for intensification and diversification of the cereal-legume systems. Prevailing agricultural production circumstances of many smallholders favour maize monocropping. Research and development intitiatives have also tended to ignore the multiple roles of grain legumes as prioritized by communities, particularly women. Opportunities exist for multi-stakeholder platforms that generate technical and market innovations with communities to drive legume-based ISFM technologies for increased productivity and diversification of southern Africa's current farming systems.

8.1 Introduction

Nitrogen (N) deficiency is arguably an incessant problem of tropical agriculture due to high rates of soil organic matter (SOM) turnover (Nye and Greenland 1960) coupled with low levels of organic inputs and high incidences of N loss principally due to leaching. This may largely explain the invariably high demand for N inputs in the predominantly maize (*Zea mays* L.)-based cropping systems of Southern Africa, particularly in the sub-humid zones where mean annual rainfall ranges from 800 mm to ±1,600 mm. The growing human population and rising cost of living have critically diminished the scope for traditional methods of soil fertility maintenance or restoration. Consequently, food insecurity, arising from low and non-sustainable agricultural production systems under increasing climate variability, is one of the major livelihood threats for the majority of households in Southern Africa. The region is no exception to most parts of sub-Sahara Africa where per capita food production is declining (Sanchez et al. 1997). As farm sizes continue to shrink against the rising population pressure, continuous cropping has inevitably become dominant in the farming systems and there is currently a dire need for soil fertility management strategies and technologies that support intensification. For small land areas cropped every year, there are widespread reports of a downward trend in crop yields due to poor and declining soil fertility (Kumwenda et al. 1995; Sanchez et al. 1997; Waddington et al. 1998a, b). As such, scientific evidence suggests high rates of nutrient depletion in Southern Africa. Nitrogen balance estimates, for example, ranged from -31 kg N ha^{-1} for Zambia to worse than -60 kg N ha^{-1} for Malawi and Mozambique (Stoorvogel et al. 1993). These high levels of nutrient mining are largely driven by positive net nutrient exports from the fields in harvested crop products (grain, residues, fibre) since most of the farmers in the region are predominantly smallholders with limited capacity to acquire adequate external nutrient inputs for use on an annual basis.

Limited availability of nutrient resources in Southern Africa exacerbates an already existing problem of an inherently low soil nutrient capital. The dominant soil types in the whole region comprise Lixisols, Arenosols, Acrisols and Ferralsols (FAO 1990) most of which have limited capacity in holding and supplying the major plant nutrients and water. The problem cuts across the two main agro-ecologies, namely, the sub-humid and semi-arid zones. While the most apparent and obvious constraint for crop production in the semi-arid tropics is soil moisture, poor soil fertility has over the years been identified as the single most important underlying cause for low crop yields for such low rainfall areas in Southern Africa (Mapfumo and Giller 2001). Apart from the highly priced mineral fertilizers such as ammonium nitrate (AN), calcium ammonium nitrate (CAN), urea, di-ammonium phosphate (DAP) and various compound fertilizers, N_2-fixing legumes are probably the only other realistic option for supplying N and improving soil fertility in cropping systems of Southern Africa.

Leguminous plants that associate symbiotically with N_2-fixing bacteria, mainly of the genus *Rhizobium*, are able to capture atmospheric N_2 in amounts sufficient to meet their growth requirements (Peoples et al. 1989). The fixed N can significantly contribute to the N economy of agro-ecosystems (Giller 2001) and therefore constitute a renewable source of the most limiting nutrient in tropical agriculture. However, this attribute does not seem to be among the major driving factors behind the continued existence of various legume species found in the prevailing cropping systems, particularly on smallholder farms. A wide range of legumes, which include, groundnut (*Arachis hypogaea* L.), Bambara groundnut (*Vigna subterranea* [L.] Verdc), cowpea (*Vigna unguiculata* [L.] Walp), pigeonpea (*Cajanus cajan* [L.] Millsp.), common bean (*Phaseolus vulgaris L.*) and soyabean (*Glycine max* [L.] Merr.) are commonly grown by smallholder farmers in Southern Africa. Legumes are used for various purposes that include improvement of human nutrition, cash generation at local (village) and national markets, soil fertility improvement and providing high quality (protein rich) forage. Out of these multiple uses, soil fertility impact of legumes in the cropping systems is very minimal (Mapfumo et al. 2001a). Most households in Southern Africa use maize for staple food, and cereals generally rank high when compared with legumes in terms of nutritional importance. For instance, maize contributes 80% of the daily food calories and is planted to over 76% of the total arable land in Malawi (Government of Malawi 1999). With the exception of soyabean which has gained significantly in economic significance (Mpepereki et al. 1996), most of the legumes have been relegated to minor crops and are generally considered as women's crops since they are often produced by women on small land areas meant primarily for home consumption (Mapfumo et al. 2001a, b). One of the most important questions is whether, and how, legumes are serving their purpose in cropping systems. This comes in the wake of an increasing realization that legumes can play a pivotal role in sustaining crop productivity in smallholder farming systems (Giller et al. 1994; Giller 2001). Soil fertility management is considered as a means for achieving food security in Southern Africa. However, there is little documentation on the potential and realities of legumes with respect to integrated soil fertility management (ISFM). There is limited knowledge on how the other multiple functions of legumes can be turned into drivers for ISFM, particularly with reference to farming systems in Malawi, Mozambique, Zambia and Zimbabwe.

