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Sesbania sesban improved fallows in eastern Zambia: Their inception, development and farmer enthusiasm

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Abstract. In eastern Zambia, nitrogen deficiency is a major limiting factor for increased food production. Soil fertility has been declining because of nearly continuous maize (*Zea mays*) cultivation with little or no nutrient inputs. The use of short-duration tree fallows was one of several agroforestry options hypothesized to restore soil fertility. *Sesbania sesban*, an indigenous N_2-fixing tree was the most promising among species tested in screening trials. Several studies since 1987 have demonstrated the dramatic potential of two- or three-year sesbania fallows in restoring soil fertility and increasing maize yields. Analyses showed that these improved fallow systems were feasible, profitable, and acceptable to farmers. Results suggest that high maize yields following fallows are primarily due to improved N input and availability by the fallows. The potential to increase maize production without applying mineral fertilizers has excited thousands of farmers who are enthusiastically participating in the evaluation of this technology. The number of farmers who are testing a range of improved fallow practices has increased from 200 in 1994 to over 3000 in 1997. Presently, a strong network of institutions comprising government, NGOs, development projects, and farmer organizations is facilitating the adaptive research and expansion of improved fallow technology in eastern Zambia. Key elements in the research process that contributed to the achievements are effective diagnosis of farmers' problems, building on farmers' indigenous knowledge, generating several different fallow options for farmers to test, ex-ante economic analysis, farmer participation in on-farm trials, and development of a network for adaptive research and dissemination.

Introduction

Given the extraordinary success of the 'Green Revolution' in increasing food production, many argue that intensive packages of improved variety and fertilizer should be widely applied as the model for agricultural development and as a means of ensuring household and national food security (Borlaug, 1988). Whereas this sounds appealing, there are numerous exceptions and constraints that curtail adoption of this approach in many developing countries (Pretty, 1995). In Zambia, for example, agricultural production is dominated by small-scale, resource-poor farmers operating in complex, diverse, and low-input farming systems characterized by infertile soils, unreliable rainfall, and low yields. The majority of these farmers live in remote villages with little or no access to research and extension services, high-yielding seed varieties, capital and credit, fertilizers, and pesticides. If one element is missing, such as the poor delivery or use of fertilizer, yields may not be better than in traditional systems. Even if available, most small-scale farmers cannot afford to adopt Green Revolution packages in the absence of credit because they are too costly.

The Government of Zambia tried to assist farmers with policy reforms, including subsidizing agricultural production and marketing, for nearly two decades from the 1960s through the end of the 1980s. Despite widespread use of hybrids and fertilizers by farmers, these policies did not stimulate sustained increases in food production in the peasant sector. Following the implementation of structural adjustment programs (Cheru, 1995; Tabor, 1995) and subsequent removal of subsidies by the state on maize (*Zea mays* L.) purchasing monopoly and fertilizer subsidies in the early 1990s, the problem of declining food production has escalated as the anticipated improved marketing climate has not yet emerged. The challenge will be even greater during the coming decades given the rapidly increasing population, heavy public and foreign debt, and lack of appropriate technologies.

Available options for meeting food needs include increasing food imports, expanding farming to the more marginal lands, increasing the use of high-cost inputs such as fertilizers, or developing new technologies. FAO has estimated that over 50% of future gains in food crop yields in sub-Saharan Africa will come from fertilizers (FAO, 1993). This may not be feasible in Zambia in the short to medium term, given the current economic difficulties. Farmers who can neither afford nor rely on a regular supply of mineral fertilizers must be able to obtain alternative sources of nutrients. Low-cost technologies and practices for supplying nutrients to crops are needed on a scale wide enough to improve the livelihood of farmers.

In this paper, we report an alternative and practical approach of increasing domestic food production using improved fallows with sesbania [*Sesbania sesban* (L.) Merr.]. This approach builds upon farmers' traditional production strategies and on collaborative national and international research efforts.

Background

Diagnostic phase

In eastern Zambia, land use commonly comprises loosely integrated maize and livestock production systems. Bush and grass fallows of one to five years coexist with continuous maize cultivation (Kwesiga and Chisumpa, 1992). A micro-diagnostic and design survey in Katete and Chipata Districts of Eastern Province (Ngugi, 1988) revealed a serious breakdown of traditional strategies to sustain production of food, fodder, and fuelwood. Declining soil fertility was identified as the major problem responsible for low yields of maize – the main staple food crop. Nitrogen and P deficiencies are widespread, and large responses to mineral fertilizers are common. Soils of low fertility are similarly reported throughout Zambia (Kwesiga and Kamau, 1989).

Eastern Province was selected for agroforestry research and development because of its high potential as the breadbasket of the country. The traditional fallows on which farmers relied to restore soil fertility have been shortened by land pressure and are now inadequate to restore soil fertility. The consequences are a decline in crop yields and household food security. Farmers need alternative technologies to reverse these trends.

Given the generally large farms (e.g., three to five hectare) and the widespread use of short-rotation grass fallows in eastern Zambia, a solution to address the declining soil fertility problem should consider fallowing as the entry point. Improved fallow systems, utilizing fast growing, N_2-fixing leguminous trees were hypothesized not only to provide readily available nutrients for the subsequent crop, but also to increase soil organic matter and hence improved soil physical conditions.

