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Grain Legumes and Green Manures for Soil Fertility in Southern Africa: Taking Stock of Progress

Edited by:
Stephen R. Waddington

Grain Legumes and Green Manures for Soil Fertility in Southern Africa: Taking Stock of Progress

Proceedings of a Conference held 8-11 October 2002
at the Leopard Rock Hotel, Vumba, Zimbabwe

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Improving the Productivity of Grain Legumes and Green Manures

Promotion, Economics and Adoption of Annual Legumes

INTRODUCTION AND CONFERENCE OBJECTIVES

STEPHEN R WADDINGTON and MULUGETTA MEKURIA

One of the main thrusts of Soil Fert Net and its members since the mid 1990s has been to develop and test under farmer conditions a wide range of annual legume options that smallholder farmers will find useful for soil fertility, and for food or sale. Research has also been undertaken on the mechanisms and processes by which these legumes provide their benefits and the magnitude of benefits that can be realized under ideal conditions and on farm. More recently, initiatives have been undertaken to promote these technologies with farmers, get farmer feedback about which they prefer and encourage farmers to experiment with the legumes. Most recently, a range of studies on the economics and policy implications of these systems have been undertaken.

In recent years then, tremendous progress has been made in identifying suitable best bets, in quantifying their performance on farm, in assessing their economic potential and their suitability with farmers, and in helping farmers to access the technologies. Yet, outputs from these many efforts have been widely scattered in annual research reports, in papers and articles that are often difficult to access, and in some cases are still on computer hard disks or have yet to be written up.

This conference on the soil fertility benefits from green manures and grain legumes brought together 56 participants from Malawi, Zambia, Zimbabwe and Mozambique, along with some further key presenters from Ethiopia, Kenya and the Netherlands.

The conference objectives were to:

- Provide an opportunity for Soil Fert Members and other interested persons to present their research on grain legumes and green manures for soil fertility management, and to learn from others
- Document and synthesize the state of the art on this important topic in the region
- Showcase the benefits that these technologies are having with clients, especially smallholder farmers
- Identify socio economic, institutional, and policy constraints affecting the promotion and use of legumes and green manures
- Develop strategies to fill research gaps and maximize the benefits from these technologies.

The conference was divided into several thematic sessions where a mixture of invited and offered oral and poster papers were presented and discussed. Several key papers were given on strategic topics by persons from the region, from East Africa and beyond. The conference emphasized work conducted in Malawi, Zimbabwe, Zambia and Mozambique.

Session themes included:

- Introductory Session of Key Themes
- Rhizobium, N fixation and Microbiology
- Screening of Annual Legumes for Adaptation and Use
- Identification of Best Bet Legumes for On-farm Performance as Grain Legumes, Intercrops, Rotations, Green Manures
- Legume Benefits on Maize Productivity and Soil Properties
- Improving the Productivity of Grain Legumes and Green Manures
- Targeting, Integration and Promotion of Legumes
- Adoption, Economics and Impacts of Annual Legumes with Farmers.

Towards the end of the conference, synthesizers reported key findings. Working Groups met to summarize progress and gaps, and examine the way forward. A summary of findings from the Working Groups is given at the end of these proceedings.

The meeting was a great success, with enthusiastic participation throughout. The important papers presented that document the state of the art with green manure and grain legume research and development for soil fertility improvement in southern Africa are given in these proceedings.

ENHANCING THE CONTRIBUTION OF LEGUMES AND BIOLOGICAL NITROGEN FIXATION IN CROPPING SYSTEMS: EXPERIENCES FROM WEST AFRICA

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Abstract

The lack of adoption of improved soil fertility management options to counteract soil fertility decline has led to major changes in the research and development paradigm, leading to the currently widely adapted concept of Integrated Soil Fertility Management. Legumes in general and biological N fixation specifically have a potentially important role to play in ISFM strategies. Four examples are summarized of attempts to enhance the soil fertility status using legumes in various agro-ecozones of the West African savanna. These case studies cover the technical aspects of the various legume-based systems but also focus equally on the evaluation, adaptation, and adoption processes.

