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Does farmer participatory research matter for improved soil fertility technology development and dissemination in Southern Africa?

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Crop management research is increasingly involving farmers in evaluating new technologies, identifying adoption constraints and opportunities for improving farm performance to produce more sustainable impact. ICRISAT and its partners worked with farmers in Malawi and Zimbabwe during the 1999/2000 and 2000/2001 seasons to evaluate a range of 'best bet' soil fertility and water management technologies and evaluate the impact of farmer participatory research. Although there was some variation in methods implemented at different sites, the study found that there is a basis for a comparison of methods. Community entry and participatory approaches that engage farmers in decision making throughout the research-development-diffusion-innovation process have higher setup costs compared to traditional 'top-down' approaches. But they improve efficiency, both in technology development and in building farmers' capacity for experimentation and collective learning. This results in the development of more relevant technologies, joint learning among farmers, researchers and extensionists and better impact. To make farmer participatory research projects more sustainable and introduce them on a wide scale, the study recommends that public and NGO investments be targeted to building district and village-level innovation clusters.

Keywords: Farmer participatory research, innovation, mother and baby trials, soil fertility management technologies

Introduction

Smallholder farmers in semi-arid areas throughout Sub-Saharan Africa face a severe soil fertility crisis (Anderson, 2001; Sanchez *et al.*, 1997; Smaling *et al.*, 1997). Smallholders have widely adopted improved varieties and hybrids, but not improved soil fertility technologies. Researchers have hypothesized that adoption is poor because the technologies are a poor fit to farmers' heterogeneous resource endowments and risk-return preferences and that farmer participatory research (FPR) is required to develop and disseminate more relevant and profitable technologies.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) implemented a pilot project in Malawi and Zimbabwe from 1999 to 2001 in collaboration with the national agricultural research and extension programmes, non-governmental organizations, the International Maize and Wheat Improvement Center (CIMMYT), and the Tropical Soil Biology and Fertility Programme. The project aimed to jointly verify with farmers 'best bet' soil fertility technologies suited to varying

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resource endowments, farming goals and risk preferences and test the impact of FPR methods. FPR was used to increase the efficiency of technologies and to engage farmers in dialogue about options. FPR was combined with crop simulation modelling to evaluate risk-return tradeoffs to investment in soil fertility management under various scenarios, and use simulation model results to engage extension agents, NGO representatives and agribusiness firms in discussions about scaling out successful technologies to wider areas.

This paper reports the study's findings. We focus on three questions: (1) How do alternative ways of organizing FPR interact with characteristics of households and village communities and result in different patterns of engagement? (2) Does FPR make a difference in soil fertility management technology development, dissemination and uptake? (3) What good practice options to guide FPR processes can be learned from the Malawian and Zimbabwean experiences?

Research approach: theory and methods

The conceptual framework that guides this study is drawn from the literature on farmer participatory research and agricultural research and technology adoption. This conceptual framework is applied to derive hypotheses for testing and to guide data collection and analysis.

Conceptual framework

There exists a growing literature on farmer participatory research. Selener (1997) provides a comprehensive review of the literature. FPR evolved in the late 1980s and early 1990s from farming systems research, which in turn emerged from farm management research. Early farm management research was 'station based', applying production economics theory to analyse farm management strategies. The field became dominated by theoretical models, and ultimately became irrelevant to the situation prevailing among resource-constrained smallholders in developing countries. Farming system research (FSR) was developed as an alternative in the 1970s. It sought to make research more relevant – and hence increase adoption – by moving research to the farm while maintaining rigour by retaining experimental techniques in on-farm experiments and through ties with station-based research. But FSR was criticized for its emphasis on testing or demonstrating solutions developed by 'outsiders'. This gave way to a more participatory approach in the 1980s. The new emphasis was on 'outsiders' and 'insiders' working together, with 'outsider' technical considerations being guided by 'insider' needs and preferences. In recent years a range of farmer empowerment approaches have emerged. These argue that redistribution of political power from elites to powerless poor farmers is a precondition for improving their agricultural productivity and incomes through technological change.

Biggs (1989) has developed a typology of FPR based on objectives of the research and the organizational and managerial arrangements for implementation. He defines four types of farmer participatory research approaches. The first type is contractual under which farmers have a minimal role, mostly providing land for experiments. The second is consultative that involves researchers consulting farmers, diagnosing problems and developing practical solutions through surveys, trials and field days. Third, there is collaborative research, involving joint participation throughout the research process. The fourth type is collegial, characterized by strengthening farmers' capabilities to carry out research and demand services from formal systems.

Pretty *et al.* (1995) developed a typology of participation based on levels and forms of farmer engagement. These include passive participation whereby people get told what is going to happen; information-giving participation; participation by consultation; participation for material incentives; functional participation by forming groups to meet predetermined objectives; interactive participation where people participate in joint analysis leading to action plans, formation of new local institutions and strengthening of existing organizations; and self-mobilization under which people participate by taking initiatives to change systems and retain control over resources.

Selener (1997) classifies research conducted on farms based on the level of control and management exercised by farmers into four main types: researcher-managed on-farm trials; consultative researcher-managed on-farm trials; collaborative farmer–researcher participatory research; and farmer-managed participatory research. Lilja and Ashby (2000) and Johnson *et al.* (2003) define five types of participatory research based on who makes the decision in the research-development-diffusion-innovation process, and whether or not the decision is made with organized communication.

Recent work provides insights on the economics of risk, uncertainty and learning in the adoption of new agricultural technologies (Marra *et al.*, 2001). Abadi Ghadim and Pannell (1999) have developed a framework for analysing how experimenting with a new technology results in learning that improves the farmer's ability to implement the technology, make better decisions about the technology, and develop better perceptions about the present and future probability distribution of returns from the new technology and covariance of returns between the new and old technologies. Trials provide an opportunity for learning, which reduces uncertainty and improves decision making. Information generated in the trials enables farmers to revise their subjective beliefs about the profitability of the new technology and to decide whether or not to continue using it and what resources to allocate to it.