The strategy was to use leguminous fallows to accumulate N in the biomass and recycle it into the soil, to act as a break crop to smother weeds (De Rouw, 1995), and to improve soil physical and chemical properties (Juo and Lal, 1977). Nitrogen availability would be increased through N_2 fixation by trees (Sprent, 1987; Giller and Wilson, 1991). The other essential nutrients such as P could be cycled to some degree through plant biomass and returned to the soil during litter decomposition thereby converting nutrients to more available forms (Sanchez and Palm, 1996).

The choice of sesbania

Since planting of trees to improve soil fertility was unknown in Zambia, the challenge was to identify a tree that was well adapted to increase soil fertility during the fallow period. Such a tree must grow fast and be out of reach of free-ranging livestock by the first dry season, be resistant to annual fires, and be tolerant of periodic droughts. The selected tree must grow and survive under N-limiting conditions prevalent in most small-scale farms in Zambia. Sesbania, an indigenous tree, was identified as a potential species because of its wide distribution in Zambia (Kwesiga, 1990), fast growth, ease of propagation and removal, and because it nodulates easily, fixes N, and produces high biomass (Evans and Rotar, 1987).

Propagation of sesbania

Direct sowing is the cheapest method of propagating sesbania. However, seedlings established by direct sowing grow slowly because of unreliably low and erratic rainfall. Such slow-growing seedlings would be susceptible to browsing and would need a longer fallow period before farmers could expect benefits. With these considerations, the initial trials were established using nursery-raised, potted seedlings. Although this option resulted in fast growth, it was very expensive. At the recommended spacing of 1 m by 1 m, or 10,000 seedlings ha^{-1}, a farmer would need to spend at least US$100 ha^{-1}.

Bare-root, nursery-raised seedlings were tested as a cheaper alternative that eliminated the need for polythene pots. Our approach in promoting sesbania production was to build upon farmers' knowledge of raising seedlings of other crops. Many small-scale farmers in Zambia know how to set up and manage small nurseries for tobacco, kale, or fruit tree seedlings. They use bare-root seedlings that are easy and cheap to produce and, with precaution, are also easy to transport in baskets or ox-drawn carts. We opted to use raised beds in order to overcome the problem of root damage when transferring from sunken nursery beds.

Farmers found these innovations easy to implement, and they modified them – an example being the construction of several phased beds to cater for fluctuations in the onset of the rains and planting dates. Inoculation was achieved using soil from well-established stands of sesbania. Where this was not available, we supplied topsoil from well-established stands of sesbania at the station as the inoculum.

On-station research

Agronomic performance of researcher-managed trials

Field studies conducted on-station since 1987 have shown that sesbania improved fallows have a great potential to increase maize yields with or without application of mineral fertilizers. Maize grain yields of 5.0 and 6.0 Mg ha^{-1} were obtained in 1990 and 1991 following two- and three-year sesbania fallows, respectively (Table 1). This compared to 4.9 and 4.3 Mg ha^{-1} from continuously cropped maize with fertilizer (112 kg N ha^{-1}) and 1.2 and 1.9 Mg ha^{-1} without fertilizer. The fallows had strong residual effects on maize yields, and total yield in the four cropping seasons following the two-year fallow was 12.8 Mg ha^{-1} compared to 7.6 Mg ha^{-1} for six seasons of continuous unfertilized maize. In addition, 15 and 21 Mg ha^{-1} of fuelwood were harvested after two- and three-year fallows, respectively (Kwesiga and Coe, 1994).

With these initial encouraging results, we decided in 1991 to experiment under farmers' field conditions, using researcher-designed and managed trials. The trials were laid out in farmers' fields at Feni and Kagoro camps in Chipata and Katete Districts, respectively. The two fields had been abandoned due to low yields. We used potted seedlings and a phased-entry experimental design to compare maize yields after one- and two-year sesbania improved fallows against the farmer control of continuous maize monocropping without fertilizers.

Table 1. Maize grain yield following one-, two-, and three-year sesbania fallows as compared with yield of continuously cropped maize with different levels of fertilizer at Chipata in eastern Zambia.

Fallow duration (year)	N fertilizer (kg ha^{-1})	Maize grain yield (Mg ha^{-1})					
		1988	1989	1990	1991	1992	1993
0 (control)	0	1.8	1.6	1.2	1.9	0.2	0.9
0 (control)	112	6.5	6.1	4.9	4.3	1.8	5.8
1	0	F(10)[a]	2.3	3.8	4.4	0.4	1.5
1	112	F	6.7	6.0	6.7	0.5	5.7
2	0	F	F(15)[a]	5.0	5.6	0.5	1.7
2	112	F	F	7.2	7.9	0.5	5.4
3	0	F	F	F(21)[a]	6.0	0.9	1.7
3	112	F	F	F	7.4	0.9	6.2
SED 1[b]			0.17	0.27	0.38	0.08	0.18
SED 2[b]			0.52	0.83	1.18	0.25	0.52
Annual rainfall (mm)		1050	1182	1108	779	825	1337

[a] Values in parenthesis denote fuelwood production in Mg ha^{-1} from the sesbania fallow.
[b] SED 1 = standard error of the difference in means for comparison of fertilizer levels for the same system. SED 2 = standard error of the difference in means for comparison of the control with other treatments.
Source: Reprinted from Forest Ecology and Management, vol. 64, Kwesiga and Coe, The effect of short rotation *sesbania sesban* planted fallows on maize yield, pp. 199–208, 1994, with permission from Elsevier Science.