Alley cropping with leguminous hedgerows is a first example. The technology was proven to be technically sound and generated a lot of process work in agroforestry systems. Especially important to note is that the impact assessment phase was not in synchrony with the technology development phase, which excluded any useful feedback and delayed the identification of the appropriate niches for this system. These were unfortunately found to be geographically limited. The Mucuna *cover cropping system is a second example. As with alley cropping systems, the inclusion of* Mucuna *in a cropping system was observed to significantly enhance crop yield. Contrary to alley cropping, however, impact assessment was implemented during the testing and evaluation phase and useful feedback loops led to clearer insights about the specific role* Mucuna *could play in farmers' fields. This role was more associated with its ability to suppress* Imperata cylindrica *weeds than with improving the soil fertility status, thereby also limiting its niche for adoption. As a third example and a reaction to the lack of widespread adoption of the former two technologies, dual purpose grain legumes – cereal rotations are evaluated. Such systems, using improved legume germplasm that provides net N benefits to the cropping system besides grains, significantly enhance cereal yield and supply the farmer with immediate products that can be consumed or sold. This technology shows a lot of promise and is currently spreading in the Northern Guinea savanna zone of Nigeria, but required the creation of local processing skills and/or markets for the grains and intensive interaction between breeders, soil fertility specialists, and farmers. A last example deals with the role of cowpea in rotations in the dry savannas. As with soybean, improved germplasm of cowpea can also be used to enhance the soil fertility status while yielding immediate benefits to farmers.*

In conclusion, several aspects are highlighted that need to be considered when aiming at enhancing the contribution of legumes and biological N fixation to cropping systems. These include the need for immediate benefits and the role of multipurpose germplasm in providing these, the need to identify niches and the role of markets, and the need for multidisciplinarity and full participation of all stakeholders. Finally, some potential routes for future research are indicated.

Key words: Grain legume, green manure legume, forage legume, dual or multi-purpose legume, biological N fixation, cropping system, impacts, west Africa

Introduction

The soil fertility status of the soils in sub-Saharan Africa (SSA) is generally believed to be poor due to poor inherent soil quality and inappropriate soil management practices. Such statements are usually backed-up by a demonstration of highly negative nutrient balances for the major plant nutrients and the existence of wide gaps between yields obtained under well-managed compared to on-farm conditions for the major crops. These facts are generally also applicable to the West African savanna agroecozone. Although soil fertility replenishment has been on the research and development agenda for several decades in SSA as this is believed to have substantial impacts on the livelihoods of the rural population, relatively little has been achieved. The reasons for this are plenty and beyond the scope of this paper but importantly, the paradigms underlying the soil fertility research and development agenda have continuously changed to attempt to deal with the issue of non-adoption of improved

Table 1. Paradigm shifts underlying the tropical soil fertility research and development agenda and accompanying changes in the framework for interactions between the various stakeholders.

Period	Soil Fertility research and development paradigms	Interactions between the various stakeholders
70's	*Nutrient replenishment* paradigm: 'Overcome soil constraints to fit plant requirements through inputs' (Sanchez, 1994); Green Revolution paradigm	*Top-down*, little understanding of the various stakeholders in the development process
Mid-80's	Focus on *biological management* of soil fertility; development of the term 'low input sustainable agriculture' (LISA)	*Technology transfer*; technologies move from research to the extension services to the farmer with little feedback
Mid-90's	*Second paradigm* (Sanchez, 1994): 'Overcome soil constraints by relying on biological processes by adapting germplasm to adverse soil conditions, enhancing soil biological activity, and optimizing nutrient cycling to minimize external inputs and maximize their use efficiency'; still little or no mention of human and social factors	*Participatory approaches*; feedback is sought mainly from the farmer community regarding improved soil management options
Today	*Integrated Soil Fertility Management*: 'Develop adoptable and sustainable soil management practices that integrate the biological, chemical, physical, social, cultural and economic processes that regulate soil fertility'; full recognition of the equal role of biophysical and social sciences in developing and disseminating improved soil management interventions	*Integrated Natural Resource Management*; recognition that all stakeholders need to dialogue with each other at all stages in the research-to-development continuum

soil management interventions (Table 1). The changes in paradigm with time also lead to the establishment of platforms for increasingly more intensive interactions between all stakeholders involved in improving the status of the soil resource (Table 1).