8.2 Dominant Cropping Systems in Southern Africa

In general, most of the cropping systems in Southern Africa are maize (*Zea mays* L.) based, with maize accounting for an average of 60–90% of the seasonal cropped areas and providing the staple diet for the majority of people (Kumwenda et al. 1995). With respect to soil fertility management, however, the farming systems are as diverse as the socio-cultural and environmental settings that have dictated their evolution, ranging from the *Chitemene* and *Fundikila* systems of northern Zambia to the manure- and fertilizer-based management systems of Zimbabwe. *Chitemene* is a 'lop and burn' system characteristic of shifting cultivation, while *Fundikila* is basically an *in-field* composting of predominantly low quality veld grasses in small mounds (explained in detail later in this chapter). In most of the farming systems, the maize is either monocropped (predominantly), intercropped with legumes, rotated with legumes and small grain cereals or interrupted by periods of natural fallowing. Maize is sometimes replaced with pearl millet (*Pennisetum glaucum* [L.] R.Br.) and sorghum (*Sorghum bicolor* [L.] Moench) in semi-arid zones (Chivasa 1995; Ahmed et al. 1996). Traditional intercrops involve, cowpea and Bambara groundnut with maize and sorghum. Cowpea has often been sparsely intercropped with the staple cereal crops. Dominance of any of these cropping systems partly depends on human population densities and hence land-holding, and also on availability of labour and draught power. Farm size in most areas average ~0.5 ha household in Malawi to >5 ha in Zambia. In Zimbabwe, Mozambique and southern Zambia, most households rely on animal draught power (particularly cattle) while hand-hoeing is predominantly used in Malawi (Waddington 1994; Scoones et al. 1996). Average population densities range from <45 persons km^{-2} in parts of Zimbabwe (CSO 1998) to ~250 persons km^{-2} in Malawi. With high population densities, periods of natural fallowing are reduced, and there is decreased availability of organic resources such as cattle manure. Although a wide range of nutrient resources are used, almost all are traditionally targeted towards the staple cereal crops, especially maize, with legumes and minor crops rarely receiving any external fertilization (Campbell et al. 1998; Mapfumo et al. 1999).

8.3 Legumes as a Critical Source of N in Croppings Systems

The main sources of N inputs in farming systems are mineral fertilizers, legume BNF, organic resources transferred from outside the field such as animal manures and plant biomass, and NO_3^--N reclaimed from subsoil by deep rooted shrubs

Table 8.1 A summary of N_2 fixation potential from different categories of tropical legumes

Legume system	%N derived from fixation	Amount fixed (kg N ha^{-1})	Time (days)
Grain	60–100	105–206	60–120
Pasture	45–98	115–280	120–365
Green manure	50–90	110–280	45–200
Trees	56–89	162–1,063	180–820

Adapted from Giller (2001)

and/or perennials. Of these, only mineral fertilizers and legumes (through BNF) effectively provide real N additions to the cropping systems. Nitrogen fixing legumes are, therefore, an essential driver of ISFM technologies for smallholder farming systems given the ever escalating costs of accessing mineral fertilizers. A synthesis of findings from decades of research based on controlled trials from both on-station and farmers' fields demonstrate a high potential of diverse legumes to fix large amounts of N under tropical environments (Giller 2001). Legume species commonly used for provision of grain, green manure and pastures have potential to fix between 100 and 300 kg N ha^{-1} from the atmosphere (Table 8.1).

Most annual legumes have a low C:N ratio and low levels of lignin and polyphenols, thereby satisfying the minimum chemical quality attributes required for net-mineralization in the short-term (e.g. within a single cropping season). The relatively high amounts of N fixed in legume biomass can therefore be readily available to subsequent crop, substantially reducing annual demands for chemical fertilizer use at field and farm scales. Fertilizer equivalency values between 50 and 100 kg N ha^{-1} have been reported from regional field trials from both on- station and on-farm (e.g. Bogale et al. 2001; Bezner Kerr et al. 2007). Fertilizer equivalency for legume biomass of different quality was estimated at 16% to >100% from different on-farm experiments in east and southern Africa (Murwira et al. 2002). Mineral N fertilizers constitute the largest fertilizer cost in Southern Africa's predominantly cereal-based cropping systems, further suggesting that any small N contributions from BNF can translate into significant subsidies to prevailing production costs.

Main factors that determine the amount of N fixed by legumes include: (a) legume genotype (including cultivar); (b) establishment of an effective symbiosis between the legume (macro-symbiont) and the rhizobial bacteria (micro-symbiont), from which N is fixed; (c) the amount of N accumulated in the legume plant biomass during the growth cycle as influenced by agronomic management factors including soil fertility. For purposes of enhancing the N economy in cropping systems, the area cultivated to the legume constitutes the fourth factor (d). Optimization of BNF in smallholder cropping systems will therefore hinge on management strategies that are designed to address these four factors. For instance, inoculation usually becomes necessary when a new legume is introduced into an area where the soils do not contain rhizobial strains that can effectively nodulate that legume. Inoculation may also be necessary in soils that do not support a sufficiently large populations of the rhizobia nodulating a given legume species.

8.4 Estimated Amounts of N Fixed by Different Legumes on Farmers' Fields

To date, there are limited studies quantifying N_2-fixation by different legumes in Southern Africa despite increasing awareness among research and development communities about their potential benefits to smallholder farming systems. Notably, there is a critical absence of BNF related studies from smallholder farming systems in Mozambique. However, the relatively few studies available have generated critical lessons and technical knowledge on the potential contributions of legumes to the region's farming systems. Most of the traditionally grown grain legumes that include cowpea, groundnut, Bambara groundnut and pigeonpea effectively nodulate with native soil rhizobia, and will not require inoculation across the diverse agro-ecologies (e.g. Mpepereki and Makonese 1994; Mapfumo et al. 2000). Similar patterns have been observed for most tropical legumes used for green manures such as sunnhemp species (*Crotalaria* spp.) and mucuna (*Mucuna pruriens* [L.] DC.), and a wide range of agroforestry shrubs/trees. There is therefore enormous potential for tapping the diversity of both the legumes and native rhizobia to increase BNF contributions to smallholder farming systems for increased crop productivity and enhanced nutrition of humans and livestock. Contrary to the above-mentioned legumes, soyabean generally requires inoculation in most of the region's soils, with the exception of known promiscuous varieties (Giller 2001; Musiyiwa et al. 2005). Soyabean is arguably the most researched grain legume in the region because of its economic value as a cash crop, and available national innoculant factories are basically build around production of suitable *Bradyrhizobium* strains. Thus, technically, there is a broad scope for enhancing BNF driven soyabean production for smallholders.

Field studies have shown that commonly grown grain and green manure legumes derive most of their N from N_2-fixation (Table 8.2). On granitic sandy soils with <10% clay, the legumes depend almost entirely on BNF, deriving ~90% of their N (e.g. Mapfumo et al. 1999; Kasasa 1999). Tree legume species derive about 50% of their N from fixation (Table 8.2), and it is not clear how much N_2-fixation is influenced by their ability to access subsoil N that is otherwise leached beyond the rooting zone of most annual crops. The limited studies quantifying BNF on farmers' fields seem to suggest a relatively higher dependence on N_2-fixation by annual legumes grown on poorer soils and in intercrops than those in sole cropping (e.g. Giller 2001; Giller et al. 2002). Further quantitative research is necessary to determine the implications for sustainability of some of traditional and promising (community prioritized) intercrops such as the maize/pigeopea in southern Malawi and the maize/cowpea and maize/groundnut systems in Mozambique.

