# Comparative performance of cereal legume intercrops and rotations in Zimbabwe's semi-arid farming systems: An application of first degree Stochastic Dominance Analysis.

**R. Foti[1*], N. Mlambo[2], T. J.Chikuvire[1], V. Muringai[1], C. Mapiye[1], and Z. Mavunganidze[1]**
[1] Department of Agriculture, Bindura University of Science Education, P.Bag 1020,Bindura, Zimbabwe. Corresponding author: rfoti@buse.ac.zw
[2] Department of Computer Science, Bindura University of Science Education, P.Bag 1020, Bindura, Zimbabwe.
**Accepted 4 September 2006**

## Abstract

For farmers to adopt farming technologies, they should derive satisfactory returns from these technologies and the technologies should also be compatible with the farmers' attitudes towards risk. Many studies that have been carried out on the potential and actual returns from incorporating legumes into smallholder farming systems have not recognized and taken into account the stochastic nature of these returns. As a result many technologies that were proved to be superior experimentally in terms of physical gains have suffered low rates of adoption. This paper uses the principles of first-degree stochastic dominance analysis to compare four cereal-legume based production systems in Zimbabwe's semi-arid areas. Stochastic dominance analysis ranks technologies according to risk efficiency based on the notion of direct utility maximisation. Results of the study show that combinations that include maize and groundnuts are more efficient under favourable climatic conditions but have a high chance of complete failure under adverse conditions and are therefore risky. As a result, such combinations can be recommended in high crop potential areas and seasons and for farmers who are not risk averse (usually the well-off farmers). Sorghum and cowpea based production systems are not efficient in high rainfall areas due to their restricted potential to yield very high returns. They are however more risk efficient under adverse climatic conditions than maize and groundnut based systems. These technologies would therefore be the best-bet for risk averse farmers living in marginal areas. More rigorous and widely encompassing studies are however recommended.

**Key words:** intercrop, legumes, rotation, stochastic dominance, technology.

## Introduction

Maintenance of soil fertility on smallholder farms in Southern Africa has continued to be a great challenge that threatens to thwart efforts to improve food production in the region. It is widely acknowledged that poor soil fertility is the principal constraint to crop production in smallholder farming systems in Sub-Saharan Africa (Mpepereki and Pompi, 2003). The maize-based cropping systems of Southern African smallholder farmers are characterized by persistent and recurring drought and widespread soil fertility decline resulting in either stagnant or decreasing food production. Under smallholder production systems, yields of most staple food crops have been less than 1 tonne/hectare (Rowe and Giller, 2003).

As well as being a direct contributor to reduced productivity, soil infertility is a major source of inefficiency in the returns to other inputs and management committed to smallholder farms, including seed and labour (Mekuria and Waddington, 2002). Ways to reduce and manage soil infertility have therefore received major attention from agricultural research by development agencies and donors in recent years (Sanchez et al, 1997; 2002).

One of the increasingly popular research areas in soil fertility management is the inclusion of legumes in smallholder farming systems. Legume-based technologies have been considered one of the best candidates for inclusion in crop farming systems either in rotation or as intercrops with cereals or with other non-legume crops (Rowe and Giller, 2003). They have also played an important role in livestock farming systems for they provide sources of high protein diets at low costs. The growing interest in the use of legume-based technologies as nutrient sources in smallholder farming systems in Sub- Saharan Africa has mainly been due to constraints on expansive fertilizer use and because governments and non-governmental organisations (NGO) are increasingly concerned about the negative externalities that synthetic fertilizers might have on the environment.

In Zimbabwe however, agricultural extension has in the past 50 years discouraged intercropping and has promoted the growing of pure crops targeted for commercial purposes (Meerman, 1996). Despite this advice, farmers have continued to grow legume based intercrops albeit in small areas. To re-introduce legumes into the system on a large enough scale to enable farmers to capture potential benefits of biological nitrogen fixation, the legume technologies need to give a competitive rate of return on investment compared to alternative investment options available to households, while at the same time addressing farmers' risk requirements. That is, the returns from the technologies should be high but with low variability. In general, however, highly rewarding production systems are associated with higher risks. A compromise has therefore to be established between the level of returns desired and the level of risk to be borne.

