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Sustainable soil management options for Malawi: can smallholder farmers grow more legumes?

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Abstract

Sole-cropped, unfertilized maize is the dominant cropping system throughout southern Africa. Yields have become stagnant and legumes are frequently advocated as an affordable option for resource poor farmers, to enhance productivity. Farmer participatory research was employed to test legume intensification as a means to improve maize-based systems in Malawi. A range of options were evaluated, from grain/legume intercrops of long-duration pigeonpea (*Cajanus cajan*) and groundnut (*Arachis hypogaea)* rotated with maize (*Zea mays*), to a relay green manure system of maize with *Tephrosia vogelii* (Fishbean). Two years of on-farm experimentation indicated that under on-farm conditions legume-intensified systems produced residues that contained about 50 kg N/ha per year, two-fold higher than sole-cropped maize residues. Grain yields from legume-intensified systems were comparable to yields from continuous sole maize, even in a dry lakeshore ecology. These preliminary findings were linked to farmer assessment, where farmers participating in the trials expressed strong interest in the technologies. Yet the probability of adoption remains uncertain. Associated surveys outlined constraints and trade-offs underlying technology choice, information that is not usually considered in conjunction with on-farm trials. Although the legumes were highly productive, farmers expressed worries about the marginal loss of maize production. While the trial performance was similar across regions, differences in market condition, farm resources and household composition appears to stimulate different technology choices. Farmers weigh the benefits of weed suppression and potential cash earnings, against the costs of seed, problems of seed access, labor requirements and problems of grain market access and price. Surveyed farmers commonly manage residues by burning. Promotion and experimentation with more efficient use of legume residues may offer higher short-term impacts than efforts to promote adoption of another cash crop. Ultimately, adoption and soil fertility benefits may depend on market returns to legume production. This study documents the value of researchers and farmers partnering in evaluation of technologies, adoption constraints and competing technology choices.

Keywords: Soil fertility; Southern Africa; Malawi; Female-headed households; Resource management; Adoption constraints; Pigeonpea; *Tephrosia vogelii*

1. Introduction

Legume intensification is often advocated to improve the productivity and sustainability of cereal-based cropping systems in developing countries (Cromwell

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and Winpenny, 1993; Thapa, 1996). These technologies include agroforestry systems, green manures, and legume intercrops or rotations. Experimentation has show that these systems can enhance soil productivity through biological N fixation, carbon inputs and conservation of nutrients (Snapp et al., 1998). Yet farmer uptake of these technologies has been limited. Due to rising population density, the average area of land sown by most farmers is less than 2 ha (Cromwell and Winpenny, 1993). Maize (*Zea mays*) accounts for 60–80% of the area sown. The remainder of smallholder arable land is sown to tobacco (*Nicotiana tabacum*), cotton (*Gossypium hirsutum*), groundnut (*Arachis hypogaea*), common bean (*Phaseolus vulgaris*), pigeonpea (*Cajanus cajan*) and other crops. A unimodal pattern of precipitation generally limits farmers to one crop per season. Planting starts around November, and harvest is in April or May, with the exception of long-duration pigeonpea which is harvested several months later (Fig. 1).

Malawian farmers commonly identify soil fertility constraints as their primary farming challenge (CARE International, 1998). This perception correlates with a sharp decline in the use of chemical fertilizer during the mid-1990s. Purchases fell because of a reduction in the availability of farm credit and a sharp increase in fertilizer prices, to an unprecedented 14 times the price of grain between mid 1980s and late 1990s (Benson, 1997). In addition, access to manure is extremely limited because few farmers own livestock. Soil nutrient status varies tremendously across Malawi, reflecting variability in topography, parent material and management (Brown and Young, 1965). However, soil fertility is generally low. Phosphorus levels range from sufficient to low on Malawian smallholder fields with widespread deficiencies in nitrogen; organic carbon is in the range of 0.8–1.5% (Snapp, 1998).

Current soil fertility recommendations in Malawi do not take account of diversity in topography, soil types, cropping systems and farm resources. A single fertilizer recommendation of 92 kg/ha N and 20 kg/ha P is advised for hybrid maize (*Z. mays* L.) production throughout the country (Malawi Ministry of Agriculture and Livestock Development, 1995). In 1993, fertilizer applied to maize was estimated at 26 kg of nutrients per ha nationwide, and fertilizer use has declined further in recent years (Heisey and Mwangi, 1996). Scientists in Malawi have researched alternative organic nutrient sources for smallholder farmers, who cannot always afford chemical fertilizers. Building on green manure research conducted early in

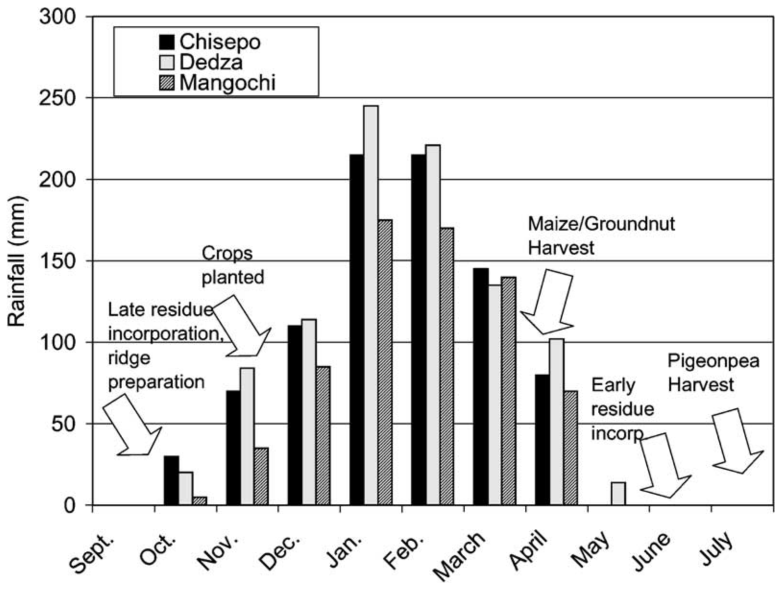

Fig. 1. Rainfall pattern and cropping system management practices in three agroecosystems of Malawi, where case study sites were located.

the 1900s (Blackshaw, 1921; Brown, 1958), recent experimentation has targeted agroforestry systems (*Leucaena* hedgerows with maize, or relay intercrops of maize with *Sesbania seban*), green manures (e.g. maize/mucuna rotations) and grain legume rotations (Banda et al., 1994; MacColl, 1989; Phiri et al., 1999). Most trial results show these technologies are productive under smallholder cropping conditions. Country-wide efforts have promoted the most promising of the technologies, initially hedge-row intercropping and relay intercropping of legumes in maize systems (Banda et al., 1994; Phiri et al., 1999). Even so, adoption levels remain low (Kanyama-Phiri et al., 2000).