The results were mixed. At Feni, maize yield following two years of improved fallows was 4.0 Mg ha^{-1} compared to 0.15 Mg ha^{-1} obtained from the control plots. But at Kagoro, sesbania failed to grow due to shallow soils and much lower rainfall.

In order to avoid dangers associated with developing a technology based on a narrow genetic base, a range of other species and provenances were evaluated alongside sesbania fallows. Other species included tephrosia (*Tephrosia vogelli* Hook. f.), *Sesbania macrantha* Phil. & Hutch., and pigeonpea [*Cajanus cajan* (L.) Millsp.], which were sown directly. These species were nodulated by the native soil rhizobia. Grain yield of hybrid maize after a two-year sesbania fallow was 5.4 Mg ha^{-1} as compared to 4.0 Mg ha^{-1} for fertilizer maize following maize monocropping (Table 2). Two-year fallows of sesbania, tephrosia, and *S. macrantha* had residual benefits on maize in the second season after the fallows (Table 2.)

Experiments with three-year fallows included species that could coppice, thereby providing a possibility of eliminating the need for fallow re-establishment. These were *Calliandra calothyrsus* Meiss., *Flemingia macrophylla* Roxb., *Gliricidia sepium* (Jacq.) Walp., *Leucaena leucocephala* (Lam.) de Wit, and *Senna siamea* Lam. After three-year sesbania fallows, maize grain yield was 5.6 and 7.4 Mg ha^{-1} in two experiments (Table 3). Fully fertilized maize yielded 4.1 and 6.9 Mg ha^{-1} in the experiments. Gliricidia emerged as the

Table 2. Maize grain yield one season (1993/94) and two seasons (1994/95) after one- and two-year fallows and other cropping systems at Chipata in eastern Zambia.

Land use before maize	Maize grain yield (Mg ha^{-1})	
	1993/94	1994/95
1 year pigeonpea	2.4	1.6
2 years pigeonpea	2.8	1.8
1 year Sesbania macrantha	2.1	1.6
2 years Sesbania macrantha	3.0	2.6
1 year Sesbania sesban	3.4	2.3
2 years Sesbania sesban	5.4	3.3
1 year Tephrosia vogelii	2.8	2.0
2 years Tephrosia vogelii	3.2	2.3
Grass fallow	1.8	1.6
Groundnut–maize rotation	1.9	1.5
Continuous unfertilized maize	1.1	1.2
Continuous fertilized maize	4.0	3.6
SED[a]	1.1	0.4

[a] SED = standard error of the difference in means.

second best improved fallow species after sesbania, producing 3.8 and 6.1 Mg ha^{-1} of maize grain in the season after the fallow.

We also monitored the occurrence of striga [*Striga asiatica* (L.) Kuntze] following three-year fallows in the two experiments. Sesbania and senna were outstanding in striga suppression, with ≤ 6 striga plants 100 m^{-2} appearing in the season following the fallow (Table 3). Continuously cropped maize plots without fertilizer averaged 1532 and 195 striga plants 100 m^{-2} in the two experiments, and continuously cropped maize with fertilizer averaged 157 and 124 striga plants 100 m^{-2}.

Financial analysis of researcher-managed trials

The results from the trials above were very promising from a biological point of view. However, economic analyses were required to evaluate (i) whether improved fallows were still attractive after considering their costs, (ii) the duration of the payback period of the improved fallows, and (iii) differences in profitability across the different fallowing options.

Because the improved fallow was demonstrating strong residual yield effects, the economic analyses utilized the data from the six-year, on-station trial that ran from 1988 to 1993 (Table 1). The costs and benefits of continuous maize cropping without fertilizer and with the recommended dose of mineral fertilizer (112 kg N ha^{-1}) are compared with one-, two-, and three-year sesbania fallows followed by continuous maize cropping without fertilizer.

Price information was based on the prices farmers faced in 1993 and was

Table 3. Maize grain yield and population of *Striga asiatica* in the season following fallows at Chipata in eastern Zambia.

Land use before maize	Maize grain yield ($Mg\ ha^{-1}$)		Striga population (no. 100 m^{-2})	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
Calliandra calothyrsus	2.6	3.0	44	80
Flemingia macrophylla	3.5	3.7	448	15
Gliricidia sepium	3.8	6.1	712	50
Leucaena leucocephala	3.7	4.2	10	19
Senna siamea	2.1	2.1	0	6
Sesbania sesban	5.6	7.4	0	2
Grass fallow	2.2	3.2	130	191
Goundnut–maize rotation	3.1	4.1	130	93
Continuous unfertilized maize	2.0	2.3	1532	195
Continuous fertilized maize	4.1	6.9	157	124
SED[a]	0.33	0.71	329	56

[a] SED = Standard error of the difference in means.

collected from relevant institutions and key informants. A full treatment of the types of inputs used and their costs is given in ICRAF (1994). However a few points will be highlighted here. A discount rate of 0.2 was used. Labor was costed using the going wage rate (US$1.00 day^{-1}), since most households in Eastern Province hire at least some labor (Celis et al., 1991). Data for labor hours were estimated from on-station monitoring of workers. The trial used potted seedlings that were estimate to cost US$0.01 per seedling. Finally, it is important to note that the price used to value the firewood from the sesbania fallows was only US$2 t^{-1}. This low figure arises due to relative abundance of woodland firewood sources in most areas of eastern Zambia. The largest part of the benefits from the fallow is thus from increases in maize yield.