A lot of work has gone into the assessment of legumes and legume-based cropping systems (intercrops and rotations) but most of this work has concentrated on the physical gains from the legumes in terms of yield increases and estimates of soil fertility gains from legumes (Mekuria and Waddington, 2002; Mtambanengwe and Mapfumo, 2003; Rowe and Giller, 2003). The positioning of smallholder Sub-Saharan African farmers in the lower ranks of the income spectrum makes their decision-making and technology adoption vulnerable to risk considerations. There is therefore need to carry out studies that incorporate the stochastic nature of the benefits from legumes and legume technologies instead of only considering the potential magnitude of these benefits. This would allow the selection of legumes that both give favourable returns to farmer investments, while at the same time addressing farmers' risk concerns.

The purpose of this paper is to compare the performance of legume-based technologies (intercrops and rotations with cereals) using stochastic budgeting and stochastic dominance analysis. These analytical methods allow the incorporation of risk into farm decision-making by introducing uncertainty into some of the variables included in the budgets (Fackler, 1991). The attractiveness of legume-based intercrops or rotations with cereals is assessed by considering both the level of returns and the probability of obtaining each of these levels.

## Methodology

### Data Collection

The data used in the simulation modelling reflect the situation of cereal-legume intercropping and rotations in smallholder agriculture in semi-arid Zimbabwe. The data are drawn from on farm trials that were in Tsholotsho, Gwanda and Zimuto in the 2002/2003 and 2003/2004 farming seasons. Sampling of farmers to host the trials was done randomly. The trials involved the following treatments, which are the most popular production systems in the study areas:

Maize-groundnuts intercrop
Maize-cowpea intercrop
Sorghum-groundnut rotations
Sorghum-cowpea rotations

Of the three districts, Gwanda is the driest (receiving annual rainfall of around 200mm) followed by Tsholotsho (250 mm per year) and Zimuto is relatively wet (500 mm per year). Soils in Tsholotsho are heavy clays with high levels of fertility while relatively weaker clay loams largely cover Gwanda. Zimuto consists mainly of granite derived sands and sandy loams.

Forty-five replications were established in Tsholotsho, another forty-five were established in Gwanda while Zimuto had sixty replications. This gave a total of 150 replicates from which 110 provided results used in this paper. The trials were mainly researcher designed but farmer managed. Costs, returns and gross margins were calculated per season per hectare by averaging values for the two seasons (2002/2003 and 2003/2004).

### Data Analysis Tools

### Stochastic Budgeting

An economic analysis can be carried out to assess the relative performances of legume technologies using stochastic budgeting. Stochastic budgets are like ordinary budgets, except that uncertainty in some variables is recognised and taken into account (Hardaker et al, 1997). Stochastic features are introduced into the budget by specifying probability distributions for selected variables, usually those judged to be most important in affecting riskiness of the selected measure of performance. A Monte Carlo sampling procedure is used to evaluate the budget for a sufficiently large number of scenarios. Output can be in the form of a cumulative probability distribution of the selected performance measure (gross margin in this study) or as moments of the distribution, such as mean, variance or standard deviation (Schlaifer, 1969).

Stochastic budgeting presented in this paper was carried out using a computer software called @Risk. This software is an add-on to spreadsheet packages such as Lotus 123 and Microsoft excel. @Risk uses probability distributions to describe uncertain values (such as prices and yields) in the budget. Some of the distributions from which one can choose are the: triangular, rectangular, normal, beta and gamma distributions. The most used distributions are however the normal and triangular distributions owing to the simplicity of their underlying assumptions.