Against the potential for annual fixation rates of 300 kg ha^{-1}, the amounts measured on farmer's fields are still very low (Table 8.2). The high rates of N_2-fixation of about 70–90% for most annual grain legumes do not translate into effectively high amounts N fixed at farm and field scales. Based on studies conducted mainly in Malawi, Zambia and Zimbabwe, only soyabean fixes relatively high amounts of N per unit of land, yielding between 100 and 260 kg N ha^{-1} within periods of no more than 3 months (Table 8.2). Most of the tested legumes fixed as low as 6 kg N ha^{-1} to

Table 8.2 Estimated amounts of nitrogen fixed by different legumes under smallholder farmer management conditions in Southern Africa

Legume type	%N from N_2-fixation	N fixed (kg ha^{-1})	Soil texture	Location/country of study	References
(a) Annual grain and green manure legumes					
Cowpea (*Vigna anguiculata*)	76%	73	Coarse sand	Chinamora, Zimbabwe	Mapfumo et al. (2001a, b)
	92%	79	Coarse sand	Chinyika, Zimbabwe	
	65%	54	Coarse sand	Murehwa, Zimbabwe	
	58%	28	Sandy clay loam	Domboshava, Zimbabwe	Chikowo et al. (2003)
	15–56%	21–109	Sandy loam	Matopos, Zimbabwe	Ncube et al. (2007)
Bambara groundnut (*Vigna subterranea*)	75%	47	Coarse sand	Chinamora, Zimbabwe	Mapfumo et al. (2001a, b)
	88%	54	Coarse sand	Chinyika, Zimbabwe	
	72%	57	Coarse sand	Murehwa, Zimbabwe	
	34–61%	2–72	Sandy loam	Matopos, Zimbabwe	Ncube et al. (2007)
Groundnut (*Arachis hypogaea*)	52%	28	Coarse sand	Chinamora, Zimbabwe	Mapfumo et al. (2001a, b)
	68%	46	Coarse sand	Chinyika, Zimbabwe	
	59%	50	Coarse sand	Murehwa, Zimbabwe	
	19–83%	7–86	Sandy loam	Matopos, Zimbabwe	Ncube et al. (2007)
Pigeonpea (*Cajanus cajan*)	42%	13	Sandy	Lisasadzi, Malawi	Sakala et al. (2001)
	85%	163	Sandy loam-clay	Chitedze, Malawi	
	84%	97	Sandy clay loam	Domboshava, Zimbabwe	Chikowo et al. (2003)
	81%	6	Coarse sandy	Murehwa, Zimbabwe	Mapfumo et al. (1999)
	91%	43	Coarse sandy	Murehwa, Zimbabwe	
	92%	16	Coarse sandy	Murehwa, Zimbabwe	
	28–57%	25–56	Sandy loam	Matopos, Zimbabwe	Ncube et al. (2007)
Soyabean (*Glycine max*)	92%	115	Sandy loam	Hurungwe, Zimbabwe	Kasasa (1999)
	93%	127	Sandy loam	Hurungwe, Zimbabwe	
	93%	128	Sandy loam	Hurungwe, Zimbabwe	
	88%	258	Clay	UZ farm (on-station)	

(continued)

Table 8.2 (continued)

Legume type	%N from N_2-fixation	N fixed (kg ha^{-1})	Soil texture	Location/country of study	References
Sunnhemp (*Crotalaria juncea*)	48%	16	Sandy loam – clay	Malawi	Giller (2001), Giller et al. (2002)
	49%	43		Malawi	
Mucuna (*Mucuna pruriens*)	42%	58	Sandy loam	Malawi	Giller (2001)
	73%	78	Sandy loam	Malawi	
(b) Agroforestry tree legumes (1 year)					
Tephrosia vogelii	37–78%	12–45	Clay	Malawi	Giller (2001)
Faidherbia albida	32–52%	nd	Sandy loam	Malawi	
Acacia angustisima	52%	210	Sandy loam	Kalichero, Zambia	Mafongoya et al. (2003)
Acacia angustisima	56%	122	Sandy loam	Domboshava, Zimbabwe	Chikowo et al. (2003)
Calliandra calothyrsus	44%	214	Sandy loam	Kalunga, Zambia	Mafongoya et al. (2003)
Sesbania sesban	55%	84	Sandy loam	Domboshava, Zimbabwe	Chikowo et al. (2003)

Table 8.3 Amounts of N Fixed and land areas commonly allocated to different grain legumes on smallholder farms in Zimbabwe

Legume type	N_2 fixed (kg N ha^{-1})	Area allocated to legume (ha farm^{-1})	Total N fixed per farm (kg N farm^{-1})
Groundnut	52	0.08	4.2
Cowpea	47	0.03	1.4
Bambara nut	33	0.22	7.3
Pigeonpea	39	0.34	13.3

Adapted from Mapfumo et al. (2001a, b)

a maximum that rarely exceeded 80 kg N ha^{-1}. However, medium to long-term pigeonpea fixed up to 163 kg N ha^{-1} when grown on soils with more than 20% clay. Agroforestry tree crops fixed up to 200 kg N ha^{-1}, and this can be largely attributed to their superior biomass accumulation due to the relatively long growth duration of these semi perennial and perennial crops. For both annual and perennial legumes, the actual amounts of N available to enhance soil fertility are undermined by small areas allocated to legumes at farm scales. A field survey in Zimbabwe showed that legumes were allocated to 3–15% of farm arable areas (Mapfumo et al. 2001a, b). The actual amounts of N fixed per farm are effectively reduced to an average of ~5 kg N ha^{-1} year^{-1} (Table 8.3). The practical realities of BNF contribution to cropping systems at farm scales will not therefore likely happen if constraints to legume integration are not addressed.