A summary of the cost-benefit analysis per hectare of land using the baseline assumptions is given in Table 4. The fertilizer option generated a surplus (US$1303 ha^{-1}) over the six-year period – far greater than that from the other options. The control of continuous unfertilized maize yielded the lowest discounted net benefit of US$307 ha^{-1}.

The one- and two-year fallows generated 78% and 92% more wealth respectively, than the control with continuous unfertilized maize. The three-year fallow was only marginally better than the control (2%) because it permitted cropping in only three of a possible six seasons and one of the three cropping seasons was poor due to drought.

In addition to total financial returns, the timing of the cash flows is important. There was a considerable lag before financial returns from the improved fallows exceeded those of the control of continuous maize (Table 4). By the end of the fourth year, the one-year and two-year fallows became

Table 4. Sum of discounted net benefits over time for five maize cropping options examined in a researcher-managed, on-station trial at Chipata in eastern Zambia.

Option	Sum of discounted net benefits (US$ ha^{-1})					
	1988	1989	1990	1991	1992	1993
Continuous maize (no fertilizer)	119	201	235	310	299	307
Continuous maize (112 kg N ha^{-1} yr^{-1})	483	844	1054	1195	1153	1303
One-year sesbania fallow	–155	–6	222	453	457	545
Two-year sesbania fallow	–171	–151	175	475	488	588
Three-year sesbania fallow	–171	–171	–147	182	205	313

more profitable than the control while the three-year fallow did not become as financially attractive as the control until the end of the sixth year.

Returns to labor, as opposed to land, may be a more appropriate indicator of financial attractiveness to farmers, especially in areas where labor is relatively more scarce than land. An examination of the returns to labor (the discounted net cash flow divided by discounted labor days) showed that the fallows were attractive. The return to labor from a two-year fallow was a respectable US$3.45 day^{-1}, which was 70% above that from continuous maize without fertilization. Although the control did not perform as poorly in the analysis of returns to labor as in the analysis of returns to land, it was again the least attractive option.

Numerous sensitivity analyses were undertaken. They included changes in the wage rate, cost of seedling, maize yields, and fuelwood prices and an investigation into how changing occurrences of drought affected fallow performance. In virtually all reasonable scenarios, the fertilizer option remained the most profitable. Similarly, the two-year fallow was shown to be more attractive than the unfertilized maize control in every scenario except for one with an extremely high discount rate (> 0.4).

In order to translate the above results into a ‘real-farm’ situation in eastern Zambia, we looked at how an operational improved fallow system might perform on a typical farm of three hectares. Assuming that two hectares are cultivated with maize and one hectare is under fallow (i.e., one-half hectare of trees are planted every year on a rotating basis), the net benefits to the farmer are equal to the average of the actual (non-discounted) net returns for each year from Table 4. That is, on one-half hectare, the farmer will incur a negative return due to the planting of a fallow and on the other field with the more advanced fallow the farmer will again not harvest any maize. On the remaining fields under maize, the farmer will receive different benefits depending on the stage of the rotation, earning the greatest return from the field that has just come out of the fallow.

If we use the returns from a drought free year, a typical household would receive an annual return of US$746 yr^{-1} by operating a rotating two-year fallow system. Viewed from the farm-level perspective, each of the fallow systems is considerably superior to the continuous maize control option, with the two-year fallow achieving a surplus of 205%.

The financial analyses of the on-station improved fallow results were in summary very encouraging. Two important lessons were used in subsequent research. First, a three-year fallow appeared to be less attractive than the one- or two-year fallows (even if drought had not occurred) and therefore should be given less attention. Second, the cost of the seedlings were a major consideration in overall profitability and length of payback period, suggesting that cheaper methods of establishment be considered in future work. Based on the favorable agronomic and financial results, it was then felt that the technology was ready to be tested by a larger number of farmers to evaluate the feasibility, profitability, and acceptability of improved fallows in an on-farm situation.

On-farm research

Testing a new technology with the potential users is a critical link between research and development. On-farm research on improved fallows in eastern Zambia served (i) to assess biophysical and economic responses under farmer management, (ii) to expose the technology to potential extension agents and farmers and obtain their feedback on problems and performance, and (iii) to assess how farmers used and modified the technology to suit their needs.

Our approach to on-farm research was first to establish solid relationships with the extension staff, and through them to the farmers. We spent much time exposing the technology to the extension camp officers in their extension target villages, where each camp officer is responsible for about 200 farm families. Camp officers were thus the main facilitators at the grassroots level.