**Stochastic dominance analysis**

Cumulative probability distributions of the performance measure resulting from stochastic budgeting can be compared using principles of first-degree stochastic dominance to find out the legume technology that dominates others. With first degree stochastic dominance, if given two actions A and B, each with a probability distribution of outcomes, x, defined by cumulative distribution functions $F_A(x)$ and $F_B(x)$, respectively, action A dominates action B in the first degree sense if: $F_A(x) \leq F_B(x)$, for all x, with at least one strong inequality (Moss et al, 1991; Hardaker et al, 1997).

Graphically this means that the cumulative probability distribution of A must lie below and to the right of that of B. If the cumulative probability distributions for A and B cross, then first degree stochastic dominance analysis becomes inconclusive, that is, neither activity (technology) dominates and it becomes necessary to move to second degree stochastic dominance analysis (King and Robinson, 1984). In this paper, however, the analysis is only limited to first degree stochastic dominance analysis due to the practical complexities of applying second degree stochastic dominance analysis.

**Table 1:** Assumptions for stochastic parameters used in the budgets

| Parameter | Unit | Probability distribution | | | |
|---|---|---|---|---|---|
| | | Type | Min | Mode | Max |
| **Yield:** | | | | | |
| Maize | Ton/ha | Triangular | 0.30 | 0.90 | 2.90 |
| Sorghum | Ton/ha | Triangular | 0.35 | 0.84 | 1.13 |
| Groundnut | Ton/ha | Triangular | 0.22 | 0.97 | 1.57 |
| Cowpeas | Ton/ha | Triangular | 0.28 | 0.59 | 0.94 |
| ***Output prices:** | | | | | |
| Maize | $/Ton | Triangular | 5300 | 6800 | 8000 |
| Sorghum | $/ton | Triangular | 3400 | 5500 | 6900 |
| Groundnut | $/ton | Triangular | 11200 | 16500 | 18000 |
| Cowpea | $/ton | Triangular | 9000 | 15000 | 18000 |

* The prices are CPI deflated using 2000 as base year.

The triangular distribution was used in the stochastic budgets due to its simplistic nature. It is described by the minimum, a measure of central tendency (either mean or mode), and the maximum. These figures can easily be obtained from any data set. Variations in prices for inputs and outputs were as a result of the market where the farmer bought the inputs or sold the output. It was also as a result of the absence of market integration resulting in different markets being able to maintain different prices. For output, local shops bought at very low, almost exploitative prices. The Grain Marketing Board (GMB) offered a higher price while those farmers who sold to large agro-processing companies got the highest prices. Inputs bought from local shops were the most expensive followed by those from urban shops while the cheapest inputs were obtained from the GMB or NGO agro dealers through the input voucher scheme of the Agricultural Recovery Program.

**Results and Discussion**

Figures 1 to 3 show the cumulative probability distributions for the gross margins of the four legume-based technologies for the three districts in which the on-farm trials were carried out. Applying the criteria of first-degree stochastic dominance to Figure1 shows that in Tsholotsho, the legume technology that dominates is maize-cowpea intercrop. The cumulative probability distribution for the returns under this technology lies below and to the right of the cumulative probability distributions of the returns under all the other technologies. The high levels of inherent soil fertility in Tsholotsho district coupled with the high local prices of maize grain in the district may be labelled as the main reasons behind the dominance of the maize-cowpea intercrop. The technology immediately following the maize-cowpea intercrop is the sorghum-cowpea rotation then the sorghum groundnut rotation and lastly maize-groundnut intercrop. Maize-groundnut intercrops do not do well due mainly to dry climatic conditions in Tsholotsho resulting in high chances of getting a complete crop failure (zero yield) and hence a negative gross margin (about 25 % chance as compared to 0 % chances for sorghum-cowpea rotations).

Figure 2 shows the cumulative probability distributions of the returns for Gwanda. Sorghum cowpeas rotation dominates all the other legume-based technologies by a great margin. There is a zero per cent chance of getting a negative gross margin with sorghum-cowpea rotation. This could be attributed to the fact that sorghum and cowpeas are both very highly drought resistant crops that can do well in dry areas than maize and groundnuts. The results tally well with the findings of a mean-variance study by Foti (2005), which rated sorghum and groundnuts very high in Zimbabwe's arid areas. Sorghum-groundnut rotation also does well but this was mainly because of the good yields from sorghum. Maize-groundnut intercrop almost always fails. This is mainly because both maize and groundnuts are not drought resistant. The chances of getting a zero yield under dry conditions are therefore very high resulting in high chances of getting negative returns (around 70 %).