8.5 Opportunities for Increasing Legume Productivity

Apart from small areas allocated to legumes at farm level, some of the commonly cited biophysical reasons behind low amounts of N fixed include poor fertility of soils, rainfall related constraints, lack of improved crop varieties and limited capacity of farmers. Under favourable rainfall conditions (<750 mm year^{-1}) and relatively clayey soils (>15% clay), most of the commonly grown legumes are able to accumulate high amounts of biomass that often exceed 2 t ha^{-1}. Biomass yields of 3.5–8 t ha^{-1} have been reported for annual legumes under researcher-managed trials in Zambia and Malawi where soils are relatively fertile (e.g. Kumwenda and Gilbert 1998). Such yields would be sufficient to positively impact on N economy of the cropping systems. However, major soil parent materials in Southern Africa are well known for their limited phosphorus availability (Brown and Young 1965; FAO 1990; Nyamapfene 1991; Maria and Yost 2006). Most of the farming systems are characterised by decades of monocropping and associated nutrient mining, exacerbating an already inherent problem of a low nutrient capital, and often causing multiple nutrient deficiencies (Stoorvogel et al. 1993; Mapfumo and Giller 2001). Phosphorus deficiency is known to undermine nodulation and N_2-fixation processes, and limit biomass accumulation of the candidate legumes (Giller 2001). Responses of different legume types and varieties to P and other forms of fertilization in the dominant soils of southern Africa has, however, not been systematically investigated. Legume

Table 8.4 Response of different legumes to fertilization under smallholder farm management conditions

Legume type	Fertilizer added	Yield attained (kg ha^{-1})	% yield change over control (%)	Location of study	Reference
Sunnhemp (*Crotalaria juncea*) green manure	100 kg P_2O_5 ha^{-1} as single super phosphate (SSP)	1.7[a]	+97	Gokwe South, Zimbabwe (on-farm)	Hikwa et al. (1998)
Velvet bean	100 kg P_2O_5 ha^{-1} as single super phosphate (SSP)	2.4[a]	+24	Gokwe South, Zimbabwe (on-farm)	Hikwa et al. (1998)
Soyabean	Mono-ammonium phosphate at 60 kg P_2O_5 ha^{-1} +70 kg K ha^{-1} + 26 kg S ha^{-1} + 24 kg N ha^{-1} + 360 kg ha^{-1} of lime	4.4[a]	+92	Chibwe, Zambia (on-station)	Lungu and Munyinda (2003)
Soyabean	26 kg P ha^{-1} + cattle manure @ 6.5 t dry matter ha^{-1}	3.8[a]	+153	Chinyika, Zimbabwe	Kanonge et al. (2009)
Cowpea	Mono-ammonium phosphate at 120 kg P_2O_5 +70 kg K ha^{-1} + 26 kg S ha^{-1} + 24 kg N ha^{-1}	2.1[a]	+19	Mwanachingw-ala, Zambia (on-farm)	Lungu and Munyinda (2003)
Cowpea	Partially acidulated phosphate rock at 60 kg P_2O_5 +120 kg K ha^{-1} + 26 kg S ha^{-1} + 24 kg N ha^{-1}	2.3[a]	+35	Mwanachingwa-la (on-farm)	Lungu and Munyinda (2003)
Cowpea	26 kg P ha^{-1} + cattle manure @ 6.5 t dry matter ha^{-1}	2.2[a]	+82	Chinyika, Zimbabwe	Kanonge et al. (2009)
Groundnut	Partially acidulated phosphate rock at 60 kg P_2O_5 +70 kg K ha^{-1} + 26 kg S ha^{-1} + 24 kg N ha^{-1} +360 kg ha^{-1} lime	1.7[a]	+70	Mwanachingwala (on-farm)	Lungu and Munyinda (2003)
Groundnut	8.5 kg P ha^{-1}	0.6	39	Marange, Zimbabwe	Mupangwa and Tagwira (2005)
	34 kg P ha^{-1}	0.9	51		

[a] Biomass yield

biomass productivity on most of the smallholders' fields requiring soil fertility improvement has remained below 2 $\mathrm{t\,ha^{-1}}$, limiting the scope for significant rotational influence to subsequent cereals as well as the much needed markatable yield incentives for farmers. The limited research findings available are nonetheless indicative of significant increases in both biomass and grain yield of different legumes following P application. Modest amounts of P, ranging from ~10 to 50 kg $\mathrm{ha^{-1}}$ have been shown to increase legume productivity by about 20–100% (Table 8.4). Studies from different agro-ecologies in Zimbabwe, Zambia (Table 8.4) and more recently Mozambique (Mapfumo et al. 2009a, b) underscore the challenges of addressing poor soil fertility in order to 'kick-start' a meaningful production of legumes and derive the associated benefits.

Significantly high yield improvements have been attained following application of combinations of P containing inorganic fertilizers with organic nutrient sources, and in some cases lime. On some of Southern Africa's challenging sandy soils which occur widely in Zimbabwe, application of P at 26 kg $\mathrm{ha^{-1}}$ and organic manure (cattle manure or woodland litter) at ~5 $\mathrm{t\,ha^{-1}}$ increased cowpea and soyabean biomass yields by 50–150% with effective yields > 2–4 $\mathrm{t\,ha^{-1}}$ (Kanonge et al. 2009). Yields from farmers' fields often range from total crop failure to 1 $\mathrm{t\,ha^{-1}}$. Combinations of cattle manure and a compound fertilizer which provided P and starter N, consistently gave superior legume yields in Zimbabwe (Fig. 8.1), suggesting a possibility of multiple nutrient deficiencies among other soil fertility constraints. Mupangwa and Tagwira (2005) achieved groundnut yield increases of 39–51% on similar soils when P was applied at rates between 8.5 and 34 kg $\mathrm{ha^{-1}}$. However, yields increased by 57–81% when calcitic lime (200 kg $\mathrm{ha^{-1}}$) was combined with P, and by 50–90% when gypsum (100 kg $\mathrm{ha^{-1}}$) was used in place of lime. These findings were consistent with results from Zambia where combinations of acidulated phosphate rock and lime increased cowpea and groundnut biomass yields by 35% and 70% respectively (Table 8.4).