The model shows that the impact of risk is ambiguous. It depends on he farmers' perceptions of the relative riskiness of the old and new technologies, the levels of uncertainty, and on whether the new technology is knowledge-intensive. Adoption of soil fertility technologies is very different from that of new varieties. With improved varieties the farmer can capture the benefits by simply planting the new seed. With soil fertility technologies, farmers need additional knowledge and experience: what product to use, when and how to apply it. If the nutrients are applied too late there may be no benefits. The technologies are risky and uncertain. High uncertainty and lack of experience with the technologies increases the risk of implementation failure and reduces adoption.

Given the importance of farmer learning, the nature of the learning system is crucial. Mbigi (2000) argues that most indigenous African knowledge is uncodified and difficult to access, transfer and learn. It can only be accessed and learnt through practical experience. This requires collective learning methods to codify the knowledge and make it universal by developing frameworks, which require intellectual capital. African learning systems are characterized by collective learning processes and bonding rituals and ceremonies that facilitate the dissemination of uncodified knowledge. For example, learning-by-doing is important and learning is through teaching others. The social process of learning is as important as the learning curriculum. Learning is based on group solidarity such as collective work. Learning is accelerated by being focused on survival challenges.

But African knowledge systems have been very weak in learning through intelligent borrowing and copying ideas and technologies and adapting best practices to their contexts (Eicher 1984; Mbigi 2005). Cowan *et al.* (1999) developed a matrix taxonomy of collective knowledge producing and using activities that can be applied for conceptualizing how smallholders' learning systems can be improved (Figure 1). The taxonomy distinguishes the extent of codification along the vertical axis and the extent to which knowledge is manifest along the horizontal. Different knowledge groups can be conceptualized as working out at any moment in their history in different states-space regions. Formal instruction and knowledge transfer activities are located at the top and apprenticeship at the bottom. The world of scientific research extends across the 'ham-shaped' region oriented along the southwest–northeast axis. Smallholder indigenous knowledge systems can be conceptualized as operating mostly in the southeast region with no codebooks and authority. Individual and organizational 'gurus' supply personal knowledge about technological and organizational performance. To accelerate development, African indigenous knowledge activities need to be combined with relevant modern universal knowledge by extending upwards through codification, validation, dissemination and utilization to the locus of global agricultural research systems. Because of the rapid pace of global technological and organizational change, smallholders need to upgrade their learning systems and learn at a rate faster than the rate of change in the environment (Senge, 1990).

Research hypotheses

Two hypotheses, developed using the above framework, are tested in the study:

- If FPR makes a difference in soil fertility management technology development, dissemination and

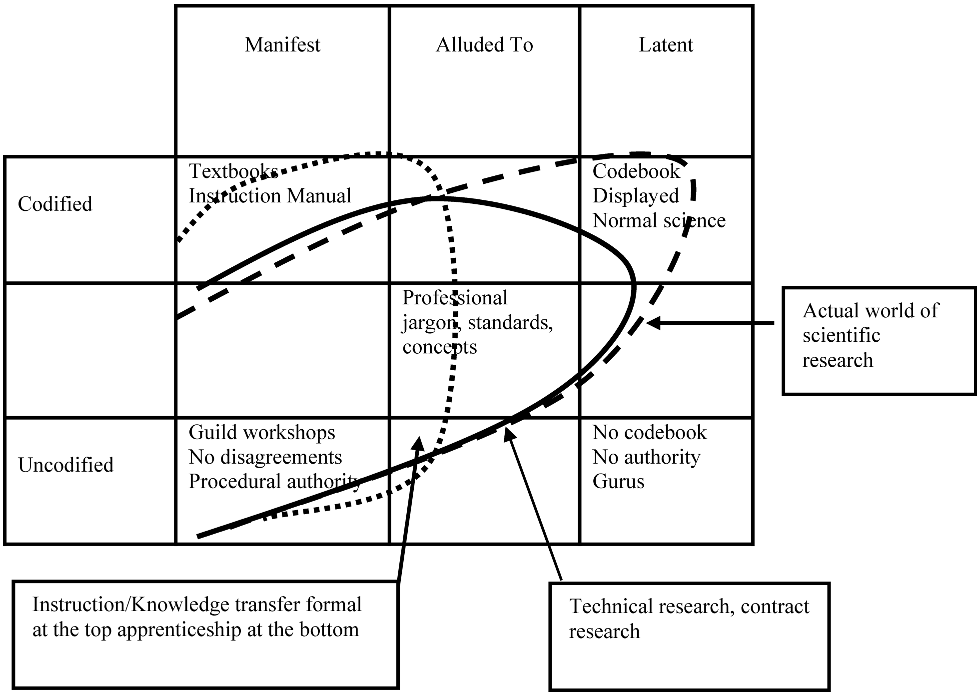

Figure 1 Classification of knowledge and knowledge generation activity on two axes (codification and knowledge manifestation). *Source*: Cowan *et al.*, 1999

uptake then the proportion of households gaining new knowledge and taking up new practices for treated households (participating in the programme) will be higher than for untreated households (not participating in the programme) accounting for heterogeneity in preferences and selection on observable and unobservable characteristics that affect outcomes.

- If FPR soil fertility management technology development, action research and learning empower farmers to develop better experimentation, communication and information and knowledge management skills then capabilities for intelligent borrowing of technologies from national and global research systems are improved.

Study areas and research design

Fieldwork was conducted in six case study areas: Tsholotsho, Gwanda and Zimuto in Zimbabwe; and Chisepo, Dedza and Mangochi in Malawi. The areas were chosen to represent different agro-ecological zones, population densities and market conditions. Stakeholder meetings were organized in Malawi and Zimbabwe in May 1999 to develop a common research agenda and protocols, select sites, assign leadership and institutional responsibilities, and develop work plans. Training of collaborators on FPR methodology and simulation modeling followed in October 1999.

Field activities were carried out during the 1999/2000 and 2000/2001 seasons. Collaborators selected target districts and villages; negotiated entry into the communities; organized meetings to discuss the objectives, research problems, technologies to be tested and experimental designs; identified and trained farmers to conduct trials; procured and delivered seed and fertilizer; and monitored and evaluated the trials with farmers. At the NGO-led sites – Concern Universal in Dedza and Intermediate Technology Development Group (ITDG) in Gwanda – participatory rural appraisals (PRAs) were conducted at the start of the fieldwork to understand the agricultural and livelihood systems, diagnose soil fertility, identify technologies for evaluation and conduct training. Technologies were tested using formal and informal trials in farmers' fields. Formal trials used the

Mother–Baby approach. Mother trials are randomized complete block design with factorial levels determined basing where responses are expected and with two to four replications per site in order to give statistically valid results in farmers' fields (Snapp, 2002). They are researcher-designed and managed trials. Baby trials are located around mother trials, and consist of a few treatments chosen from the mother trial by the farmers. They are unreplicated, and may be managed by researchers or farmers. Baby trials allow farmers to see for themselves the performance of treatments at different trial sites, and allow for faster, larger-scale testing at different locations under different management conditions. Informal trials were designed and managed by farmers using their choice of technologies and experimental methods.