For Zimuto, Figure 3, which is relatively wetter than the other two districts, maize-based legume technologies perform better than sorghum-based technologies. Maize-groundnut intercrop performs far better than all the other technologies. There are higher probabilities to get high returns with maize-groundnut intercrop than with any other technology. These results agree with the findings by Mtambanengwe et al (2003). The least performing production technology in Zimuto district was sorghum-cowpea rotation. Although the chances of getting negative returns for the sorghum-cowpea rotation are zero, it is dominated by other technologies because its chances of yielding very high returns are limited and this explains its rather steep cumulative probability distribution function showing restricted yield potential but stable returns under poor agronomic and climatic conditions.

First-degree stochastic dominance analysis is not conclusive regarding maize-cowpea intercrop and sorghum-groundnut rotation. This is because the returns (gross margins) for the maize-cowpea intercrop can go much lower than the returns with sorghum-groundnut rotation but the maize-cowpea intercrop returns can also go much higher on some farms, thus maize-cowpea intercrops have a tendency to either fail completely or perform quite well while returns from sorghum-groundnut rotation tend to be stable on average. This results in the cumulative probability distributions for the two production technologies (maize-cowpea and sorghum-groundnut) intersecting thus rendering first-degree stochastic dominance analysis inadequate. According to Hardaker et al (1997), this would call for the use of more discriminatory methodologies such as second degree stochastic dominance. In this study, however, the practical complexities associated with the rigorous mathematical computations restricted the analysis to first degree stochastic dominance and then inspection, though not reliable can be used to deduce the technology that dominates by estimating the areas under each of the curves that intersect.