To ensure farmer involvement, we combined the training of camp officers with village discussion groups arranged by extension agents. The approach was initially to select a village near a farmer training center (FTC), which would later be used for demonstration and experimentation. Meetings were then arranged where both the researchers and extension staff interacted with farmers and discussed the causes of low maize yields, farmers' fallowing practices, and the potential of improved fallows. Such a combination of strategies gave us ideas about which farmers could be trained in establishing nurseries and conducting improved fallow experiments on their farms.

We invited farmers from these villages to visit the station and see the results of our trials. Such visits generated much discussion among farmers and confirmed that the farmers were genuinely interested in the technology. At the end of each visit, the camp officers made a list of farmers who were interested in trying out the technology and initiated contact. The activities culminated in the establishment of on-farm research trials and demonstrations.

We also utilized research 'open days' when farmers, the extension staff, and development agencies were invited to the research station or to on-farm trials to see and discuss the progress on research and technologies being developed. We increased the frequency of field days so that they coincided with the major phases of improved fallows: the nursery, the fallow, and crop phases. We also decided to reach out to more farmers by using the 'pilot area' approach, setting up trials at a few farmers' fields and FTCs in the villages where the farmers lived. In this way, we were able to increase our contacts with the camp extension staff and the farmers. Three types of on-farm trials were established each with different objectives, as discussed below.

Researcher-designed, researcher-managed trials

Several researcher-designed, researcher-managed trials were established in the 1992/93 season on farmers' fields. These were designed to measure biological performance under farmers' soil conditions. The example of the trial on Mr Mphanza's farm shows how the research benefited greatly from early collaboration with farmers. Mr Mphanza's trial evaluated contrasting techniques of establishing sesbania. After two years of improved fallows, there was no significant difference in biomass production and maize yield between the use of potted and bare-root seedlings, but direct sowing of sesbania was distinctly less productive. Fallows established from bare-root and potted sesbania seedlings resulted in remarkable maize yield increases compared with yields achieved following continuous unfertilized maize and grass fallows. Maize yields following sesbania were similar to those achieved for the fully fertilized control maize. Mr Mphanza was very impressed by the results and established his own nursery to produce bare-root seedlings. He was also a pioneer in using sesbania natural regeneration to expand the area under sesbania improved fallow. Mr Mphanza, along with other farmers participating in these trials, were enthusiastic about the results and later expanded the use of improved fallows on their own.

Researcher-designed, farmer-managed trials

We started farmer-managed trials at a small scale by selecting types of farmers that were likely to benefit from improved fallows. Between 1992 and 1994, we were involved with eight farmers testing sesbania improved fallows and methods of establishing these fallows. Establishment and tree growth were satisfactory and bare-rooted seedlings emerged as farmers' preferred establishment method. In 1994, the team decided to greatly expand participatory on-farm research as a follow up to the encouraging on-station results, the positive indications from the financial analysis, and the on-farm trials.

In 1994/95, the team assisted four FTCs and six individual farmers to establish nurseries in various agricultural camps in Chipata, Chadiza, and Katete Districts. Using bare-rooted seedlings from these nurseries and in some cases direct sowing, 158 farmers initiated researcher-designed, farmer-managed trials ('type 2' trials) with 400 m^2 plots of improved fallows (Franzel et al., 1999).

The objectives were to assess the biophysical response of trees and crops under farmers' management, assess costs and returns of the technology, and to obtain farmers' assessments. We made a distinct effort to involve farmers representing the range of different types found in the area – e.g., high and low income, male and female, and oxen and hoe-users. In the trials, farmers selected one of the six options of improved fallow technologies. The options represented a factorial combination of three species (sesbania, tephrosia, or pigeonpea) and two methods of fallow management (pure stands or inter-cropped with maize during the first year of establishment and then allowed to grow into a pure stand fallow in the second year). These options were compared with continuous cropping of fertilized and unfertilized maize.

Sesbania was planted using bare-root seedlings, while tephrosia and pigeonpea were established by direct sowing. Researchers were involved in laying out about half of the trials; extension staff helped farmers plant the rest. The project supplied sesbania seeds, inoculum, maize seed, and fertilizer for the trials.

Rainfall was low and sporadic during the 1994/95 season. Trees in two-thirds of the trials had to be re-seeded or gapped, one to two times. Many farmers throughout eastern Zambia shared the experience of reseeding and gapping maize. We estimate that 60% survival of the fallow species in the first three months is required for satisfactory biomass production at the end of two years. In 1994/95, 82% of the surveyed farmers for tephrosia, 63% for pigeonpea, and 48% for sesbania achieved this level of survival. Aside from drought, other problems affecting survival were weed competition and browsing.

In a survey of farmers one year after planting, the main problems affecting establishment and growth of improved fallow species were a leaf-defoliating beetle, *Mesoplatys ochroptera* Stal. for sesbania, livestock browsing for pigeonpea, and drought (especially during the long dry season) (Table 5). A

Table 5. Problems cited by farmers as having affected establishment and growth of species in improved fallows during the first 12 months after establishment in 1996 in eastern Zambia.