Currently, the Integrated Soil Fertility Management (ISFM) paradigm is widely adhered to. Maybe except for the Nutrient Replenishment paradigm, organic resources and consequently legumes, have played a major role in improved soil management strategies. This is obviously related to their capacity for biological N fixation (BNF) and other positive rotational effects. In the Integrated Soil Fertility Management paradigm, which advocates the most efficient use of all sources of nutrients (organic, mineral, soil organic matter-related) and the potential interactions between each of these for the provision of goods and services, legumes can be hypothesized to contribute to crop growth and soil fertility improvement in many ways (Figure 1).

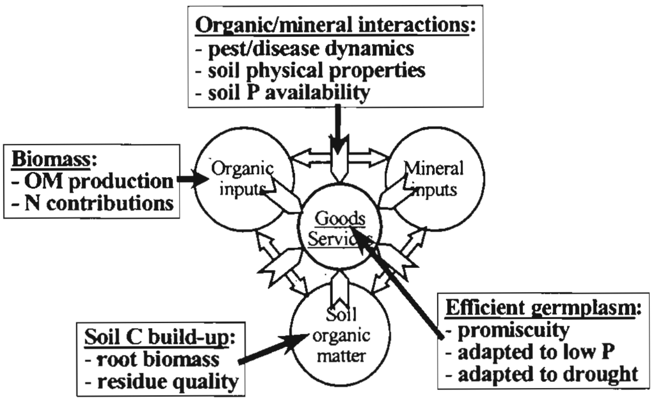

Figure 1. Legumes can potentially contribute to the generation of a wide set of properties and functions required in an Integrated Soil Fertility Management framework.

This paper aims at (i) illustrating relevant experiences with enhancing the contribution of legumes and BNF to cropping systems in the West-African savanna, (ii) evaluating the efficiency of the research and development process in relation to the paradigm underlying this process, and (iii) highlighting the current line of thought about improved soil management through the integration of legumes. The paper does not intend to cover all progress made with legumes in West Africa, but to foster the often lacking exchange of relevant experiences and information with other regions in SSA, that are more often than not facing similar soil-based constraints to improved crop production.

The West African Savanna Agroecozone: A Biophysically and Socio-economically Diverse Environment

Broadly, rainfall decreases from South to North and the rainfall pattern changes from clearly bimodal to unimodal (Table 2). Agro-ecozones within the region are usually defined in terms of length of growing period (Japtap et al., 1995) as highlands are virtually absent. Livestock densities also increase from South to North due to diminishing disease pressure (Mohamed-Saleem and Fitzhugh, 1995).

Human population density varies widely and is less directly linked to latitude, as in each agroecozone centres can be identified with large population densities (e.g., Southern Benin in the derived savanna, Zaria/Kaduna in the Northern Guinea savanna, etc). This is obviously related to pressure on land and land use intensification. Smith and Weber (1994) postulated that the determinants of intensification are either population density or access to markets. Within each path of the evolutionary proc-

Table 2. Agro-ecozones, rainfall distribution, presence of livestock, potential legume-based technologies and potential problems encountered with the latter for the West African savanna zone. Source agroecozone definition: Jagtap et al., 1995.