To address limited adoption, new methods in participatory research trial and design have been suggested to integrate farmer evaluation and involvement in technology development. Participatory methods include farmer expert panels, employed to select superior bean and cowpea cultivars (Kitch et al., 1998; Sperling et al., 1993). Soil fertility participatory research methods recently explored in Malawi include linkage of farmer surveys and community resource mapping with on-farm trials (Kanyama-Phiri et al., 2000).

Legumes have long been advocated as the missing ingredient for conserving soil resources in subsistence agriculture (Cromwell and Winpenny, 1993; Thapa, 1996). Interest in the pursuit of alternative fertility management options was stimulated in Malawi by an unprecedented increase in fertilizer costs, associated with market liberalization. The relatively high population density in central and southern Malawi—three-fold higher than in neighboring countries—is a potential driving force for legume intensification and organic matter-based technologies (Mortimore, 1970). Further, privatization has encouraged investment by commodity traders and processors to expand grain markets for legumes such as soybean and pigeonpea (Phiri, 1999). A reconnaissance survey found that Malawian farmers are experimenting with the application of low fertilizer rates, a wide range of new crops, and the incorporation of crop residues (Rohrbach and Snapp, 1997).

In view of these opportunities, this study evaluated three promising legume-intensified systems: (a) maize intercropped with long-duration pigeonpea, (b) maize relay intercropped with a green manure (*Tephrosia vogelii*, Fishbean), and (c) groundnut/pigeonpea intercrop (or a soybean (*Glycine max*)/pigeonpea intercrop) with a subsequent maize crop for a 2-year rotation (Kanyama-Phiri et al., 2000; Snapp et al., 1998). The analysis focused on farmer and researcher evaluation of performance, and took into account targeting legume technologies toward specific agroclimatic zones and farm circumstances (e.g. socio-economic characteristics, farmers' gender and perception of technologies).

2. Materials and methods

2.1. On-farm trial design

Three sites were selected for on-farm experimentation, to represent a range of agroecozones, from central Malawi high and mid-altitude zones to the southern Malawi lakeshore (Fig. 2). Legume-intensified technologies were chosen for evaluation using selection criteria of minimal cash and labor investment required (no seedling transplants or mineral fertilizer inputs), food production every year (no fallow period), and sufficient legume residues to contribute at least 40 kg N/ha per year. This was hypothesized as the minimum residues required to enhance subsequent maize yields.

The trial design used was one-field, one-replicate, with four plots per field (Fielding and Riley, 1998). A total of 44 on-farm trials were initiated to test the three legume-intensified systems—16, 13, and 15 in Chisepo, Dedza and Mangochi, respectively. Thirty-three of the trials were successfully implemented over 2 years with acceptable data quality. Due to the small size of most fields cropped by farmers in Malawi plot sizes were 8 m × 8 m. Four plots were laid out as a large square, which allowed the comparison of three legume "best bet" technologies with common farmer practice, continuous production of sole-cropped maize (Table 1). Farmers were asked to choose which legume to include in the intercrop systems. Farmers in Dedza often chose soybean and pigeonpea. Groundnut and pigeonpea were the preferred choices at the other sites. Enumerators were based in each research site. Trial establishment and measurements were conducted in collaboration with extension staff and farmers. Researchers chose farmers at group meetings from among those that volunteered to host

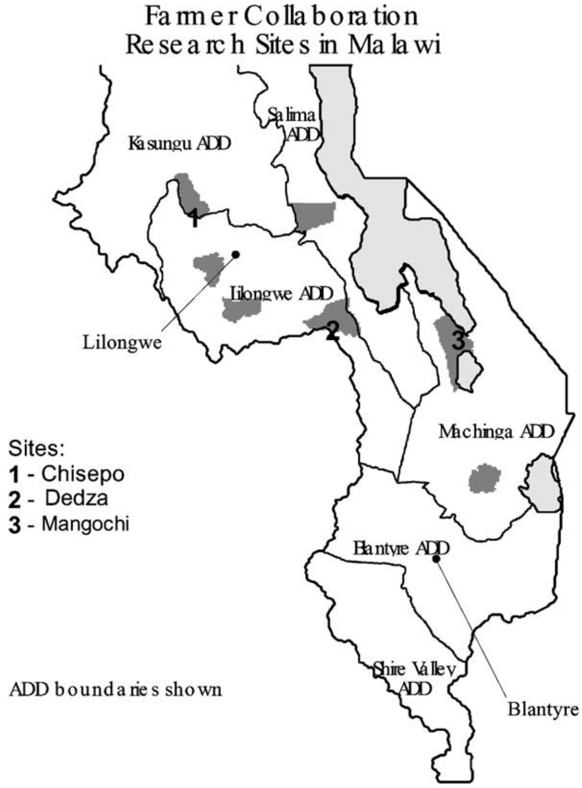

Fig. 2. Map of central and southern Malawi with boundaries indicated for the major administrative unit used in the country, agricultural development division (ADD). The location of the three case study sites for participatory research is indicated.

trials. Attention was paid to include resource-poor as well as well-off farmers, and female-headed as well as male-headed households (Mutsaers et al., 1997).