8.6 Rotational Benefits to Subsequent Cereal Crops

Research over the past two decades has investigated soil fertility benefits of technology options based on rotations and intercrops involving N_2-fixing green manure and grain legumes (Snapp et al. 1998; Waddington 2003) as well as agroforestry-based crop management systems (Mafongoya et al. 2006; Akinnifesi et al. 2006). Overall, there is overwhelming evidence of cereal yield benefits under these soil fertility management options, and numerous examples can be cited of grain yield increases from 50% to >400%. However, the magnitude of yield benefits, particularly for maize, vary considerably according to agro-ecology, field and farm types, farmer resource endowment, and whether the legume is used for green manuring or grain crop and in a rotation or intercrop. While the multiplicity of scenarios arising from these factors present considerable challenges for researchers to integrate legumes into the farming systems, it also broadens opportunities for

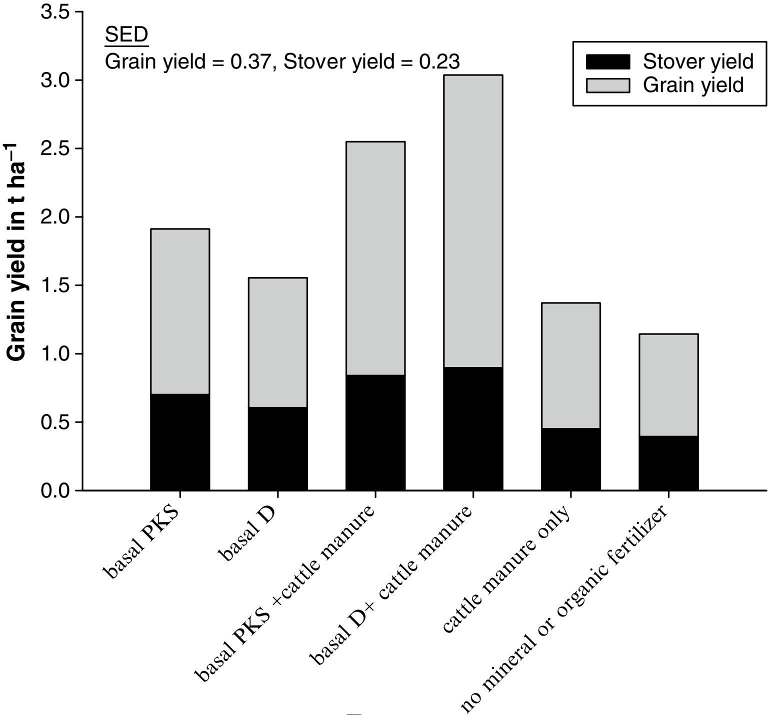

Fig. 8.1 Grain and stover yields from cowpea as affected by soil fertility management practice, in Makoni District, Zimbabwe (*SED- Standard error of the difference between means*) (Kanonge et al. 2009)

satisfying the need for the widely diverse and heterogeneous smallholder farmer circumstances.

Green manures and agroforestry biomass transfer systems have often registered the highest yield contributions to beneficiary cereals crop (Table 8.5), but have increasingly emerged as the least prioritized by smallholders farmers under their prevailing production circumstances. This can be largely attributed to their lack of short-term benefits in terms of both food and income. Critical technical lessons can, however, be drawn from research experiences in the region. In central and southern Malawi, sunnhemp (*Crotalaria juncea*), tephrosia (*Tephrosia vogelii*) and velvet bean (*Mucuna pruriens*) green manure often resulted in maize yields of 3–6 t ha^{-1} even with no additional mineral N fertilizer added (Kumwenda et al. 1998), and were able to generate critical biomass yields of ≥2 t ha^{-1} to influence cereal yields in rotation (Gilbert 1998). However, the same species had mixed results on granite-derived sandy soils of Zimbabwe (see Waddington et al. 1998a, b), even as they have remained the prioritized 'best-bet' green manure legumes. Higher biomass yields of green manure legumes are achieved under sole stands than when the legumes are either intercropped or relay cropped. This is often reflected in yields of the subsequent maize (Table 8.5). In trials where maize following a legume green manure was fertilized,

Table 8.5 Maize yields following different legume-based soil fertility technology options in Southern Africa

Legume technology option	Attained maize grain yield (kg ha^{-1})	% yield increase (+) or decrease (−) over controls (%)	Study area/ Country	Reference
Legume green manure – rotations				
Maize following sunnhemp/ cowpea green manure	4.3	+230[a] +148[a]	Harare research station (on-station)	Agronomy (1993)
Maize following cowpea green manure	6.2	+280[a]	Mangwende, Zimbabwe (on-farm)	Chibudu (1998)
Maize follwing mucuna green manure +100 kg P ha^{-1}+45 kg N ha^{-1}	1.6	+252[a] +140[b]	Chihota, Zimbabwe (on-farm)	Murata et al. (2000)
Maize mucuna green manure +23 kg N ha^{-1}	2.4	+170[a] +13[b]	Muswishi, Zambia (on-farm)	Mwale et al. (2003)
Sunnhemp green manure +100 kg P ha^{-1}+45 kg N ha^{-1}	2.5	+449[a] +273[b]	Chihota, Zimbabwe (on-farm)	Murata et al. (2000)
Maize following mucuna green manure	1.6	+45[a] −125[b]	Ntecheu, Malawi (on-farm)	Sakala et al. (2003a, b)
Maize following mucuna green manure	0.7	+75[a] −100[b]	Angalala, Malawi (on-farm)	Sakala et al. (2003a, b)
4th year fertilized maize following mucuna green manure	5.8	+21[b]	Chitedze, Malawi (on-station)	Kumwenda et al. (2001)
Legume/maize intercrops				
Maize relay intercropped with sunnhemp	1.3	−12[b]	Domboshawa, Zimbabwe (on-station)	Jeranyama et al. (1998)
Maize relay intercropped cowpea +120 kg N ha^{-1}	4.5	−32[b]	Domboshawa, Zimbabwe (on-station)	Jeranyama et al. (1998)
Maize undersown in pigeonpea in year of improved fallow	0.4	−14[b]	Chinyika, Zimbabwe (on-farm)	Nyakanda et al. (1998)
Maize after maize/ mucuna intercrop +Compound D	2.0	+116[a] −6[b]	Muswishi, Zambia (on-farm)	Mwale et al. (2003)
Maize/ mucuna intercrop	1.0	+25[a] −110[b]	Mangwende, Zimbabwe (on-farm)	Chibudu (1998)
Maize/ cowpea intercrop	1.5	+88[a] −75[b]	Mangwende, Zimbabwe	Chibudu (1998)
Maize/*Sesbania sesban* intercrop	1.7	+244[a] −25[b]	Malosa, Zomba, Malawi (on-farm)	Phiri et al. (1999)

(continued)

Table 8.5 (continued)