In Malawi several 'best bet' technologies were tested on maize: maize-legume intercrops (mucuna, *Tephrosia vogelii*, pigeonpea, groundnut, soybean); maize-legume rotations; targeted cattle and goat manure application; and small amounts of nitrogen fertilizer. These were compared to unfertilized sole maize control, the dominant current practice. In Zimbabwe 'best bet' technologies were evaluated on both maize and sorghum: cereal-legume rotations, small quantities of nitrogen fertilizer, cattle and goat manures, inorganic nitrogen-manure combinations, anaerobically-composted manure, and soil water conservation (modified tied-ridging, dead level contours, infiltration pits). Participatory monitoring and evaluation tools, including ranking and scoring and matrix ranking, were used to evaluate the performance and benefits of the technologies. Evaluations conducted during field days and end-of-season workshops were used to identify farmers' criteria for adoption.

The intended plan was to compare three alternative FPR approaches using a randomized sample of households: traditional researcher-led approach, researcher-led with farmer input, and farmer-led with research input. The design was to randomly select four villages from each case study area and test the impact in each trial village. The plan involved testing one FPR method per village and evaluating the impact of alternative methods across different villages. The comparison intended to focus on four experimental villages at each site: a control village without intervention; a demonstration trial village using traditional on-farm research and extension; a researcher-led village using mother and baby trials; and a farmer-led village in which farmer-research groups were to be selected, trained and empowered to conduct trials. In practice, trials were carried out differently from what was planned. Focus group interviews conducted in Malawi and Zimbabwe in April and May 2001 revealed a selection bias; researchers often relied on extension agents when choosing target sites, and choices were biased to areas with previous exposure to researchers. Selection of farmers to host trials did not specifically target female-headed households. Researchers pursued different options for selecting host farmers and women farmers were included in an *ad hoc* way. Scientists concentrated on trials with good results (for publishing papers) while NGOs not interested in writing journal articles focused on farmer empowerment. The comparison of methods was also contaminated because it was difficult to prevent some farmers in control villages from conducting trials. Some farmers in demonstration villages implemented researcher-led researcher-managed trials and some farmers in researcher-led villages implemented a wide variety of farmer-led and farmer-managed trials.

Despite differences between intended and realized plans, a reconnaissance study in April and May 2000 found that the range of practices pursued could be classified into three methods based on the kinds of researcher–farmer interactions at different stages in the research-development-diffusion-innovation process (Freeman 2001). These included researcher-led and researcher-managed trials, with low level of farmer participation; researcher-led and farmer-managed trials in which farmers had more input; and farmer-led and farmer-managed trials where farmers had a high degree of control. The study also found that sufficient differences existed for a comparison of methods.

Data sources

The data used in the study are drawn from primary and secondary sources. Primary data were obtained through surveys, trial monitoring, and focus group discussions. During the 1998/1999 cropping season baseline surveys were conducted to help set research priorities and establish benchmark adoption levels of crop management technologies targeted by the research. For the baseline surveys, villages targeted for experimentation and neighbouring control villages were first selected. Households were then randomly selected from population lists, and farmers interviewed. The sample consisted of 328 households in Malawi and 248 households in Zimbabwe. Field enumerators monitored experiments throughout the two cropping seasons and collected plot level data. Farmers evaluated the technologies during field days, and at the end of the cropping season using group discussions and matrix-ranking methods. Focus group discussions were also conducted with participating and non-participating farmers. At the end of the 2000/2001 season, a formal survey was conducted at all six sites, covering farmers who participated in trials as well as non-participants in neighbouring villages. The sample consisted of 199 households in Malawi and 194 households in Zimbabwe. Researchers and extension agents were surveyed at the end of the 2000/2001 season to collect their perceptions of changes in farmers' practice, and changes in research and extension practice.

Secondary data were collected from work plan budgets, and expenditure statements were analysed to estimate the cost of FPR approaches. The cost estimates included researchers' time, expenses incurred during field visits, seed and fertilizer inputs, labour, training, and field days. Price data were obtained from district and national agricultural and statistical offices and input supply companies.

Results and discussion

The formal questionnaire surveys collected data on households' perceptions of the approaches used by researchers to enter village communities, select farmers to host trials, and engage households in dialogue about research and socio-economic variables affecting knowledge, attitudes, and soil fertility management practices. Factor analysis was used to identify the main dimensions of households' perceptions of practices pursued in the study; compare what was implemented in practice with what was planned; and compute factor scores for different factor dimensions for subsequent multivariate regression analysis.

Patterns of engagement of farm households

Factor analysis was carried out using the principal components analysis (PCA) to summarize the original information in few factors and determine approaches actually tested. The analysis included 24 variables. Nonmetric variables were included using dummy variables. The measure of sampling adequacy for all variables and the overall MSA exceed the threshold value of 0.5 for both Malawi and Zimbabwe (Table 1). The Bartlett test of sphericity, which provides the statistical probability that the correlation matrix has significant correlations among some variables, is highly significant. We conclude that factor model is appropriate (Hair *et al.*, 1998). The procedure extracted seven factors for both Malawi and Zimbabwe with eigenvalues greater than 1 (Table 2). The scree test showed that only the first four factors are significant and these are retained for further analysis (Figure 2). The cumulative variance measure indicates that the four factors explain about 52% of the variation in the original variables for Malawi and 57% for Zimbabwe. The communalities indicate that the four factors explain substantial proportions of variances of most of the original attributes.