2.2. Trial implementation

At trial sites ridges were prepared by hoe, following conventional smallholder farmer practice in Malawi. Ridges were located approximately 0.9 m apart, where planting stations were located along the ridge at 0.9 m spacing. Following local practice, maize was planted three seeds per planting station for a plant population density of about 37,000 ha^{-1}, in a 0.9 m × 0.9 m grid. Seeding rates and planting arrangements for different legume-intensified best bet technologies are presented in Table 1.

Farmers planted trials within 1 week of the arrival of the rainy season. Farmers had been provided with the seeds, and assistance in choosing the field and laying out the trial design earlier in the season. Planting rains varied throughout the country, from late-November through early-December of 1997, and mid-November through mid-December of 1998. During these two seasons, the level and consistency of rainfall was moderately better than average.

Researchers and technical assistants provided supervision through monthly visits, combined with trial monitoring by enumerators and local extension staff based at the sites. Farm advisors from local NGOs were collaborative partners at two locations, Concern Universal in Dedza, and Tulimbe Nutrition in Mangochi. Data collected from trial sites included: precipitation, plot size measurements, planting date, population density at emergence, dates when plot was weeded (plots were weeded twice, approximately 5 and 10 weeks after planting), plant population and grain yield at harvest. Grain yields were determined for all on-farm trials. Six rows per plot—all

Table 1
Plant population density, cropping system pattern and description of 'best bet' legume-intensified maize technologies evaluated in on-farm trials

Technology	Population density (×1000)	Biological characteristics (variety and planting arrangement and cropping system pattern)	Farming system characteristics
(1) Maize sole-cropped	Maize: 37	Maize hybrid cultivar MH18, three maize plants per planting stations, 0.9 m × 0.9 m intervals between ridges. Occasional low density intercrop planted by farmers, at less than one per three maize plants, so considered "sole-cropped".	Current farmer practice throughout Malawi, produces staple maize crop with minimal labor.
(2) Maize + PP[a] intercrop	Maize: 37; PP: 37	Temporal compatibility: PP cultivar ICP 9145 planted at the same time as maize, three plants per planting station spaced halfway between each maize station. PP grows slowly, which reduces competition.	Low cost, low risk strategy: PP is a bonus crop, in a low density intercrop system that prioritizes maize yields.
(3A) G'nut[a] + PP intercrop year 1, rotation with maize year 2	G'nut: 74; PP: 37	G'nut cultivar JL 24 or CG 7 was grown as a single row, 15 cm spacing on ridges spaced at 0.9 m intervals. To enhance residue biomass quantity and quality, a 'bonus' PP crop intercropped with a short-duration grain legume.	A higher cost system that prioritizes grain legumes as well as maize. G'nut seed is minimized to lower costs, and use farmer-adoptable seeding rates. PP is a bonus crop.
(3B) Soybean + PP intercrop, rotation with maize year 2	Soybean: 222; PP: 37	Same as G'nut + PP, except a double row of 15 cm spaced soybeans planted along each ridge. Indeterminate variety Magoye, does not require inoculum (nodulates with indigenous Rhizobium) to maximize performance on-farm.	Higher density of seed is possible given that seeds are smaller and cost is cheaper than groundnuts. PP is a bonus crop.
(4) Maize + *T. vogelii* relay intercrop	*T. vogelii* 20 kg seed broadcast/ha; maize: 37	Temporal compatibility, enhanced by planting Tephrosia with maize at first weeding. Green manure screening studies indicated widespread adaptability of Tephrosia.	Planting designed to minimize labor, seed is broadcast along ridge and incorporated by weeding operation.

[a] PP: pigeonpea; G'nut: groundnut.

of the plot except the two border rows—were hand harvested and weighed with hanging scales in the field (±10 g accuracy). Sub-samples of about 10 kg were collected and brought back to the laboratory to determine yield components (grain, residue, cob), grain moisture content and to conduct dry weight to fresh weight conversions. After harvest, farmers followed their usual residue incorporation practice, early or late in the season, but were asked to not burn residues.

2.3. Sampling methodology

To provide an estimate of residue nitrogen status, aboveground biomass was monitored. Samples were collected from seven representative trial sites at each case study area, before harvest. Aboveground biomass of five plants per plot was harvested, where plants were selected randomly from plot border rows. Biomass fresh weights were determined in the field, and dry weights determined in the laboratory after drying at 65°C. Plants were ground to pass a 2 mm mesh and total nitrogen determined by wet acid digestion and colorimetric determination of ammonia (Anderson and Ingram, 1989).

Soil samples from the top 0–25 cm of all trial sites were collected at the start of the experimentation process, in October and November of 1997. This was at the end of the dry season. Randomly collected from the 0 to 25 cm ridge soil, 10 sub-samples were mixed for a composite, representative sample. Samples were air dried for at least 96 h, ground to pass through a 2 mm sieve and analyzed for organic C by acid dichromate digestion (Anderson and Ingram, 1989). Soil pH was read in a suspension of 1:2.5 soil:distilled water. Texture was determined using a hydrometer in a dispersant solution of 3% sodium hexametaphosphate. Soil organic carbon averaged 12 g/kg across the sites, and was lower than 8 g/kg on very sandy soils. The soil pH (1:2.5 soil:water ratio) varied from moderately to

Table 2
Farmer evaluation of technologies from semi-formal interviews where comments were summarized as positive or negative traits ($n = 40$)

Technology	(1) Maize	(2) Maize + PP[a]	(3A or 3B) Legume + PP/maize rotation	(4) Maize + Tephrosia
Positive traits				
Less labor per two crops		25[b]	25	0
Easier to weed required		25	41.7	19.4
Less land per two crops		16.7	25	0
Less weeds and other pests		8.3	5.6	0
Early harvest	30.6	16.7	25	0
Increased food security	16.7	58.3	69.4	25
Fuelwood produced		16.7	2.8	13.9
Early emergence	19.4			
Low labor requirement	22.2	2.8	11.1	
Soil fertility improved		38.9	36.1	36.1
Cash sales potential		30.6	33.3	16.7
Negative traits				
Weed control problems	25			36.1
Pest problems	11.1	16.7	5.6	8.3
Seed availability	5.6	19.4	41.7	22.2
Requires expensive fertilizer	11.1	0	0	16.7
Reduced food security	58.3	13.9	8.3	61.1
Soil fertility decline	11.1			
Low grain legume price		8.3	30.6	
Late harvest or slow growth		16.7	33.3	
Livestock damage		27.8	19.4	
Limited market access		11.1	19.4	5.6

[a] PP: pigeonpea; legume: groundnut or soybean; Tephrosia: *T. vogelii*.