Problem	Farmers having species who mentioned the problem (% of total)[a]		
	Sesbania sesban	*Tephrosia vogelii*	Pigeonpea
Beetles	80	0	1
Browsing by livestock	16	36	78
Drought	68	80	72
Poor seed	0	20	33
Termites	48	32	50
Other[b]	28	8	12
Number of cases	25	25	18

[a] Percentages do not sum to 100 because each farmer could mention more than one problem.
[b] Includes fire, poor soil, waterlogging, late planting, weeds, and competition between trees and crops.

paired comparison of survival rates at six months and at one year after planting showed that sesbania ranked highest in ability to withstand the long dry season. Sesbania survival declined from 81% to 63% between six and 12 months, whereas tephrosia survival declined from 91% to 51%, and pigeonpea survival dropped from 73% to 21% (Table 6).

Intercropping trees with maize during the first year appeared to have a negative effect on both maize yields and tree survival. Maize yields when intercropped were 29% to 39% lower than when sole-cropped. Tree survival rates 12 months after planting were 14 to 25 percentage points lower than when planted in pure stand, depending on the species (Table 6). However, many farmers prefer intercropping as a means of economizing on land and labor.

Rainfall was high during the 1995/96 season and survival improved; 80% of sesbania growers and 84% of tephrosia growers achieved survival rates over 60%. Pigeonpea was not planted because of the browsing problem. Over 70% planned to plant an improved fallow during the 1996/97 season, and two-thirds wanted to plant sesbania. Farmer experimentation is helping both researchers and farmers to understand the advantages and disadvantages of different improved fallow practices.

Farmer-designed, farmer-managed trials

In this type of trial, farmers were given seed or seedlings and advice on available options, such as fallow length, tree density, and planting method. They were left to design their own trials, planting trees where they wished on their own farms. The main purpose of this type is to understand how improved fallows are accepted by farmers into their existing farm practices. The number of farmers with these ‘type 3’ trials increased from five in 1993/94, to 37 in 1994/95, to 797 in 1995/96, and to 2786 in 1996/97.

Farmers planted fallows on areas ranging from about 0.04 to 0.09 ha. Many farmers who initially started off as ‘type 2’ farmers also planted ‘type 3’ trials after experiencing the benefits of improved fallows or after viewing experiences of others. Usually, they used planting material from their own farms.

We have noted many interesting innovations by ‘type 3’ farmers. One farmer planted seedlings into a bush fallow and weeded around each seedling – but without preparing the land first. Another planted sesbania seedlings behind an ox plow. As the plow moved along an adjacent furrow, it covered the seedling roots with soil. Several farmers gapped up their sesbania fields with seedlings planted one year after the first planting. Several relay planted sesbania at weeding time into parts of fields where maize was performing poorly.

During 1996, five farmers harvested maize following two- or three-year sesbania fallows. Maize yields were very impressive, and for four of the five farmers yields were comparable to those achieved from fully fertilized controls (Figure 1). These results have been a source of inspiration and have generated much enthusiasm among farmers.

Table 6. Mean survival rate of trees at six and 12 months after establishment from a sample of farms having 60% or greater survival after six months in 1996 in eastern Zambia.

Species	Number of cases	Survival (%)		Standard deviation	
		6 months	12 months	6 months	12 months
Pigeonpea, pure stand	13	73	21	17	18
Pigeonpea, intercropped with maize	5	72	7	18	9
Sesbania sesban, pure stand	19	81	63	12	16
Sesbania sesban, intercropped with maize	5	61	38	17	19
Tephrosia vogelii, pure stand	15	91	51	6	32
Tephrosia vogelii, intercropped with maize	9	81	33	10	30

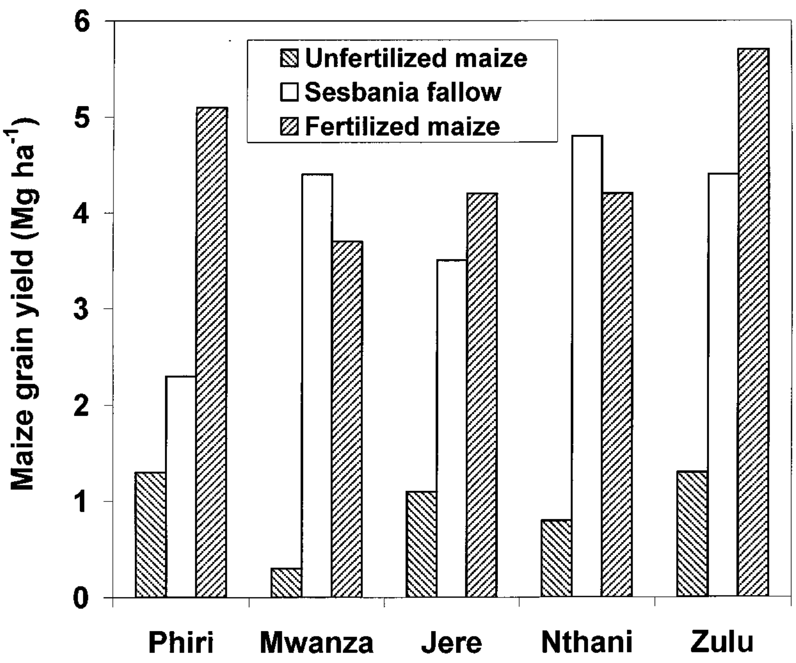

Figure 1. Effect of continuous maize cropping with and without fertilizer and sesbania fallows on maize grain yield obtained by five farmers in farmer designed and managed trials in eastern Zambia. The fertilizer rate was 112 kg N ha^{-1}, 17 kg P ha^{-1}, and 17 kg K ha^{-1}.