To interpret the factors the VARIMAX method, which gives a clearer separation of factors and uncorrelated variables for subsequent regression analysis, was used to obtain orthogonal rotation of factors (Tables 3 and 4). After rotating the factor axes, the variables that have high statistically

Table 1 Overall measure of sampling adequacy and partial correlations among variables, Malawi and Zimbabwe, 2001/2002

	Malawi	*Zimbabwe*
Overall measure of sampling adequacy	0.79	0.77
Bartlett test of sphericity: chi-square	2344.10	2932.48
Degrees of freedom	276	276
Significance	0.000	0.000

Table 2 Results for the extraction of component factors, Malawi and Zimbabwe, 2000/2001

Factor	*Malawi eigenvalue*	*Percent of variance*	*Cumulative percent of variance*	*Zimbabwe eigenvalue*	*Percent of variance*	*Cumulative percent of variance*
1	7.0	29.3	29.3	7.1	29.8	29.8
2	2.1	8.6	37.9	2.9	12.2	42.0
3	1.7	7.1	45.0	2.3	9.4	51.4
4	1.7	6.9	51.9	1.4	5.9	57.3
5	1.5	6.3	58.3	1.4	5.7	63.0
6	1.2	5.0	63.3	1.3	5.2	68.2
7	1.2	4.9	68.1	1.1	4.4	72.6

significant loadings on factor 1 include who recorded the results-researchers; know how host farmers were selected; formal meeting to identify research problem; who marked plots-researchers; farming problems considered by researchers; what was done with the information collected during experimentation-taken to researchers; who chose fields for trial plots-farmers; who identified research problem-researchers and enumerators; who chose treatments-researchers; who designed trials-researchers; who is using the results-researchers, enumerators and extension; and how host farmers were selected-volunteering. This group describes a dominant role for researchers in decision making and management throughout all stages of the process. The farmers' role was primarily to provide land for researchers to carry out experiments. We identify factor 1 as reflecting the researcher-led and researcher-managed approach. In contrast, the variables that load very high on factor 2 include the number of times researchers, enumerators and extension agents visited trials per cropping season, farming problems considered by researchers; know how farmers were selected to host trials; who chose treatment-farmers; who chose fields for trials-farmers; who selected host farmers-volunteered; and who chose technology options tested-farmers. This cluster describes balanced researchers and farmers' participation during problem definition, design, management and implementation of trials. We identify factor 2 as capturing the researcher-led and farmer-managed approach. Variables that have significant loadings on factor 3 include how host farmers selected-volunteering; who selected host farmers-volunteered; who chose treatments-farmers; who chose technology options tested-farmers; who marked out plots-farmers; and who designed

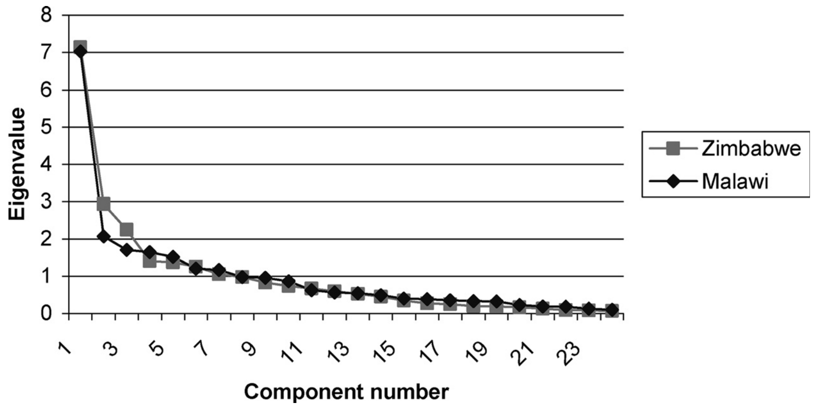

Figure 2 Scree plot

Table 3 VARIMAX-rotated component analysis factor matrix, Malawi, 2000/2001

Variables	***VARIMAX-rotated loadings***				
	Factor 1	***Factor 2***	***Factor 3***	***Factor 4***	***Communality***
Who recorded results-researchers?	0.84	0.24	0.05	0.14	0.78
Do you know how farmers were selected?	0.77	0.28	0.12	0.12	0.70
Formal meeting to identify research problem?	0.76	0.19	0.09	−0.28	0.70
Who marked plots-researchers?	0.76	0.22	−0.08	−0.14	0.66
Were problems considered by researchers?	0.68	0.18	0.13	−0.31	0.61
What was done with information-researchers?	0.67	−0.14	−0.02	0.19	0.51
Who chose fields-farmers?	0.61	0.21	0.22	0.28	0.54
Who identified problems-researchers?	0.55	0.41	−0.18	−0.19	0.53
How many times researchers visited?	0.52	0.48	−0.02	−0.04	0.51
How many times enumerators visited?	0.51	0.45	0.01	0.02	0.46
Who is using results-researchers?	0.46	0.57	0.05	−0.04	0.53
How many times extension visited?	0.39	0.17	0.44	−0.03	0.37
Who chose technology-researchers?	0.34	0.82	−0.03	−0.01	0.78
Who selected host farmers-volunteered?	0.26	0.18	0.64	0.11	0.51
How host farmers selected-nominated?	0.24	0.08	−0.40	−0.16	0.25
Who selected host farmers-farmers?	0.24	0.06	−0.43	−0.24	0.31
Who chose treatment-researchers?	0.14	0.84	0.04	0.08	0.73
Who designed-farmers?	0.13	−0.14	−0.10	0.74	0.60
Who recorded results-farmers?	0.13	−0.07	−0.12	−0.18	0.07
How host farmers selected-volunteered?	0.09	−0.01	0.72	−0.13	0.54
Who designed trials-researchers?	0.06	0.80	0.26	0.09	0.72
Who chose technology-farmers?	0.05	−0.04	0.37	−0.04	0.14
Who chose treatment-farmers?	0.02	0.17	0.42	−0.05	0.21
Who marked plots-farmers?	0.01	0.18	−0.01	0.80	0.68

trials-farmers. Therefore, it is a farmer-led and farmer-managed approach. Finally, variables that load on factor 4 are who marked plots-farmers; who designed trials-farmers; who selected host farmers-farmers and how host farmers selected-nominated in the positive direction and formal meeting to identify research problem; and how host farmers selected-volunteered in the negative direction. This pattern indicates limited understanding of the methods researchers used to enter villages, select farmers, and engage them in research. Therefore we interpret factor 4 as reflecting the control group.