[b] Data presented as percentage of farmers that noted a trait (positive or negative) in an open-ended question regarding traits farmers associated with the maize and maize–legume-intensified technologies included in the trials.

slightly acid in trial fields, confirming previously observed findings in central and southern Malawi (Snapp, 1998).

The trial design allowed farmers to assess the performance and labor requirements of the technologies (Kanyama-Phiri et al., 2000). An open-ended questionnaire was administered in August 1998 to all farmers that conducted trials. Farmers were asked to rate technologies on a scale of 1 (poor) to 4 (favorable). Farmers were asked in a separate questionnaire to list negative and positive traits associated with each technology (Table 2). The grain yield of maize and legumes was monitored each year. This allowed a comparison of the 2-year rotational technology with the intercrop technologies. Descriptive statistics were calculated using the statistical package Statistica for Windows (1995).

2.4. Farm survey

The 1999 farm survey targeted the seven villages hosting on-farm trials in Chisepo, Dedza and Mangochi, and six neighboring villages (within a radius 8–22 km of the trial villages) without trials. Two questionnaires were administered to 329 randomly selected farm households (120 from Mangochi area, 119 from Chisepo area, 90 from Dedza). The selections were made from household lists maintained by village leaders. These had been updated in 1998 for a national development program distributing small packs of agricultural inputs — enough to plant 0.1 ha — to every rural household. A relatively large sample size was employed for Mangochi and Chisepo to increase the number of female-headed households (FHH). This improves the opportunity to draw inferences about the impact of the gender of the household head on farm decision-making and performance. Over 50% of the farm households in Dedza were led by women, compared with 20% in Mangochi and Chisepo (Table 3).

The first survey, conducted in March of 1999, collected data on farm resources, crop choice and management strategies. Particular emphasis was placed on collecting data relating to soil fertility management decisions. The second survey, conducted with the same sample households in October 1999, gathered information on crop harvests and farmer perceptions about legume-based technology options. Given the length of the cropping season (Fig. 1) multiple surveys were viewed to be essential. Interviews were conducted with

Table 3
Farm characteristics, production patterns and food security status of male- and female-headed farm households in Chisepo, Dedza and Mangochi areas[a]

	Chisepo		Dedza		Mangochi	
	MHH ($n = 100$)	FHH ($n = 19$)	MHH ($n = 42$)	FHH ($n = 48$)	MHH ($n = 87$)	FHH ($n = 33$)
Family size	5.2 (2.2)	3.4 (1.5)	4.2 (2.6)	3.9 (1.7)	5.2 (2.7)	4.5 (2.4)
Adults[b] per family	3.8 (1.7)	2.4 (1.6)	3.6 (1.2)	2.7 (1.6)	3.7 (1.7)	3.2 (1.7)
Children per family	1.4	1.0	0.6	1.2	1.5	1.3
Farm size (ha)	2.9 (1.8)	1.5 (0.8)	1.7 (1.2)	1.5 (0.9)	1.5 (0.9)	1.4 (0.9)
Cultivated area (ha)	2.2 (1.4)	1.3 (0.8)	1.4 (1.1)	1.2 (0.8)	1.1 (0.8)	1.0 (0.6)
Maize area (ha)	1.1	0.8	0.9	0.9	0.8	0.7
Groundnut area (ha)	0.3	0.3	0.2	0.1	0.1	Negligible
Pigeonpea area (ha)	Negligible	0	0	0	Negligible	Negligible
Cash crop[c] (ha)	0.7	0.2	0.3	0.2	0.1	Negligible
Other area (ha)	0.1	Negligible	Negligible	Negligible	0.1	0.2
Estimated maize harvest (kg per adult equivalent; children = 1/2 adult)	317	359	300	355	194	218
Households with fallow land (%)	53	52	61	51	63	64

[a] Average values presented with standard deviation in parentheses.
[b] All people over the age of 12 in the family were included as an adult equivalent.
[c] Tobacco, cotton, soybean and potato.

the head of household, spouse or, whenever possible, both key decision-makers. The surveys were conducted by enumerators under close field supervision by the authors.

2.5. Statistical analysis

Data entry and analysis were conducted using the statistical package SPSS 6.0. Descriptive statistics of the variables and the Student's *t*-test was conducted to evaluate significant differences in variable means. Open-ended questions were evaluated by determining the major categories represented by the answers, then calculating the percentage of responses per category.

3. Results

3.1. Trial results

Smallholder farmers require technologies that perform in the near-term as well as over the long-term, so we report here on initial biological performance and farmer evaluation. Two years data from three sites are presented, which can only estimate the potential for multi-year soil fertility benefits. The aboveground residue measurements indicated that legume residues contained about 50 kg N/ha in the best bet systems, averaged across three sites and 2 years. This is similar to the levels observed in central Malawi by MacColl (1989) for grain legume/maize rotations. Maize residues provided only about 16 kg N/ha, on average. Potentially, the legume residues mineralized N for subsequent crops, whereas maize residues could have immobilized soil N over the short-term.

The four technology options for legume intensification produced at least as much grain yield, over the two trial years, as the traditional practice of planting continuous sole-crop maize (Table 4). These results were consistent across the three locations, including the low rainfall lakeshore site of Mangochi. This implies that these are relatively low-risk technologies. However, it is important to note that these are initial results, and rainfall at the study sites was about 10–20% above average rainfall for the 2 years of the study, 1997–1998 and 1998–1999. The technologies were not tested in a low rainfall year. The data imply that farmers can experiment with legume intensification options without sacrificing grain yield, although more rigorous testing over time is required.