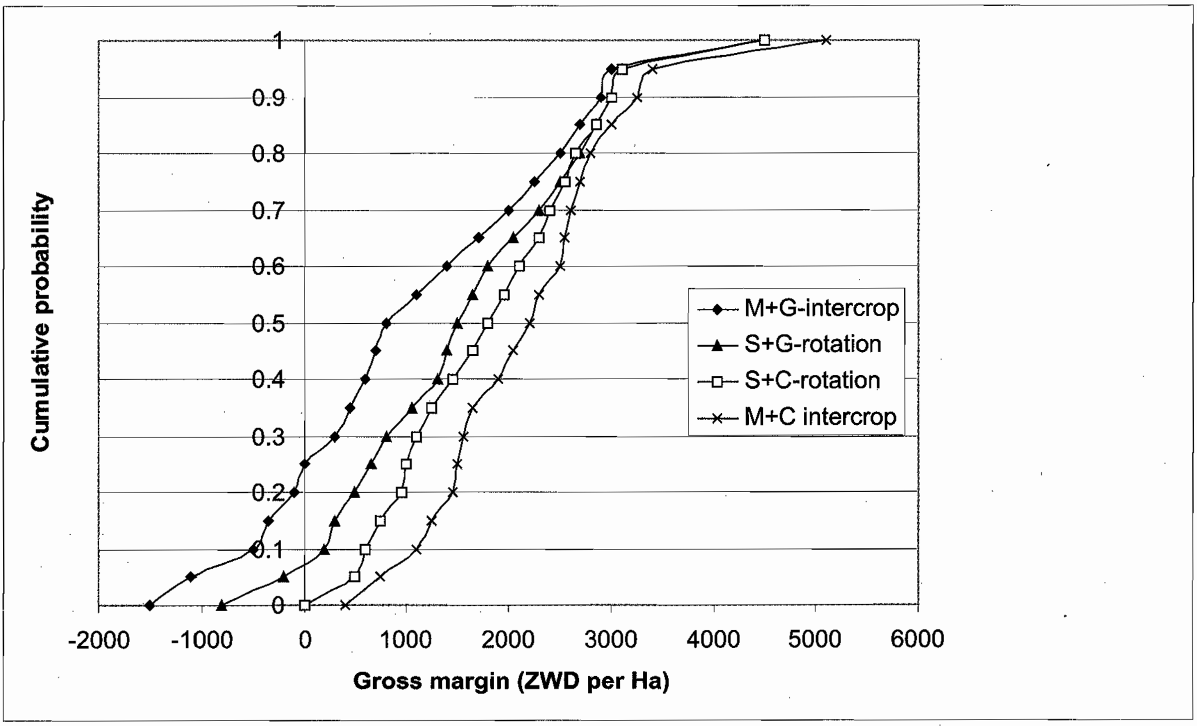


**Figure 1:** Cumulative probability distributions for the four cereal-legume technologies for Tsholotsho district

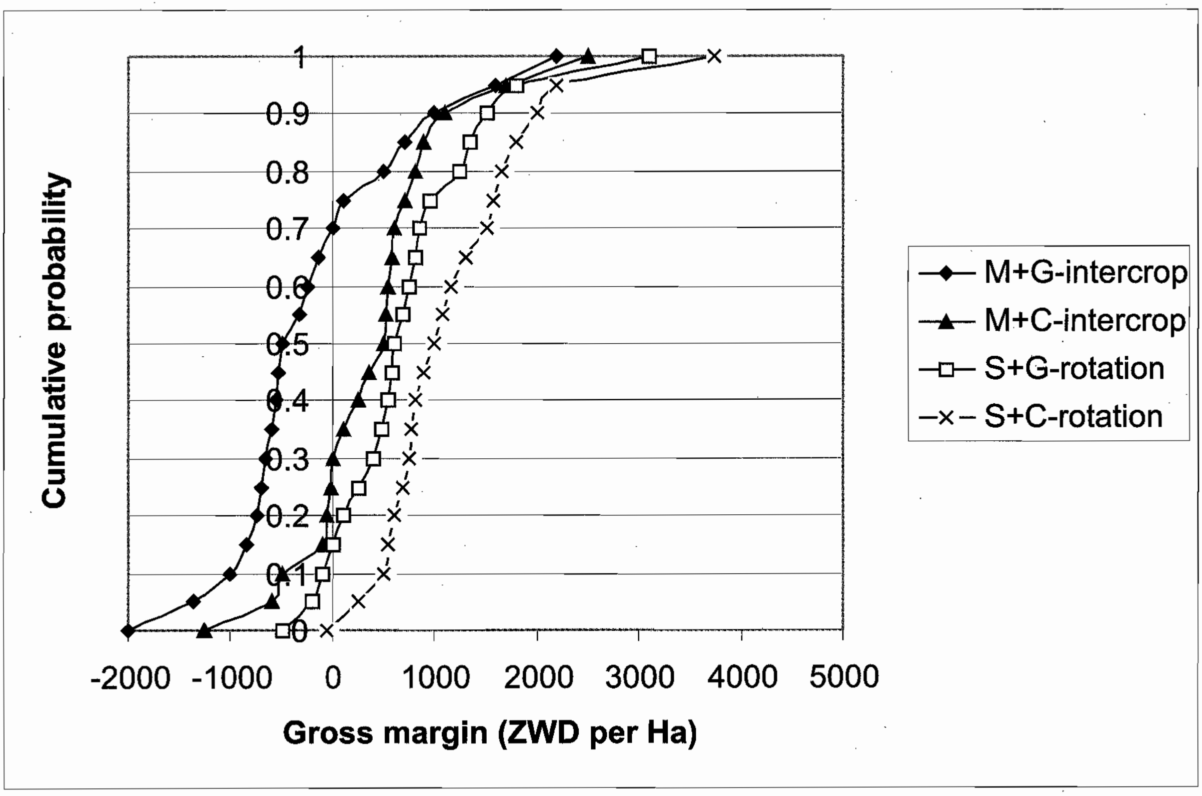


**Figure 2:** Cumulative probability distributions for the four cereal-legume technologies for Gwanda district

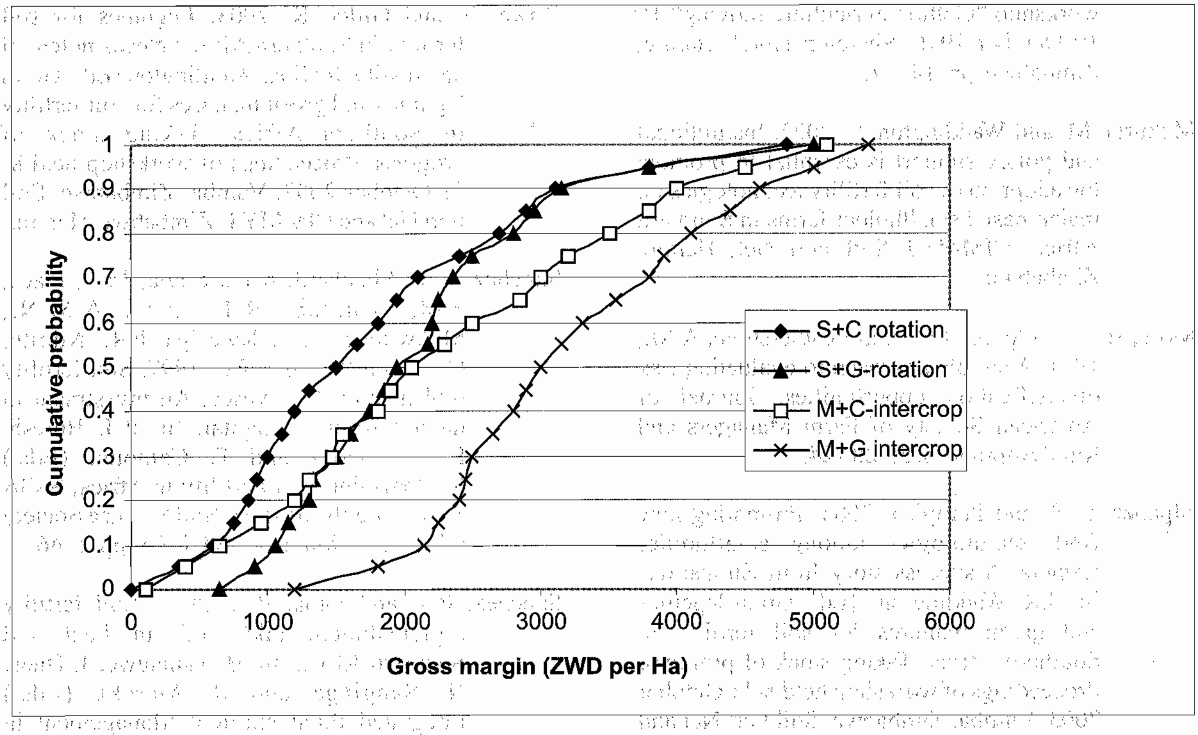


**Figure 3**: Cumulative probability distributions for the four cereal-legume technologies for Zimuto district.

## Conclusion

The study has used stochastic dominance analysis to assess four cereal legume-based cropping systems that are mainly practised in semi-arid areas of Zimbabwe. Rotations and intercrops that contain either maize or groundnuts or both were found to be more efficient in the wetter district (Zimuto) than those that contain sorghum and cowpea. The maize and groundnut production systems were however found to be less risk efficient than sorghum and cowpea based systems under unfavourable farming conditions. Sorghum based cropping systems on the other hand performed better in higher risk low rainfall areas with low inherent soil fertility and are therefore suitable for the risk averse farmers living in such areas (Gwanda and Tsholotsho).

The analytical tool used in this paper (first degree stochastic dominance), however, is not always a satisfactory way of assessing technologies for it sometimes offers inconclusive results, especially for technologies with similar performance patterns.