The interpretation of the four factors identified by factor analysis is consistent with farmers and extension agents' responses to open-ended questions during focus group discussion and informal interviews. Key informants explained that in researcher-led and researcher-managed trials, researchers and field assistants generally entered villages by contacting local leaders; organized meetings to explain their objectives and programmes; and asked for volunteers to host trials. Researchers identified problems, chose options tested, designed trials, determined treatments, marked out plots, collected data, and took the results to the research stations for analysis. Researchers and enumerators visited trials very infrequently and often without farmers knowledge. Researchers provided little feedback in useful form to the farmers to help translate the yields measured in small experimental plots to field sizes managed

Table 4 VARIMAX-rotated component analysis factor matrix, Zimbabwe, 2000/2001

	VARIMAX-rotated loadings				
Variables	***Factor 1***	***Factor 2***	***Factor 3***	***Factor 4***	***Communality***
Who chose treatment-researchers?	0.9	0.0	−0.2	0.2	0.8
Who chose technology-researchers?	0.8	0.1	0.0	0.2	0.7
Who designed trials-researchers?	0.7	0.2	−0.1	0.1	0.6
Who identified problems-researchers?	0.7	0.1	0.2	0.0	0.5
Who chose fields-farmers?	0.6	0.5	0.2	0.0	0.7
Who marked plots-researchers?	0.6	0.1	−0.1	0.1	0.4
Do you know how farmers were selected?	0.6	0.6	0.2	0.1	0.8
Formal meeting to identify research problem?	0.5	0.6	0.2	0.0	0.7
What was done with information-researchers?	0.5	0.3	0.0	−0.1	0.4
Who is using results-researchers?	0.5	0.1	0.0	0.0	0.3
How host farmers selected-volunteered?	0.4	0.5	0.2	−0.6	0.8
Who selected host farmers-volunteered?	0.4	0.5	0.1	−0.6	0.8
Were problems considered by researchers?	0.4	0.6	0.0	0.0	0.5
Who recorded results-researchers?	0.3	0.0	−0.1	0.0	0.1
Who selected host farmers-farmers?	0.2	0.1	0.0	0.9	0.8
How host farmers selected-nominated?	0.2	0.1	0.1	0.8	0.8
How many times researchers visited?	0.2	0.7	−0.1	0.1	0.6
How many times extension visited?	0.1	0.4	0.1	0.0	0.2
How many times enumerators visited?	0.1	0.8	−0.1	0.0	0.6
Who designed-farmers?	−0.1	0.0	0.9	0.0	0.8
Who marked plots-farmers?	−0.1	0.0	0.9	0.1	0.9
Who chose technology-farmers?	−0.1	0.4	0.3	−0.2	0.3
Who recorded results-farmers?	−0.1	0.1	0.0	−0.1	0.0
Who chose treatment-farmers?	−0.2	0.5	0.5	0.0	0.5

by farmers. This explains why farmers perceived researchers and extension as mostly using the results. Researchers similarly established farmer-managed trials through village formal meetings through traditional leaders and local area extension workers. But researchers spent more time explaining objectives and identifying research problems, which explains why farmers felt that they knew how host farmers were selected and chose technology options tested, treatments, and fields for trial plots. In contrast to researcher-managed trials, field assistants and extension agents visited farmer-managed trials more frequently and carried out operations with farmers. In farmer experimentation trials researchers entered villages through community-wide meetings, comprising several villages, but farmers were selected through nomination and simple majority voting. Farmers chose options tested, designed trials, determined treatments, fields for trial plots, marked out plots, recorded data and shared results with other farmers. Control farmers had a poor understanding of researcher objectives, selection process and why they were not selected to host trials. We conclude from the focus group discussions and key informant interviews that the marker variables summarized by PCA analysis closely reflect hypothesized underlying factors. This indicates that the three FPR approaches were actually tested in the study and the results have practical significance.

Impact of FPR

To determine the impact of alternative FPR approaches, factor scores for the four-solution model were computed and applied to multivariate regression analysis. This section discusses whether or not different approaches produced different impacts in terms of change in farmer practice.

Farmers were asked to recall details of trials and trial results they had conducted, whether or not they had learnt and taken new practices onto their main fields. To evaluate the impact of alternative FPR approaches, we apply latent variable modelling methods developed in the treatment effects literature on evaluation of social programmes when outcomes are discrete and responses to treatment vary among observationally identical persons (Aakvik *et al.*, 2004; Heckman, 2001). This literature starts with a counterfactual against which to measure net programme impacts. Each sample household has a potential outcome with and without treatment. Because an individual household cannot be observed in both states at a given time, there is a missing data problem of outcome measures. Because households self-selected to participate in FPR programmes, regression coefficients estimates of the impact of the programme may be biased if there are systematic differences between participating and non-participating households in observed and unobserved characteristics that affect outcomes (Heckman, 1979; Vella, 1998; Grilli and Rampichini, 2006). If the selection is not ignorable, procedures are needed to eliminate selection bias (Little and Rubin, 2002). To correct the selection bias, Heckman (1979) developed a two-step procedure for single-level models. This was subsequently extended in several ways for panel data (Vella, 1998) and multilevel hierarchical model data (Grilli and Rampichini, 2006).

Following Aakvik *et al.* (2004), for each household i let Y_{1i} be the outcome with treatment and Y_{0i} without treatment. FPR intervention can be thought of as movement of a household from the 0 to the 1 state. Let $Di = 1$ if the household is in 1 (i.e. participated) and $Di = 0$ otherwise (i.e. did not participate). If the observed Y_{1i} is defined as $Y_i = D_i Y_{1i} + (1 - D_i) Y_{0i}$ then the potential outcome equation for the participation state is

$$Y_{1i} = \mu_1(X_i, U_{1i})$$

and the potential outcome for the non-participation state is

$$Y_{0i} = \mu_0(X_i, U_{0i})$$

where X_i is a vector of observed random variables and U_{1i}, U_{0i} are unobserved random variables. Assume that the decision whether or not to participate is generated by a latent variable D_i^*:

$$D_i^* = Z_i \beta_D - U_{Di}$$
$$D_i = 1 \text{ if } D_i^* \geq 0,\ D_i = 0 \text{ otherwise,}$$

where Z_i is a vector of observed random variables and U_{Di} is an unobserved random variable. D_i^* is the net utility or gain to the household from choosing to participate in FPR. Thus the selection outcome whether or not to participate in FPR is binary. The outcome variable whether or not to take soil fertility management practice on the main arable fields is also binary. We assume that a linear latent index generates the technology uptake outcome

$$\mu_j(X, U_j) = 1\lfloor X\beta_j \geq U_j \rfloor$$

where $j = 1$ for treated state and $j = 0$ for the non-treated state and $1[\cdot]$ is the indicator function.