Farmer enthusiasm

Farmers' interest in improved fallows has been overwhelming. The initial results showing that sesbania fallows increased maize yields without fertilizers triggered enthusiastic responses from a large number of farmers, extension staff, NGOs, and development agencies.

During the 1996/97 planting season, the number of farmers testing improved fallows increased from about 1000 to 3023. The nurseries that the farmers had set up could not meet the high demand for seedlings. Some of the farmers resorted to transplanting sesbania regenerating from FTC fallows or a neighbor's field, and a few traveled > 20 km with hired ox carts in search of sesbania seedlings from the research station.

Discussion

Partnership with farmers and extension

The improved fallow technology was conceived as a natural progression, building and improving upon the traditional approaches to improve soil fertility. Our initial approach used the diffusion model in which technologies are passed from research scientists via extensionists to farmers (Rogers, 1962). This approach was necessary in order to give extension staff sufficient time and information to develop and enhance their skills in planting, caring, and managing of trees. Tree planting was not part of agricultural extension, and as such most farmers had never planted trees for soil fertility enhancement (Kwesiga and Chisumpa, 1992).

Together with extension, we also spent much time in the villages, with farmers, NGOs, and farmer groups to ensure that planting of sesbania was incorporated into the agricultural calendar. These contacts enabled us to learn more about land use and farming problems that farmers faced, including labor shortages.

By working directly with farmers, we were able to appreciate the need for low-input and low-cost technologies that were essential for rural development. We also learnt that many of these farmers were innovators, making path-breaking advances and absorbing the cost of experimentation (Pretty, 1995). In the process of working together, mutual trust and genuine partnership developed between researchers, farmers, and extension agencies. This relationship helped enhance confidence and increased farmer participation in the modification of the prototypes and increased the range of experimentation by farmers.

The partnership has evolved into an adaptive research and extension network, involving about a dozen different institutions (Figure 2). The Zambia-ICRAF team's responsibility is to provide technical assistance, training, and seed to other network members. They, in turn, implement on-farm trials and demonstrations and provide feedback on performance and problems. Research, extension, and farmers collaborate in the management and monitoring of the trials. The network meets twice yearly to review progress and plan adaptive research and dissemination of improved fallows.