Legume technology option	Attained maize grain yield (kg ha^{-1})	% yield increase (+) or decrease (−) over controls (%)	Study area/ Country	Reference
Maize/pigeonpea intercrop	1.2	−150[b]	Chitedze, Malawi (on-station)	Kumwenda et al. (1998)
Maize/sunnhemp intercrop	1.8	−67[b]	Chitedze, Malawi (on-station)	Kumwenda et al. (1998)
Agroforestry tree crops				
S. seban improved fallow	2.1	+162[a] +17[b]	Chinyika, Zimbabwe (on-farm)	Nyakanda et al. (2002)
Tithonia diversifolia biomass transfer (without fertilizer)	3.8	+100[a] +111[b]	Bembeke, Malawi (on-farm)	Ganunga et al. (1998)
T.diversifolia biomass transfer (without fertilizer)	3.8	+100[a] +111[b]	Bembeke, Malawi (on-farm)	Ganunga et al. (1998)
1-year *S. sesban* improved fallow	3.6	+350[a] −10[b]	Eastern Zambia (on-farm)	Mafongoya et al. (2003)
1-year *Tephrosia vogelli* improved fallow	3.1	+288[a] −35[b]	Eastern Zambia (on-farm)	Mafongoya et al. (2003)

[a] % increase (+) or decrease (−) over continuous unfertilized maize

[b] % increase (+) or decrease (−) over continuous fertilized maize

grain yield gains up to four times higher than unfertilized maize were achieved, and these yields were also superior to those of maize receiving fertilizer at the prevailing recommended rates. In contrast, both intercropped grain and green manure legumes resulted in mixed yield benefits depending on quality of rainfall season. Maize grain yields following these intercrops were found to be higher than those of unfertilized maize, but often significantly lower than fertilized maize (e.g. Table 8.5). Several multilocational trials over the years have demonstrated the limited scope for legume green manuring in semi-arid areas where constraining factors of both low soil moisture and poor soil fertility are often simultaneously at play.

Most of the research studies in Malawi and Zambia demonstrated high technical feasibility of agroforestry-based soil fertility technologies, particularly with options involving biomass transfer, coppicing fallows and 2–3 year improved fallows. One-year improved fallows tended to give lower maize yields compared to continuous fertilized maize (Table 8.5). For example, in Malawi, over four consecutive cropping seasons, grain yields of maize increased by 343%, from 0.94 t ha^{-1} in unfertilized sole maize to 4.17 t ha^{-1} in gliricidia/maize intercropping (Akinnifesi et al. 2007). Despite the apparently attractive benefits of agroforestry technologies, which include improved crop yields associated with enhanced soil fertility and provision of forage and wood, there is no clear evidence to suggest sustained adoption of the technologies in the region. One underlying reason for success of agroforestry interventions in eastern Zambia and central and southern Malawi (Table 8.5) is the relatively favourable amount and distribution of rainfall received, as well as the comparatively fertile soils often with clay content >180 g kg^{-1} soil. In contrast, Zimbabwe receives less and more erratic rainfall, with poorer soils (~100 g kg^{-1} soil) predominating in the smallholder areas. Farmers' concerns about the high establishment costs (and often replacement) costs (including labour), general incompatibility with free ranging livestock management and lack of short-term food security benefits of agroforestry cropping systems will continue to haunt their large scale adoption in the foreseeable future.

Grain legume rotations and intercrops hold the most promise for diverse environments and farmer categories in all Southern African countries because of their potential short contribution to household food, nutrition and income security. Soil fertility benefits of grain legumes, though often only modest compared with those registered for green manures and agroforestry systems, can be substantially enhanced on the basis of prevailing knowledge gains from regional research. Grain yields for subsequent cereal are largely dependent on crop productivity during the legume phase, as well as rainfall distribution during the cereal phase. For instance, under semi-arid environments on southern Zimbabwe, sorghum yields increased by >200% following cowpea, Bambara groundnut, groundnut and pigeonpea during a relatively wet season (~650 mm year^{-1}), while only 30–100% yield increases were obtained during a drier year (~300 mm of rainfall). Cereal yield increases of 100–200% are commonly reported from research trials, with substantial yield gains usually realized when mineral fertilizers are additionally applied in the cereal phase. Much of the yield increases are attributable to improved N supply from the preceding legume crop, with N fertilizer equivalency values ranging from 50 to ~100 kg ha^{-1} for most of cases where high cereal yield responses are reported (e.g. Bogale et al. 2001; Bezner Kerr et al. 2007). Improved supply of base nutrients, particularly calcium and magnesium, following legumes have has also been found to contribute to some of the non-N benefits of the rotations (Mapfumo and Mtambanengwe 2004).

Major determinants of N contribution to subsequent crops under grain legume rotations include (i) the proportion of N removed in harvested materials, (ii) the amount of plant materials/residues retained in the soil, (iii) the quality of these residues, and (iv) whether or not mineral fertilizer is used on the beneficiary crop. Legume genotypes differ in their capacity to remobilize and translocate assimilates from leaves and other plant tissue into grain. The proportion of N contained in grain relative to the rest of the plant tissue constitutes the grain N harvest index. In the commonly grown soyabean genotypes, most of the fixed N is contained in grain, with N harvest index as high as 88% (Giller 2001). In contrast, N harvest indices are notably low in most varieties of cowpea, groundnut and pigeonpea, with the latter reported to have values as low as 21% (Mapfumo 2000). Promiscuous soyabean was also found to have a low N harvest relative to other soyabean varieties (Kasasa 1999). Despite high variability in measured values of net N benefits to cropping systems by different legumes, cowpea, groundnut pigeonpea often record some of the highest maize grain yields in rotations. While a high N harvest index often implies high grain protein content, as in the case of soyabean, the plant residues may effectively contribute negligible amounts of N to subsequent crops. Reports of negative N benefits to subsequent cereals are common in soyabean and *Phaseolus* bean rotational systems (Giller 2001) as the resultant low N containing residues tend to immobilize externally added and/or native soil N during cropping. On both coarse sands and sandy clay soils in Zimbabwe, Kasasa (1999) almost doubled maize yield levels obtained from unfertilized control plots following incorporation of promiscuous soyabean residues, while no yield differences were obtained with hybrid cultivars.