The three equation mixture model consisting of an equation for the decision rule, whether or not to participate in FPR, an outcome equation for participation in FPR state and an outcome equation for non-participation states is estimated by maximizing an approximation to the likelihood integrated over the random effects using the generalized linear latent and mixed model available in Stata (Rabe-Hesketh *et al.*, 2004). The Newton – Raphson numerical optimization method is used to carry out maximization. Adaptive quadrature is used for the numeric integration. We assume that the error terms follow a factor structure. The technology uptake outcome equation for the FPR participation state is

$$Y_{1i}^* = X_i \beta_1 - U_{1i}$$
$$Y_{1i} = 1 \text{ if } Y_{1i}^* \geq 0,\ Y_{1i} = 0 \text{ otherwise.}$$

The technology uptake outcome equation in the non-participation state is

$$Y_{0i}^{*} = X_i\beta_0 - U_{0i}$$
$$Y_{0i} = 1 \text{ if } Y_{01}^{*} \geq 0,\ Y_{0i} = 0 \text{ otherwise.}$$

Sample selection bias is corrected by simultaneously fitting the outcome technology uptake equation and the selection FPR participation equation conditioning on observable explanatory variables and random effects using full information maximum likelihood to yield efficient estimators (Grilli and Rampichini, 2006). Because responses are binary, the conditional distribution is specified via the binomial family and the logistic link function. The same explanatory variables are used in the outcome and selection functions for Malawi and Zimbabwe. Explanatory variables included in the technology uptake equation are household size, farming experience, cattle ownership, dummy for village hosting a trial, dummy for male-headed household, dummy for *de facto* female-headed household, dummy for household hosting a trial, and kind of FPR approach measured by factor score computed by the PCA analysis. Variables in the selection equation are learnt new knowledge, dummy male-headed household, and dummy female-headed household.

Table 5 reports the variable definitions and descriptive statistics of the variables used in the analysis for FPR participants and non-participants. The mean cattle ownership and farming experience for households in Zimbabwe is higher for participants than for non-participants. The average number of villages with trials for both countries is higher for participants than for non-participants. Furthermore, participants have more male-headed households and they are more likely to learn new knowledge and practices from the trials.

Results of the GLLAM selectivity regression model are presented in Table 6. The selectivity variable (dhost) is statistically significant in the main regression equations (v1_dhost) for both Malawi and Zimbabwe. The variance of the random effect is also significantly different from zero. This further indicates that the two equations are dependent. For the selection equations, the coefficient of learning new knowledge from trials is statistically significant. For technology uptake equations the coefficients for the researcher-led and researcher-managed approach, researcher-led and farmer-managed approach and farmer-led and farmer-managed approach are highly significant. In Malawi household size and village

Table 5 Variable definitions, means and standard deviations of characteristics for participants and non-participants, Malawi and Zimbabwe 2000/2001

		Malawi		***Zimbabwe***	
Variable name	Definition	108 participants	91 non-participants	42 participants	148 non-participants
hsize	Household size (number)	5.27 (2.00)	5.11 (2.29)	7.95 (4.24)	7.18 (3.57)
yrsfarm	Farming experience (years)	17.00 (11.44)	15.87 (13.27)	21.52 (16.10)	17.56 (11.17)
cattle ownership	Cattle owned (number)	0.40 (1.46)	0.34 (1.54)	12.26 (11.09)	8.03 (8.86)
viltrial	Village trial status, dummy variable, equal to 1 if trials conducted in village, 0 otherwise	0.81 (0.39)	0.26 (0.44)	0.95 (0.22)	0.80 (0.41)
dmale	Male-headed household, dummy variable, equal to 1 if male headed, 0 otherwise	0.73 (0.45)	0.58 (0.50)	0.81 (0.40)	0.69 (0.46)
deffem	*De facto* female-headed household, dummy variable, equal to 1 if defacto female headed, 0 otherwise	0.08 (0.28)	0.19 (0.04)	0.07 (0.26)	0.15 (0.36)
learnnew	Learnt new knowledge from trials, dummy variable, equal to 1 if household learnt, 0 otherwise	0.92 (0.28)	0.31 (0.46)	0.93 (0.26)	0.66 (0.48)

Table 6 Estimated coefficients of the GLLAM selectivity random effects model for technology uptake and participation in FPR selection equations, Malawi and Zimbabwe, 2000/2001

	Malawi			Zimbabwe		
Response[a]	***Coef.***	***Std. err.***	***P > z***	***Coef.***	***Std. err.***	***P > z***
v1_hsize	0.031	0.014	0.026	−0.015	0.009	0.110
v1_yrsfarm	0.003	0.002	0.164	0.001	0.002	0.663
v1_cattle	0.180	0.020	0.376	0.008	0.003	0.016
v1_viltrial	−0.148	0.750	0.047	−0.082	0.097	0.397
v1_dmale	−0.023	0.077	0.765	0.036	0.100	0.715
v1_deffem	0.000	0.108	0.996	0.248	0.131	0.058
v1_dhost	−0.273	0.146	0.062	−0.529	0.202	0.009
v1	0.480	0.138	0.000	1.017	0.199	0.000
fac1_1	0.413	0.068	0.000	0.279	0.077	0.000
fac2_1	0.193	0.041	0.000	0.315	0.068	0.000
fac3_1	0.075	0.030	0.011	0.118	0.040	0.003
fac4_1	0.026	0.030	0.376	0.059	0.034	0.083
v2_learnnew	2.778	0.444	0.000	2.229	0.417	0.000
v2_dmale	0.402	0.472	0.395	0.569	0.517	0.271
v2_deffem	−0.249	0.676	0.711	0.267	0.680	0.694
v2	−1.925	0.536	0.000	−1.455	0.568	0.010
Level 1 variance and covariances	0.172 (0.018)			0.209 (0.02)		