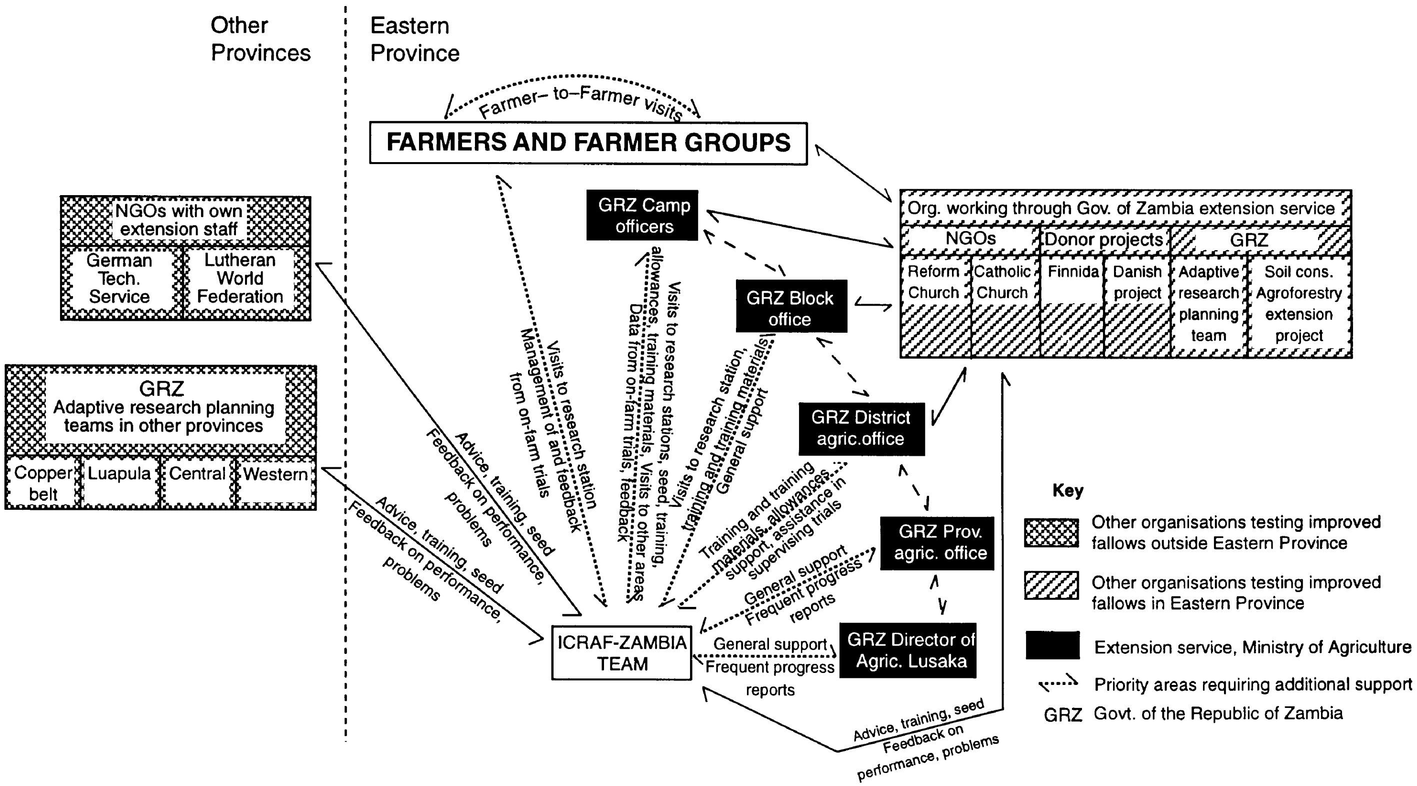

Figure 2. Institutional links between the ICRAF–Zambia team, farmers, and other organizations testing improved fallows in Zambia.

Network members have a growing experience of farmer-to-farmer extension, visitation, and peer training as a mechanism for supporting agricultural development. As local people develop the capacity to learn from and teach each other, they develop the capacity to conduct their own research. Farmer groups have become central in spreading information about the benefits of improved fallows through field tours, open days at FTCs, and visits to the research station. We also found out that farmer exchange visits, in which groups of farmers are brought to a farmer's experiment, to be very useful and practical. During such visits, farmers discuss freely as they observe the achievements, problems, confidence, and innovations of one of their own colleagues. These visits help farmers to set up their own experiments and in the future to share their experiences as well.

Contributing factors to the current achievements

Development is a process whereby people learn to participate constructively in the solving of their own problems. The driving force is people's enthusiasm for change (Bunch, 1995). People who work with development programs must motivate farmers through results not promises. Our current achievements so far can be attributed to:

- Correct diagnosis of farmers' problems from the onset of the program.
- Involvement of farmers and extension in the research process from the inception of the program. The scientists, like the camp extension staff, spent much time interacting with farmers and could respond quickly to the needs of farmers.
- Starting small and using local knowledge in the design of solutions.
- Demonstrating easily recognizable results.
- The strategy of testing a wide range of management options with farmers (e.g., offering three different species with intercropping and pure stand options) and then allowing them the freedom to modify, innovate, and improve the prototypes.
- The technology appears to be gender neutral, as half of the participating farmers are female. It also appears to be attractive to a range of different types of farmers – e.g., high income and low income, ox- and hoe-cultivators.
- The funding of the research project has been adequate and for a reasonable length of time.
- Ex-ante economic analysis helped identify key features of the technology that make it financially attractive – e.g., bare-root seedlings and the superiority of a two-year fallow over one- and three-year fallows (Tables 1 and 4).
- Development of an adaptive research and dissemination network for testing and extending the technology in new areas (Figure 2).

Looking ahead

Although there is much enthusiasm about improved fallows in eastern Zambia, it is not known whether farmers will adopt the technology and cover large portions of their farms. Moreover, there remain some constraints to adoption. Drought and pests, especially the mesoplatys beetle, have limited the effectiveness of improved fallows. Researchers have identified sesbania provenances resistant to the beetle and are currently multiplying the seed. Lack of training on nursery development and transplanting is also a critical problem, as poor methods can severely affect tree establishment and farmers' motivation. Adaptive research and dissemination networks are strengthening efforts in farmer training. Labor bottlenecks may limit the area that a farmer can plant to improved fallows. But by offering farmers a range of labor-saving options, such as direct seeding and intercropping, researchers can help farmers to integrate improved fallow systems into their farming calendars. Free-ranging livestock often damage fallow plots; efforts are underway in several areas to seek assistance from local chiefs in adopting grazing systems to accommodate the adoption of improved fallows. Lack of seed is also a constraint, but the recent establishment of seed orchards should help alleviate this problem.

Future research can also improve the effectiveness and adoption potential of improved fallows. We need a better understanding of how improved fallows work and the factors that affect their performance. This is key to assessing the long-term sustainability of the system as well as its extrapolation potential. Greater flexibility and more options are needed including more species and provenances, improved establishment methods, rotations, and other complimentary soil fertility measures including mineral fertilizer. Research is also needed to assess the expansion of improved fallows beyond the test plots and to understand the biophysical and socioeconomic factors that affect adoption. An understanding of these factors can be useful for assessing which improved fallow techniques will be useful in other land-use systems.

On the socioeconomic side, monitoring of farmer achievements, innovations, and impacts is needed. Farmer groups can be assisted to take over many of the adaptive research functions themselves, deciding which species and management techniques are best under different circumstances. Policy research can help alleviate the damage caused by fire and free-grazing livestock, identify improvements in seed supply, and improve the institutional support system for adaptive research and extension.

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