The preference rating of technology options by farmers participating in the on-farm trials was also

Table 4
Grain yields of maize and legumes from on-farm trials carried out with 33 farmers, located in three agroecozones

	Chisepo (kg/ha)		Dedza (kg/ha)		Mangochi (kg/ha)	
	Maize	Legume	Maize	Legume	Maize	Legume
1998						
Sole maize	1152[a]	NA	969	NA	1993	NA
Maize/PP	963	155	913	227	1702	372
Leg/PP[b] and maize rotation	NA	1442	NA	867	NA	1186
Maize/Tv	1016	NA	773	NA	1880	NA
1999						
Sole maize	1350	NA	1929	NA	1323	NA
Maize/PP	1514	224	1996	348	1643	280
Leg/PP and *maize*[b] rotation	2056	NA	2828	NA	2284	NA
Maize/Tv	1704	NA	2152	NA	1874	NA
Total (2-year)						
Sole maize	2502 (744)	NA	2898 (788)	NA	3316 (1097)	NA
Maize/PP	2476 (504)	379 (133)	2908 (490)	574 (165)	3593 (605)	653 (201)
Leg/PP and maize rotation	2056 (431)	1442 (173)	2828 (410)	867 (250)	2284 (632)	1186 (280)
Maize/Tv	2720 (598)	NA	2924 (577)	NA	3754 (939)	NA

[a] The data is average yield and standard deviation (in parentheses) over 2 years. Technologies are as described in Table 1.
[b] Grain yields of the phase of the rotation implemented this year are given in italics.

consistent across sites. Average ratings, on a scale of 1 (very low) to 4 (very high), were as follows (S.D. in parentheses): sole maize = 1.0 (0.9), maize–pigeonpea rotation = 2.7 (1.0), groundnut or soybean intercrop with pigeonpea followed by a rotation with maize = 3.2 (1.1) and maize–tephrosia rotation = 1.8 (1.3). Farmers seem to be expressing interest in legume intensification. A different picture begins to emerge, however, when farmers are asked to explain their views of the positive and negative traits characterizing these technologies (Table 2). More than one-third of the respondents noted the fertility gains derived from planting legumes. In addition, farmers valued the marketability of pigeonpea, groundnut and soybean. Gains were also perceived in labor efficiency obtained through the strategy of intercropping. This included the perception of reduced weed pressure, which was frequently mentioned.

Farmers appeared concerned about the food security implication of the legumes intensification strategy. Farmers note that one of the strongest relative advantages of maize is this crop's early maturity (Table 2). In addition, some farmers were concerned that total maize harvests declined when part of the area sown to this cereal grain was replaced with a legume. While the decline in maize harvests was marginal, and more than offset by the increase in legume production (Table 4), farmers still have to decide whether to accept this cost. The additional legume harvest offers the potential for significant improvement in net farm profits because the farm gate price of legumes is about two times higher than the post-harvest price of maize (Phiri, 1999). Yet, maize harvests are commonly equated with household food security in Malawi. Poor farmers may prefer to avoid having to purchase part of their maize requirement in the market.

The participants in the trials also commonly cited the problems of insect pests and livestock damage, particularly as these affect the production of pigeonpea (Table 2). This concurs with other reports that pests are major barriers to wider adoption of pigeonpea in Malawi (Kanyama-Phiri et al., 1998; Snapp and Silim, 1999). The introduction of pigeonpea in Mangochi was most threatened by the common practice of open grazing of livestock after the maize harvest.

Many trial participants raised concerns about the availability of legume seed. Lack of access to groundnut seed was most frequently noted, though pigeonpea and soybean seed availability issues were also mentioned (Table 2). This concern was echoed by the constraints to legume production identified by survey respondents (Table 5). Farmers also expressed reservations about legume prices and market access. Market access was of particular concern to male-headed households, whereas contributions to improved labor efficiency were more likely to be cited by female-headed households. Farmers in Dedza were more likely to mention cash earnings derived from expanding legume production. Farmers in the risk-prone lakeshore area of Mangochi on the other hand frequently mentioned improvements in food security.

3.2. Survey results

3.2.1. Land, labor and food security

The small size of most farms in Malawi (1–2 ha per household) places the majority of smallholder households at the margins of subsistence. According

Table 5
Constraints cited to expanding legume area, survey data presented as a percent of response for male-headed households (MHH) and female-headed households (FHH)

Constraints	Chisepo		Dedza		Mangochi	
	MHH ($n = 100$)	FHH ($n = 19$)	MHH ($n = 42$)	FHH ($n = 48$)	MHH ($n = 87$)	FHH ($n = 33$)
Lack of seed or cash to buy seed (%)	62	57	50	57	53	49
Lack of labor (%)	22	33	19	25	8	14
Low yields (%)	3	3	17	11	30	32
Land shortage (%)	5	4	10	6	7	3
Limited market (%)	5	4	0	1	2	3
Other (%)	3	0	4	1	0	0

Table 6
Farmers that fallowed land were asked the major reason they left land fallow

Reason for fallow land	Chisepo		Dedza		Mangochi	
	MHH ($n = 53$)	FHH ($n = 10$)	MHH ($n = 25$)	FHH ($n = 25$)	MHH ($n = 55$)	FHH ($n = 20$)
Lack of seed (%)	43[a]	40	22	26	49	62
Lack of labor (%)	32	40	30	52	29	28
Lack of fertilizer or to improve soil (%)	23	10	26	9	15	5
Sickness (%)	2	10	13	9	5	5
Other (%)	0	0	9	4	2	0

[a] Survey data presented as a percent of response for male-headed households (MHH) and female-headed households (FHH).

to the farm surveys, the average size farm was marginally greater in Chisepo, than in Dedza or Mangochi. Male-headed households tend to own larger farms in Chisepo — averaging 2.9 ha per family (Table 3). In the rest of the survey sample, the majority of farmers own less than 1 ha of land. Remarkably, half of the sampled farmers maintain part of this limited landholding in fallow (Table 3). The main reasons cited for the failure to plant one's entire holding are lack of seed and constraints in the supply of farm labor (Table 6). Labor constraints are frequently cited by female-headed households, whereas male-headed households were likely, additionally, to attribute fallows to problems of fertilizer access.