[a]fac1_1 is factor score for researcher-led and researcher-managed approach, fac2_1 is score for researcher-led and farmer-managed approach, fac3_1 is the score for farmer-led and farmer-managed approach, and fac4_1 is the score for control farmers.

hosting trials have statistically significant impact on technology uptake. In Zimbabwe cattle ownership and defacto female-headed household status have significant positive impact on technology uptake. This shows that all the three research approaches are instrumental for changing farmers' practices. Comparing the magnitudes of the coefficients, in Malawi the researcher-led and researcher-managed approach has the greatest impact followed by the researcher-led and farmer-managed approach and the farmer-led and farmer-managed approach. By contrast in Zimbabwe, the researcher-led and farmer-managed approach has most impact followed by the researcher-led and researcher-managed and farmer-led and farmer-managed approach. Key informants explained that in Malawi's top-down extension culture farmers are made to believe that they know less than extension workers and only carry out trials under instruction from researchers and extension agents. The researcher-led and researcher-managed approach is instrumental because of better feedback between farmers, researchers and extension, joint learning, and matching technologies to the investment objectives, resource endowments and management capabilities of different farmers. Farmers become convinced of the benefits of new technologies and develop confidence of applying results from trials because they learn to implement the practices instead of extension workers telling them. The farmer-led and farmer-managed approach is less instrumental because farmers need technical backstopping to resolve problems such as diseases that may develop in the process of conducting trials.

Good practice options for FPR processes

To identify good practices for scaling out the impact of FPR, farmers were asked their experience about what worked well and what did not for each stage of the process: entry into the community and farmer selection; identification of problems; identification of options and trial design; implementation; data collection, analysis and evaluation; and sharing of results. Farmers' assessments are summarized in Table 7.

In summary, the best FPR practices – as identified by farmers – engage farmers in genuine dialogue, address their concerns, and present technologies through learning-by-doing and learning-by-using. This develops farmers' capacity to conduct experiments on their own and to teach each other. Research and extension need to learn from farmers, ensure they are closely involved throughout and their priorities fully taken into account.

Extension agents and researchers interviewed reported that although FPR is tedious and time consuming, it improves interaction between farmers, extension officers, and researchers. Farmers are given opportunities to voice their preferences, choose technologies that most benefit them and, at the same time, advise researchers what they should do. If farmers, scientists and extension officers meet frequently there is joint learning. Mutual trust develops over time, farmers reduce their strategic bargaining and misrepresentation

Table 7 Farmers' perceptions of good and bad practices in FPR, Malawi and Zimbabwe, 2000/2001

Research stage	***Good practices***	***Bad practices***
Community entry and selection of farmers to host trials	Entry through village leaders, village meetings to explain objectives and accompanied by extension officers Opportunity for farmers to volunteer, selection fair and respect for local culture Approach based on 'teaching' about farming and way researchers work imparts knowledge	Involve only a few farmers Enter by communicating with small number of farmers (the others find out later) Favouritism by local leaders in selection and information dissemination
Problem identification	Identify problems that affect many farmers Conduct soil sampling and testing Help farmers learn new technologies Discuss options that significantly increase yield in trial plots compared to farmers' own field	Failure to report back soil test results Identify problems without discussing with farmers Failure to follow-up with trials after raising farmers' hopes initially
Identifying options for testing, trial design	Offer a choice of options that use local resources and are easy to use after withdrawal of research support Researchers choose the trial design for farmers with orderly set-up of plots on a range of soil types Researchers teach farmers new ideas that improve yield	Not offering farmers opportunities to test other legumes and crop combinations they prefer Including legumes such as tephrosia that are not edible and do not give quick benefits Too few inorganic fertilizer treatments Failure to make farmers understand trials Providing insufficient resources to implement trials
Implementation	'Educate' farmers by implementing trials Frequent visits by researchers and field assistants to provide guidance Small and manageable plots with field layouts to clearly show treatment differences Synchronize activities in trial plots with those in main fields	Treatment differences not visible Researchers not keeping appointments Researchers' visits disrupting farm operations Too much time in meetings High labour requirements for some technologies
Data collection, analysis and evaluation	Field assistants visit trial plots and record accurate information Collecting data for future use to improve local farming Teach farmers to record data themselves	Collect data without farmer's knowledge No feedback Failure to record data
Sharing results	Farmers teach each other good farming methods	Few farmers share results or help each other Farmers becoming jealous Fear of bewitching each other

of beliefs in order to continue getting access to donor funding and inputs. This helps eliminate inferior technologies and increases acceptance, thereby generating broad and permanent adoption by farmers.

When asked to compare the impact of different FPR methods on extension practice, extension officers reported that the researcher-led and farmer-managed approach was the most cost-effective because of four reasons. First, it results in them gaining more new knowledge and skills from trials that they did not acquire during their formal training. For example, how to carry out adaptive research, how to engage farmers in dialogue using Participatory Rural Appraisal tools, how legumes improve soil fertility, legume management, and magnitude of benefits from alternative legume technologies. Extension agents are better able to formulate trial results into simple messages that farmers can easily adopt with the researcher-led and farmer-managed approach compared to the other approaches.

Second, the researcher-led and farmer-managed approach enables extension officers to better shift from regurgitating information in research pamphlets and extension manuals to using FPR trials for communicating with farmers on a broader range of technologies. Extension agents who directly participated in the trials explained that researcher-led and farmer-managed approach particularly develops farmers' confidence in their ability to use results from experimental plots; farmers feel they can implement the practices even in the absence of extension workers. Compared to the researcher-led and researcher-managed approach, farmers conducting trials start adopting technologies even during the first year of trials because they – not researchers and extension staff – are carrying out the work. Compared to the farmer-led and farmer-managed approach involving extension agents in research increases the likelihood of adoption because extension officers reinforce farmers' experiential learning in a more efficient way compared to interpreting recommendations in extension manuals. The 'converted' farmers in turn teach other farmers, in effect doing the extension agent's work.

Finally, the researcher-led and farmer-managed approach better facilitates changes in research and extension culture from a top-down (teaching) to a bottom-up (facilitating) mode of operation. Researchers reported that the research-led and farmer-managed approach is more flexible for testing technologies under farmers' practices, and modifying protocols in response to farmers' comments. Farmers are better able to evaluate the technology during the research process, and farmers and researchers learn from each other. The farmer-led and farmer-managed approach results in farmers varying several factors simultaneously within the same experiment, thereby confounding treatment effects and making it harder to draw statistically significant inferences. The researcher-led and researcher-managed approach results in farmers perceiving the trials as basically for researchers and that they can only do anything when researchers, field assistants and extension workers visit them. Some households may mistrust researchers or think that researchers will take away the harvest from experimental plots after farmers have invested their land and labour. Consequently, farmers may misrepresent their opinions.