Most smallholder farmers in Southern Africa either burn crop residues, incorporate then into soil at the beginning of the next cropping season or feed them to livestock by leaving them in the field for free grazing or deliberately collecting them for controlled feeding during the dry season. Farmers in Mozambique burn most of the crops residues as part of land preparation for a new cropping season, while most farmers in Zimbabwe feed crop residues to livestock. Livestock are highly valued in farming systems of Zimbabwe, southern Zambia and parts of Mozambique where they provide a variety of services including draught power, transport, manure, meat, milk and insurance against risk associated with crop failure and lack of income. In Malawi, about 55% of farmers were found to burn crop residues (Bezner Kerr et al. 2007). These management practices effectively enlarge the loop of N management beyond the field scale, increasing potential loss pathways (e.g. farmers getting residue indirectly through manure). Most grain legumes produce high quality biomass due to their high tissue N concentration, and mineralize in soils to render most of their N available for uptake by subsequent cereal crops within a relatively short period (e.g. within a single cropping season). However, high harvest indices often result in relatively low quality crop residues, causing temporary N immobilization when they are incorporated into soil. Applications of small amounts of mineral N are often adequate to offset this immobilization and increase cereal yields in rotation. Several studies have demonstrated significant increases in yields of beneficiary cereal crops following application on mineral N during the cereal phase (e.g. Mapfumo 2000; Sakala et al. 2000). In Malawi, application of small amounts of mineral fertilizer in a legume rotations resulted in maize yields 60–110% higher than non-fertilized maize (Snapp et al. 2002). In such rotations, legumes often contribute N in amounts critical for early establishment and growth of the cereal crop, eliminating the need for supply of high rates of N in basal fertilizer or early top-dressing. The non-N benefits associated with legume rotations have, however, not been adequately studied to enhance decisions on options to improve management of legume-based rotations.

8.7 Potential Entry Points for Intensification and Diversification of Legume-Cereal Systems in Southern Africa

While appropriate field, farm and socio-ecological niches exist for legume green manure and agroforestry tree crops in southern African countries, the biggest opportunity for harnessing BNF sustainably to increase productivity of the farming systems lies in grain legume – cereal systems. Emphasis should be put on increasing the capacity of farmers, local institutions and agro-service providers to support science-based approaches in boosting productivity of staple food crops, as a precursor to sustainable natural resource use and diversification into higher value crop enterprises. Work of the Soil Fertility Consortium in Southern Africa (SOFECSA) revealed the importance that farmers in Malawi, Mozambique, Zambia and Zimbabwe place on grain legumes because of their high contribution to household nutrition, food and income (Mapfumo 2009a, b). The work revealed that local level trading of legume grains, though in small quantities, is a critical source of income for women. Legumes are commonly considered as women's crops in southern Africa (Mapfumo et al. 2001a, b). Increasingly, there is improved awareness among farmers across the different countries about the potential role of legumes, not only in enhancing food security, but also in soil fertility management. For example, in a health survey in Malawi, resource-constrained farmers admitted to hospital with malnourished children clearly identified poor soil fertility as a major source of food insecurity (Bezner Kerr et al. 2007).

In recent SOFECSA participatory action research intiatives in Malawi, Mozambique, Zambia and Zimbabwe, farmers were able to prioritize legume-based cropping systems that they considered critical in the employment of ISFM technology options to enhance soil productivity and household food, nutritional and income security (Table 8.6). Among the four countries, landholding per household is lowest in Malawi (<0.5–1 ha household^{-1}) and highest in Zambia and Mozambique (>5 ha). This influences the choice of legume cropping preferred by, and technically suitable for, different farmer categories. Strategies for intensifying grain legume-cereal intercrops and rotations on small land areas are particularly critical for Malawi. However, opportunities for intensification exist given the relatively good soils with potential for building carbon and nutrient stocks. In Mozambique, current use of mineral fertilizers is still low among smallholders and this undermines productivity of legume-cereal intercops that are currently given high priority by farmers (Table 8.6). The problem is worsened by lack of access to improved seed, including poor promotion of selected traditional/local varieties whose attributes constitute farmers' preferred criteria for domestic consumption. Systematic promotion of rotations could increase general productivity and enable diversification in Mozambique. A major challenge is the current lack of empirical agricultural research information in Mozambique, particularly quantitative data on legume-based cropping systems.

In Zambia, legume integration if faced with different problems between the northern and southern regions of the country. Northern Zambia has some of SSA's most acid soils and ISFM options integrating lime application and management provide a promising entry point for increased legume productivity and diversification. In the southern regions soil acidity in less of problem, but livestock is a strong component of the farming system. Farmers in this region prioritized options for fertilization of legumes based rotations through combinations of mineral and organic fertilizers. This was the same for Zimbabwe where similar agro-ecologies are shared. Zimbabwean farmer almost exclusively prioritized rotations as opposed to intercrops (Table 8.6), primarily due to rainfall limitations and inherently low nutrient capital of soils.

Table 8.6 Legume-based entry points for integrated soil fertility management (ISFM) technology options as prioritized by smallholder farmers under SOFECSA research intiatives in Malawi, Mozambique, Zambia and Zimbabwe

Country	Prioritized technology options	Comment
Malawi	1. Grain legume – cereal rotations dominated by groundnut (*Arachis hypogaea* L.), soyabean (*Glycine max* [L.] Merr.) or cowpea (*Vigna unguiculata* [L.] Walp.) in rotation with maize (*Zea mays* L.) 2. Grain legume/cereal intercrops involving pigeonpea (*Cajanus cajan* [L.] Millsp.), cowpea and common bean (*Phaseolus vulgaris* L.) 3. Intercrops involving pigeonpea with either groudnut or soyabean (*termed double legume intercropping*) 4. Mineral fertilizers in combination with organic nutrient sources (compost) 5. Mineral fertilizer application to legumes, especially P, N and S containing formulations	There was special focus on: (i) increasing food security, nutrition and income base for households (ii) increased availability of high quality legume seed for smallholder communities through NGO driven seed pass-on schemes (iii) Increasing the diversity of grain legumes under cultivation in response to market demands
Mozambique	1. Legume/cereal intercropping, particularly cowpea/maize; groundnut/maize; pigeonpea/maize 2. Legume – cereal rotations involving soyabean (*Glycine max* [L.] Merr.), cowpea (*Vigna unguiculata* [L.] Walp.), groundnut (*Arachis hypogaea* L.), bambara nut (*Vigna subterranea* [L.] Verdc) followed by maize (*Zea mays* L.) 3. Mineral fertilizers on legumes and cereals	Key areas of focus included: (i) Increasing legume contribution to household food and nutrition security (ii) Strengthening partnerships among extension, researchers agro-service providers and farmers for improved seed and fertilizer supply as well as marketing (iii) Optimising mineral N and P fertilization for increased productivity of intercrops and rotations (iv) Increasing the use of manures (v) Home processing of legumes
Zambia	1. Liming of maize, groundnuts, cowpea, soyabean and sunflower (*Helianthus annus* L.) on acid soils 2. Intercropping of maize with either groundnut, beans or pigeonpea	Main focus was on : (i) Enabling farmers to readily access quality seed, fertilizer and lime (ii) Evaluating different liming packages promoted by NGOs, farmers' unions and research institutions for increased legume productivity on acid soils