The survey data concur with the hypothesis that smallholders try to meet their requirements for maize production before expanding to other crops. Maize is planted on at least 50% of the cropped area, and where farmers sow relatively smaller quantities of land, maize accounts for over 70% of cropped area (Table 3). Cash crops and legumes were most likely to be grown by farmers owning and planting a larger land area. Self-sufficiency in cereal grain production requires an average harvest of about 200 kg per adult. In the drier agroecology of Mangochi, mean harvests barely reach this level. By inference, Mangochi farmers may be less willing to give up part of their maize harvest in exchange for a legume crop, compared to farmers at the other sites. The surveys confirm that female-headed households are more likely to suffer from labor constraints than male-headed households (Table 3). The status of female-headed households in Mangochi appears particularly risky. These households have the smallest farm size, the smallest cultivated area, and correspondingly, grow almost no legume crops. These data need to be taken into account by advocates of crop diversification as a strategy to improve the livelihoods of poor households with limited land (CARE International, 1998; Thapa, 1996).

3.2.2. *Cropping system constraints and opportunities*

Respondents in the main farm survey were queried about constraints limiting the expansion of the area they plant to legumes. In congruence with the results from the on-farm trial surveys, most farmers complained about the lack of seed, or the lack of cash to purchase seed (Table 5). By implication, the adoption rates for 'best bet' legume technologies appear likely to remain low unless seed markets are improved. Farmers in Chisepo and Dedza secondarily cited labor constraints as limitations to legume expansion. This partly reflects the concerns of female-headed households who are most short of farm labor. However, even if more family labor is available, investment in a legume enterprise may be constrained by a preference to invest labor in other enterprises, on or off the farm.

Farmers in Mangochi commonly complained about low yields from legume crops (Table 5). Trial data suggest these yields can be competitive with maize yields (Table 4). Yet the gain in legume production may not be large enough to offset even a small decline in maize production. Farmer perception may be the product of a longer historical experience growing legumes in non-trial conditions. While legumes performed very well in the trials, yields may decline when the specialized management associated with the trial is removed, particularly in drier years.

Table 7
Ranking of agricultural problems in terms of importance, where all farmers surveyed listed their three worst problems

Ranking	Chisepo		Dedza		Mangochi	
	MHH ($n = 100$)[a]	FHH ($n = 19$)	MHH ($n = 42$)	FHH ($n = 48$)	MHH ($n = 87$)	FHH ($n = 33$)
Lack of fertilizer	1	1	1	1	1	1
Lack of seed		3	2	3	2	3
Lack of labor		2		2		2
Lack of food	3				3	4
Lack of cash	2					
Pests			3			

[a] Response reported separately for male-headed households (MHH) and female-headed households (FHH).

If farmers are unable or unwilling to pursue timely planting and weeding, the relative gains derived from legume intensification may need to be reconsidered.

While, based on food security concerns, farmers in Chisepo and Dedza appear more likely than those in Mangochi to expand their legume area, any change in resource allocation must be competitive with alternative choices among cash crops. Chisepo experienced a rapid increase in small-scale tobacco production, since tobacco markets were liberalized in the mid-1990s. Almost one-third of male-headed households now plant tobacco, and sell maize as a cash crop (Table 3). In the Dedza region, legumes are already widely grown as cash crops (common bean in particular). Market demand and promotional efforts of non-governmental organizations have led to a rapid expansion in soybean production. In Mangochi, some farmers with larger holdings are planting cotton. If legume production is to expand, the profitability of these crops has to be competitive with tobacco in Chisepo, and cotton in Mangochi.

The pursuit of legume intensification as a means to improve soil fertility must also be evaluated in relation to other soil fertility inputs. While the quantity of inorganic fertilizer used by Malawian smallholders has dropped sharply in recent years, roughly 50% of the farmers are still using this input in Chisepo, 40% in Dedza, and less than 10% in Mangochi (Tables 7 and 8). Among farmers applying inorganic fertilizer, application rates are commonly as small as 10 kg N/ha. Most fertilizer is used for tobacco or for maize. Farmers are also using small quantities of animal manure, approximately 20–30% of households overall use manure (Table 8). Female-headed households tend to

Table 8
Soil fertility management practices of male- and female-headed households in the survey for the three locations, presented as percentage of farmers that used the practice during the 1998–1999 growing season

Farmer practice[a]	Percentage of farmers					
	Chisepo		Dedza		Mangochi	
	MHH ($n = 100$)	FHH ($n = 19$)	MHH ($n = 42$)	FHH ($n = 48$)	MHH ($n = 87$)	FHH ($n = 33$)
Inorganic fertilizer[b]	70	17	44	33	10	3
Manure	38	16	26	21	25	22
Compost	3	11	12	15	0	3
Maize residues	3	0	4	6	10	0
Legume residues	6	2	0	0	5	2
Anthill	1	0	0	1	0	0
No use of organics	50	73	64	58	65	75

[a] Alternative soil management practices were elicited from farmers, such as application of organic nutrient sources or burned construction, where more than one practice could be listed.

[b] Percent of farmers that used fertilizer over the 1998–1999 crop season, except for those farmers that used a small amount of fertilizer from a country-wide relief effort (as the survey targeted usual farmer practice).

Table 9
Farmer management of residues from maize, pigeonpea and groundnut[a,b]

Farmer practice	Percentage of farmers[c]							
	Chisepo			Dedza		Mangochi		
	PP	G'nut	Maize	G'nut	Maize	PP	G'nut	Maize
Incorporate residues early, near harvest	41	28	29	23	18	27	50	45
Incorporate residues late, during ridge preparation	47	20	19	31	22	64	30	39
Burn residues in field	28	29	44	52	65	12	36	32
Burn residues to produce ash, a cooking additive	0	10	0	6	0	0	8	1
Fuel wood	10	0	0	0	2	6	0	0
Livestock feed	1	9	2	3	1	0	7	3
Construction	0	0	8	0	0	0	0	11
Other	0	0	6	0	0	0	0	3

[a] Pigeonpea residue management was not queried in Dedza as pigeonpea is not well known at this site. Almost all farmers reported that they burned residues from tobacco and cotton, to reduce pest incidence.