Different FPR approaches have different levels of farmer participation and hence different costs. The set-up costs of FPR using reseacher-led and researcher-managed methods averages US$ 244 per trial in Malawi and US$ 300 in Zimbabwe (Figures 3 and 4). Set-up costs are higher for the more complex researcher-led and farmer-managed approach, averaging US$ 276 in Malawi and US$ 311 in Zimbabwe. This is because of higher additional expenses incurred conducting workshops with senior researchers to get buy-in and to identify target areas, training of enumerators and extension staff, travel, community entry and village meetings, wages of enumerators in the field, labour for mother trials, seed and fertilizer costs, researcher costs for monitoring trials, closer and more frequent interaction with farmers, more layered data, hence higher time and costs for analysis, workshops to present results back to farmers, field tours and field days, and more detailed surveys.

Surprisingly, the set-up cost of the complex farmer-led and farmer-managed approach in Malawi was US$ 100, lower than the researcher-led and farmer-managed approach. This was partly because researchers spent less time interacting with farmers and partly because of cost containment during training workshops. In contrast the

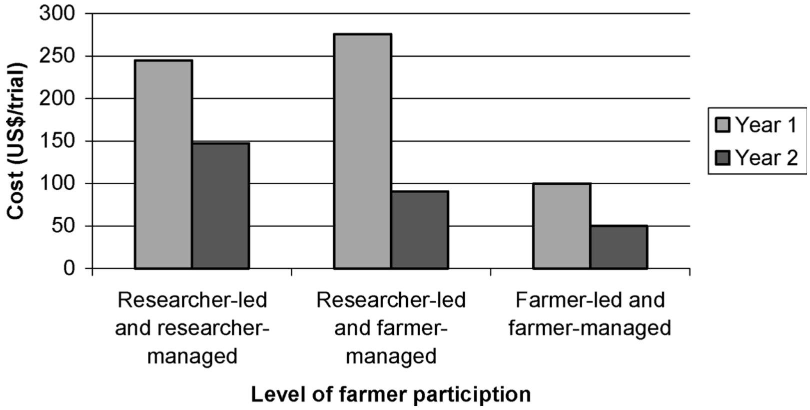

Figure 3 Investment costs per trial of conducting FPR, Malawi, 1999/2000–2000/2001

set-up costs for the farmer-led and farmer-managed approach was US$ 272 in Zimbabwe. This is because of intensive interaction with farmers during Participatory Rural Appraisals, identification of farmer innovators, capacity building and training at community and district levels, district training teams to build key stakeholders' capacity for experimentation and collective action, institutional surveys to provide management information, look and learn visits, and village meetings to provide feedback using professional consultants.

Although costs per trial are initially high they decline over time especially for the researcher-led and farmer-managed approach. This makes the FPR pilot projects replicable. But the high level of fixed costs, high exclusion costs and jointness-in-consumption requires initial public sector funding. Over time, farmer innovation groups develop within the community, and these can be used by private firms to test proprietary products and contract production, thereby shifting the funding burden to the private sector. The public sector lacks the staff and budgets to introduce FPR projects on a wide scale. However, NGOs are making substantial investments in relief programmes; a part of these investments can be used to supplement public sector finding for FPR targeting development of district and village-level clusters of innovation.

Conclusions and recommendations

A combination of qualitative and quantitative approaches was used to evaluate how alternative FPR approaches interact with characteristics of households and village communities and result in

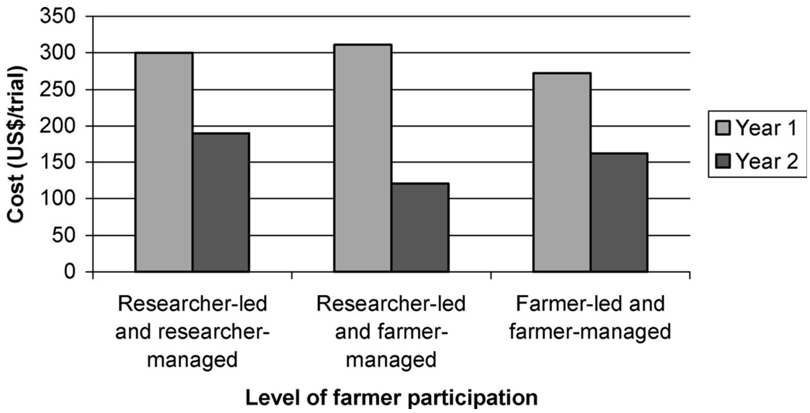

Figure 4 Investment costs per trial of conducting FPR, Zimbabwe, 1999/2000–2000/2001

different patterns of engagement, assess the impact of FPR on soil fertility technology uptake and learn lessons of good practice options for increasing the impact of FPR. Although there were differences in planned and realized FPR treatments, factor analysis of sample households' perceptions of approaches used by researchers showed that alternative FPR approaches were actually tested and the results have practical significance.

Econometric analysis correcting for sample selection bias showed that all the three research approaches were instrumental for changing farmers' practices. In Malawi the researcher-led and researcher-managed approach had the greatest impact on technology uptake followed by the researcher-led and farmer-managed approach and the farmer-led and farmer-managed approach. In Zimbabwe, the researcher-led and farmer-managed approach had most impact followed by the researcher-led and researcher-managed and farmer-led and farmer-managed approach.

The researcher-led and farmer-managed approach is the most cost-effective because it optimizes joint learning among farmers, researchers and extension agents; facilitates development of skills for farmers to implement the new technologies; and strengthens traditional African collective learning methods. Analysis of farmers' perceptions of good and bad practices used at various stages in the research-development-diffusion-innovation process reveals that investments are most likely to generate impact if targeted at building farmers' capacity to experiment with new technologies and improve collective learning systems. Because the public sector has a lack of staff and budgets to introduce FPR on a wide scale, the study recommends targeting NGO investments to supplement public sector funding and build district- and village-level innovation clusters.

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