(continued)

Table 8.6 (continued)

Country	Prioritized technology options	Comment
	3. Cover crops involving yellow sunnhemp (*Crotalaria juncea* L.) red sunnhemp (*C. ochroleuca* G. Don) and mucuna to support conservation agriculture innovations 4. Legume green manure based rotations involving yellow and red sunnhemps as well as mucuna	(iii) Inorganic x organic fertilizer combinations to support legume cereal rotations and intercrops particularly in southern region
Zimbabwe	1. Mineral fertilizer x organic (cattle manure, woodland litter, compost, crop residues) combinations for legume-based rotations 2. Grain legume – cereal rotations, involving soyabean (*Glycine max* [L.] Merr.), cowpea (*Vigna unguiculata* [L.] Walp.), groundnut (*Arachis hypogaea* L.), bambara nut (*Vigna subterranea* [L.] Verdc) and common bean (*Phaseolus vulgaris* L.) 3. Green manure legume - cereal rotations involving sunnhemp (*Crotalaria juncea* L.) and mucuna (*Mucuna prurien*s L.) for specific farm niches 4. Indigenous legumes (mixed species) for restoration of degraded (non-responsive) soils	There was a particular focus on: (i) Establishing and supporting farmer-centred co-learning and innovation platforms that enhance diversification and market linkages (ii) Developing new basal fertilizer formulations to enable legume integration (iii) increasing efficiency of nutrient use by targeting specific ISFM technology combinations to different farmer resource groups and field environments (iv) integrating water conservation techniques in semi-arid environments

Source: Adapted from Mapfumo et al. (2001a, b)

The over-arching challenge for intensification and diversification of legume-cereal farming systems in southern Africa is the lack of suitable mechanisms to deliver smallholder communities out of the '*maize poverty trap*' (Mapfumo 2009b). Experience has shown that unless there is self-sufficiency in maize at household and community levels, either through local production or sustainable marketing systems, smallholders will continue to grow maize year after year regardless of yield levels. Most of the households in southern Africa are recipients of food handouts, either through local social safety nets or food aid from donors and governments. Under prevailing intricacies of social safety net arrangements at local level, family dignity is often upheld when a household is 'seen to attempt to produce its own maize (food)' before asking for assistance, even if an outcome of total crop failure is most probable. Enhanced and sustained capacity for increased productivity of maize is therefore an apparent pre-requisite for any meaningful legume intensification and diversification. This requires broader national policy and institutional support frameworks that incorporate mechanisms for improved supply of inputs and promotion of farmer-centred co-learning processes as well as co-innovation platforms among communities and diverse stakeholders.

Other major factors constraining adoption of legumes for improved food security and livelihoods in the region include:

(i) *Lack of information, knowledge and technical support*: Education and capacity building of farmers, extension agencies and other development partners on legume-based ISFM technologies and livelihood benefits will enhance meaningful participation by farmers. For example, in their recent work to address food, nutritional and income security with smallholder communities, Mtambanengwe and Mapfumo (2009) revealed some of the prevailing misconceptions among farmers about the role of legumes in soil fertility management. Legumes are often allocated to some of the poorest soils on the farm with no external fertilization, and expected to improve soil productivity at the end of the season. Resource-constrained farmers, especially women-headed households, whose fields were poorest, could not access quality seed and the minimum levels of nutrient inputs required to boost legume productivity. More quantitative research on N_2-fixation, fertilization strategies and quantification of N and non-N rotational benefits is required, particularly under Mozambican smallholder systems. Priority should also be given to farmers' local or indigenous knowledge on sustainability of legume-based systems. For example, there is greater potential for improvement of pigeonpea/maize intercropping in Malawi than any efforts to replace it with alternative systems such as the Gliricidia/maize intercrop suggested by Chirwa et al. (2003). Following 12 years of evaluating maize-groundnut rotations, Waddington et al. (2007) found justification in farmers' current preference for maize monocropping with mineral fertilization in Zimbabwe.

(ii) *Lack of timely and ready access to quality legume seed and appropriate fertilizers by farmers*: It is apparent that currently there are limited opportunities for farmers to access legume seeds of their desired choice or characteristics. For instance, most legume seed varieties on the market tend to address industrial needs (legumes as cash crops) more than home consumption. Participatory breeding and germplasm selection initiatives should be given priority in the medium to long term strategies for legume promotion. Farmers' preferred legume genotypes tend to be ignored in current research, yet these food legumes could play a critical role in local social safety net systems in terms of enhancing food, nutritional and income security. Thus research has largely ignored the multi-functionality and gender dimension of legumes in smallholder livelihood systems.

(iii) *Increasing rainfall variability*: Although research results have shown some grain legumes (e.g. groundnut, cowpea and pigeonpea) as having high resilience in N_2-fixation and net N input across the agro-ecological and soil fertility gradients, there are concerns about increasing frequency of droughts in southern Africa. The IPCC (2007) has also projected significant reduction in rainfall amounts in the region as one of the negative impacts of climate change. The prospects of enhanced contributions of intercropping systems to smallholder farming systems are therefore somewhat limited under low and moderate rainfall areas.

(iv) *Poor soil fertility and land gedradation* : Following decades of monocropping with sub-optimal inputs, some of southern Africa's soils are now extremely poor and do not readily respond to external fertilization. Increasingly, such soils are abandoned or simply cropped as part of farmers' desparate measures to produce food, even as crop failure is often a known outcome. These 'non-responsive soils' will require non-conventional and innovative interventions, and deliberate sowing of indigenous legumes has proved a worthwhile entry point (Mapfumo et al. 2005; Nezomba et al. 2010).

(v) *Identification and development of markets for legume products*: Promotion of both local and national/international markets for legumes can potentially drive intensified production and diversification of legume-cereal systems in southern Africa by attracting the participation of agro-dealers, traders, and private agro-processors in smallholder agriculture. Currently, limited and uncertain market access, coupled to poor and highly variable prices, has remained a major disincentive for farmers to diversify (Bezner Kerr et al. 2007). There is currently a critical lack of research to determine opportunities for developing local (community and regional) markets for legumes.

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