This study was carried out for only four technology options. It does not expose farmers to other potentially lucrative cereal-legume technologies such as rotations and intercrops with pigeon pea and other tree legumes. It also shuts out the possibility of other non-legume soil fertility enhancing technologies such as manuring and the use of synthetic fertilisers. The paper however provides the basis and a direction for carrying out more rigorous and widely encompassing studies.

## References


Fackler, P.L. 1991. Modelling interdependencies: an approach to simulation and elicitation. American Journal of Agricultural Economics 73:1091 1098.

Foti, R. 2005. Risk diversification opportunities through legumes in smallholder farming systems in the semi-arid areas of Zimbabwe. Journal of Sustainable Development in Africa (JSDA) 7(2):128.

Hardaker, J.B., Huirne, R.B.M. and Anderson, J.R. 1997. (Eds.). Coping With Risk In Agriculture. CAB International, Wallingford, UK. pp. 141 - 143.

King, R.P. and Robison, L.J. 1984. Risk efficiency models. In: P.J. Barry (Ed.) Risk Management in Agriculture. Iowa State University Press, Ames: pp. 68 - 81.

Meerman, J. 1996. An analysis of semi-arid farming systems in Zimbabwe. Paper presented at a workshop "Getting agriculture moving" 15 19 October 1996. Sheraton Hotel, Harare, Zimbabwe: pp. 14 -17.

Mekuria, M. and Waddington, S. 2002. Institutional and policy support is essential to promote the adoption of soil fertility technologies on maize-based smallholder farms in Southern Africa. CIMMYT Soil Fert Net, Harare, Zimbabwe.

Moss, B.C., Weldon, N.R., and Featherstone, A.M., 1991. A simple approach to evaluating risk diversification opportunities. Journal of American Society of Farm Managers and Rural Appraisers. 55:20 - 24.

Mpepereki, S. and Pompi, I. 2003. Promoting new BNF technologies among smallholder farmers: A success story from Zimbabwe. In: S.R. Waddington (Ed.) Grain legemes and green manures for soil fertility in Southern Africa: Taking stock of progress. Proceedings of workshop held 8-11 October 2003, Vumba, Zimbabwe. Soil Fert Net and CIMMYT Zimbabwe, Harare.

Mtambanengwe, F. and Mapfumo, P. 2003. Integrating organic resource quality and farmer management practices to sustain soil productivity in Zimbabwe. In: S.R. Waddington (Ed.). Grain legemes and green manures for soil fertility in Southern Africa: Taking stock of progress. Proceedings of workshop held 8-11 October 2003, Vumba, Zimbabwe. Soil Fert Net and CIMMYT Zimbabwe, Harare.

Rowe, E. and Giller, K. 2003. Legumes for soil fertility in Southern Africa: Needs potential and reality. In: S.R. Waddington (Ed.) Grain legumes and green manures for soil fertility in Southern Africa: Taking stock of progress. Proceedings of workshop held 8-11 October 2003, Vumba, Zimbabwe. Soil Fert Net and CIMMYT Zimbabwe, Harare.

Sanchez, P.A., Shepherd, K.D., Soule, M.J., Place, F.M,, Buresh, R.J., Izac, A.M.N., Mokwunye, A.U., Kwesiga, F.R., Ndiritu, C.G., and Woomer, P.L. 1997. Soil fertility replenishment in Africa: An investment in natural resource capital. In: R.J. Buresh, P.A. Sanchez and F. Calhoun. (Eds.) Replenishing Soil Fertility in Africa, SSSA Special Publication 51. Soil Science Society of America, Madison, WI, USA. pp. 1- 46.

Sanchez, P.A. and Jama, B.A. 2002. Soil fertility replenishment takes off in East and Southern Africa. In: B. Vanlauwe, J. Diels, N. Sanginga and R. Merckx (Eds.) Integrated Plant Nutrient Management in Sub-Saharan Africa: From Concept to Practice. CAB International, Wallingford, UK. pp. 23 - 45.