[b] PP: pigeonpea; G'nut: groundnut.

[c] The percentage of farmers who carry out different residue management practices is indicated for Chisepo, Dedza and Mangochi. Farmers sometimes carry out more than one practice, so the total is greater than 100%.

use less animal manure, and use more compost than male-headed households. Despite scarcity of manure, as the costs of inorganic fertilizer have increased, it appears that farmers have expanded their experimentation with organic inputs. These efforts would benefit from technical support as farmers are confused about how to best use small amounts of different sorts of nutrients. Extension and advisory assistance still calls

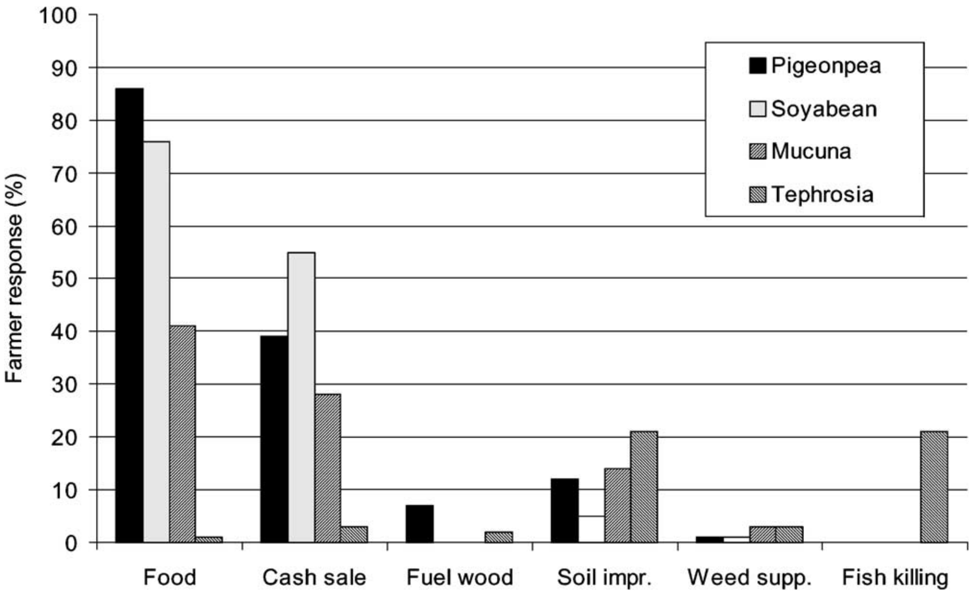

Fig. 3. Farmer response indicating major uses for different legumes: pigeonpea, soybean, *Mucuna* spp. and *T. vogelii*. Responses were from farmers that indicated they grew these legumes or had knowledge of their use, and are presented as an average across the three locations. Note that the practice of 'fish killing' referred to by farmers is an indigenous use of *T. vogelii* that involves applying ground leaves to water in a pond or stream where the residues release a toxin that stuns and kills fish, which then can be easily collected.

for application rates well above the capabilities of virtually all small-scale farmers (Kanyama-Phiri et al., 2000; Rohrbach and Snapp, 1997).

In addition, there appears substantial scope for dissemination of information about residue management. Maize residues are incorporated by 40–70% of farmers (Table 9). The remaining 30–60% of neighboring farmers burn their maize stover. Some farmers try to incorporate their maize residues in a special land preparation activity shortly after the harvest. But since almost all land is prepared and planted by hand, this is a laborious process. Farmers pursue a similar range of burning and incorporation practices for legume residues. Roughly 50–70% of farmers incorporate their groundnut residue either after the previous year's harvest, or prior to the next planting season (Table 9). Remarkably, 30–50% of farmers simply burn their groundnut residues in the field. A reconnaissance survey conducted 2 years earlier in Mangochi and Chisepo found significant amounts of groundnut residue burning as well, and limited farmer experimentation with different types of residue management (Rohrbach and Snapp, 1997). Few farmers apparently recognize the fertility benefits of the legume residue (Fig. 3), or the returns to labor are too low to justify investment in residue incorporation. Efforts to promote legume intensification may usefully start with programs to encourage better use of stover from legumes currently being grown.

4. Discussion

4.1. Adoption of legume intensification

Although the legume-intensified systems performed well in on-farm trials and were highly rated by farmers, the small proportion of legumes currently grown was a reminder that adoption of these cropping systems is not straightforward. Though many farmers claim to recognize the advantage legumes offer for soil fertility (Table 2), higher priority is commonly attached to the objectives of food security and income growth. Indeed, legumes are primarily grown for the food and cash values (Fig. 3). Participatory breeding research on cowpea in west Africa also suggested that the prioritization of grain and fodder for sale is of overriding importance to smallholders; soil fertility remains a distinctly secondary concern (Kitch et al., 1998).

The farm survey results highlight the competition of legumes with other crops for the allocation of the farm's limited land, labor and cash resources. Similarly, an analysis by Shaxson and Tauer (1992), of cropping systems near Zomba (just south of the study sites) suggested that intensive land use precludes additive changes in intercropping patterns; only substitutive changes may be possible. The capacity of crops to be competitive is key. It depends both on the returns per unit of input, and on the efficiency of markets for both seed and grain products. Despite the relatively high population density in Malawi, survey respondents indicate strong concerns about labor returns. Agronomists cannot underestimate the importance of labor requirements. This is supported by other on-farm studies of organic matter technologies (Fujisaka, 1993; Versteeg and Koudokpon, 1993). Finally, we note the high level of farmer concern about seed and market access, and farmgate price (Tables 2 and 5). Across region and household type, two key determinants of adoption appear to be the availability of legume seed, and the competitiveness of farmgate prices. Similar concerns have been identified by earlier studies in Malawi (Snapp and Silim, 1999). Grain legume seed is expensive, does not store well and is difficult to multiply. Improved seed delivery strategies may be a prerequisite to any legume intensification strategy.

Farmers frequently complain about the lack of markets for their legume crops, or the low level of farmgate prices (Tables 2 and 5). Phiri (1999) notes that farmgate prices for grain legumes tend to be relatively uniform across the country, whereas retail prices vary markedly — a three-fold difference between farmgate and retail prices is not uncommon. This implies substantial scope for improving market efficiency. One possibility is to link the delivery of technologies for legume intensification with efforts to expand product markets (e.g. traders interested in buying grain could participate in the delivery of seed).

While preliminary data suggest that absolute returns to legume intensification appear favorable throughout the country, returns relative to other farm investment strategies will differ by agroecological zone and farm type. Attempts to target organic technologies have led other agencies to a focus on Chisepo (and nearby eastern Zambia), were farm sizes are relatively large

— short-term fallow rotations and green manure intercrops have been widely promoted in this region (Banda et al., 1994; Gladwin et al., 1997; Sanchez, 1999). Interestingly, the legumes promoted by different development agencies have converged upon a few species. All are indeterminate in growth type, some are short-lived perennials managed as annuals (e.g. pigeonpea, tephrosia), and were identified as promising in earlier Malawi research (Blackshaw, 1921; MacColl, 1989).

Up until now, research and extension has not taken into account that households with larger landholdings in Chisepo are placing priority on expanding the production of cash crops — tobacco in particular (Table 3). The data suggest that there may be scope for expanding the cash crop soybean in this system, but the probability of a significant expansion of groundnut or pigeonpea production appears limited, unless the relative profitability of these crops improves. Three alternative technologies for soil fertility improvement merit examination, particularly in Chispo where fertilizer use remains widespread (Table 8). Decisions about fertilizer use may be complicated by extension advice targeting high rates, and a changing mix of fertilizer types (Rohrbach and Snapp, 1997). The relatively high degree of labor allocated to incorporating maize residues, while groundnut residues continue to be burnt, merits further investigation. Experimentation with organic inputs, and targeting efficient use of small amounts of inorganic fertilizer also merits facilitation.

4.2. Targeting by area

The trial and survey results suggest the Dedza area could offer the best prospects for legumes intensification. Legume crops are already widely grown in Dedza, for food and cash. The main opportunity seems to be to intensify the use of legume residues already available. An immediate target could be to reduce the proportion of households currently burning their groundnut and pigeonpea residues (Table 9). Recognizing that much technological change occurs in a step-wise fashion, these farmers could be encouraged to experiment with a wider range of legume species and cropping patterns.

The prospects for legume intensification in the Mangochi area appear limited by the severity of food security constraints. The small farm size corresponded to very limited planting of legume crops, and the highest area planted to maize (Table 3). Kanyama-Phiri et al. (2000) suggested maize-dominance as the primary reason why farmers in a southern Malawi watershed show almost no interest in adopting a *S. sesban* relay intercrop maize/legume system, despite demonstrated soil-enhancement (Phiri et al., 1999). Kumwenda et al. (1997) similarly argue that high population pressures represent a major barrier to the adoption of woody fallow and green manure legumes. The data presented here extends these findings and suggests that highly populated areas face constraints to the adoption of multipurpose and food legumes as well.

Across regions, there appears to be scope for better targeting technologies to meet the needs of female-headed households. Only 15% of the surveyed female-headed households purchased seed or fertilizer, compared to about 30% of male-headed households. Female-headed households were also less likely to receive agricultural credit (data not shown). Even among tobacco growers, the use of inorganic fertilizer is less likely among female-headed households. This supports contentions that female-headed households in Africa have severely limited access to fertilizer (Gladwin et al., 1997).

4.3. Labor constraints

Phiri (1999) makes the case for government policies that promote production of grain legumes, to complement the minimal use of mineral fertilizers among the poorest and female-headed households. Yet this advice fails to account for the fact that female-headed households are severely labor constrained, as cited here in both the trial interviews and farm survey. Legume-based technologies generally require a considerable investment of farm labor (Kanyama-Phiri et al., 2000). A west African farm nutrient budget study indicated that only relatively well-off households, with sufficient labor to incorporate residues, derive significant soil fertility benefits from residues (Defoer et al., 1998). Interestingly, the one exception to farmer perception of legumes enhancing labor was the labor savings perceived as an advantage of the doubled up legume system (Table 2). This is because weeding was accomplished on two crops at once (Table 2). Farmers also noted that the intercrop reduced weed pressures. Finally, over 40%

of the negative traits listed by all households were associated with worries about reduced food production (Table 2). Female-headed households were the most concerned about early food production. By inference, early maturing and labor-saving legume crops may be of greatest interest to these households.

5. Conclusions

Farm survey results indicate that farmers will choose to intensify their legume production based primarily on the contribution of the legume to food and cash income. While soil fertility contributions are valued, these alone are unlikely to encourage adoption. Malawi's poorer farmers first seek to obtain a minimum maize harvest. These initial 2 years of on-farm experimentation suggested that grain yields from legume–maize-intensified systems were comparable to yields from continuous sole-cropped maize, even in a dry lakeshore ecology. The net profit was potentially highest in the doubled-up legume systems. Yet, legume crops must assure a higher relative return to land compared with alternative cash crops, and alternative soil fertility management practices. The farm surveys reveal scope for improving the efficiency of practices farmers are already trying — such as the targeting of small quantities of fertilizer and incorporation of legume residues. The prospects for legume intensification appear to be favorable in areas like Dedza, where grain legumes are already grown, and where there have been consistent efforts to expand seed and market access. Overall, the data indicate that improvements in soil fertility in developing countries may be pursued as a by-product of market development. The study also shows how combining the results of agronomic and socioeconomic analysis can improve technology targeting, and the likelihood of research impact.

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