Agro-ecozone (Length of growing period)	Rainfall distribution	Presence of livestock	Potential legume-based technologies	Potential problems encountered with legume technologies
Derived Savanna (211-270 days)	Bi-modal	Small ruminants	Grain legume – cereal rotations within one year; herbaceous cover crops during the second short season; alley farming with tree legumes	Lack of land in densely populated areas;
Southern Guinea Savanna (181-210 days)	Bi- to uni-modal	Few cattle, small ruminants	Grain legume – cereal rotations within the same year; herbaceous cover crops; alley farming with tree legumes	Lack of land in densely populated areas;
Northern Guinea Savanna (151-180 days)	Uni-modal	Cattle, small ruminants	Grain legume – cereal rotations or intercrops; herbaceous cover crops; fodder banks; parkland trees	Lack of land in densely populated areas; disappearance of legume biomass during the dry season; free-grazing livestock
Sudano-Guinean (101-150 days)	Uni-modal	Cattle, small ruminants	Early grain legume – cereal rotations or intercrops; parkland trees	Short cropping season excludes long duration legumes; disappearance of legume biomass during the dry season; free-grazing livestock
Sudano-Sahelian (61-100 days)	Uni-modal	Cattle, small ruminants	Extra early grain legume – cereal rotations or intercrops; parkland trees	Very short cropping season limits choice of legumes; disappearance of legume biomass during the dry season; free-grazing livestock

ess, Manyong, et al. (1996) made a distinction between an expansion and an intensification phase. In population-driven expanding farming systems, increased human population results in the opening of new land. Fallow periods are still long enough to maintain soil fertility. As new land becomes scarcer, land use intensifies with little increase in purchased inputs, leading to a progressive decline in productivity of labour and land and eventually the abandonment of farming. Market-driven systems are generated through exogenous factors such as the introduction of cash crops. In the expansion phase, purchase of inputs is still moderate, while in the intensification phase, credit is usually available to increase the level of purchased inputs and hired labour. Market driven systems require a good transport system that provides access to markets. In the subhumid zones, 66% of the agricultural systems are in the population-driven phase, while 34% in the market-driven phase (Manyong et al., 1996). Each of the above pathways has implications for options available to the farmer to manage soil fertility in general, for the best-bet legumes to be integrated in existing cropping systems, and for problems related to specific legume technologies (Table 2).

In what follows, specific legume-based technologies will be evaluated in terms of their agronomic benefits, niche identification, impact assessment, and the efficiency of the research and development process that brought those technologies to the farmer.

Alley Cropping: From a Panacea to a Technology with a Very Specific Niche

The first papers on alley cropping (sometimes called alley farming or hedgerow intercropping) were published in the early eighties by Kang (e.g., Kang, 1985). They showed that short term yields of maize were substantially enhanced when applying the prunings of the hedgerows to the maize, once the trees were ready for pruning, usually varying from 1 to 2 yrs after planting. Legume trees were primarily targeted as hedgerow species, mainly because of their BNF capacity but also because of their relatively rapid growth and potential source of fodder.

The great potential demonstrated by the initial published results led to a substantial amount of effort to understand and fine-tune the technology and its management. Sanginga et al. (2001) reports that certain hedgerow trees could fix between 100 and 300 kg N ha^{-1} yr^{-1} while other species fixed less than 20 kg N ha^{-1} yr^{-1}. Substantial differences between provenances from the same species were also observed. Because the recovery of applied pruning-N was often observed to be very low and hardly exceeding 20% (Vanlauwe et al., 1998a), efforts were made to quantify the fate of N not taken up by a maize crop using isotopes (Vanlauwe et al., 1998a, 1998b). Initial observations using litterbags to assess pruning-N release and the N difference method to calculate pruning-N recovery, showed poor synchrony between N availability and demand by the crop. Studies with isotopes, however, could also quantify the fate of applied pruning-N as it moved through other pools of the alley cropping system and consequently the system was observed to be tighter in terms of N cycling as compared to earlier estimates (Figure 2). Most of the initial testing of the resource quality – decomposition hypotheses formulated by Swift et al. (1979), was also implemented using hedgerow species (e.g., Tian et al., 1993).

Stimulated by these promising results, the Alley Farming Network for Tropical Africa (AFNETA)

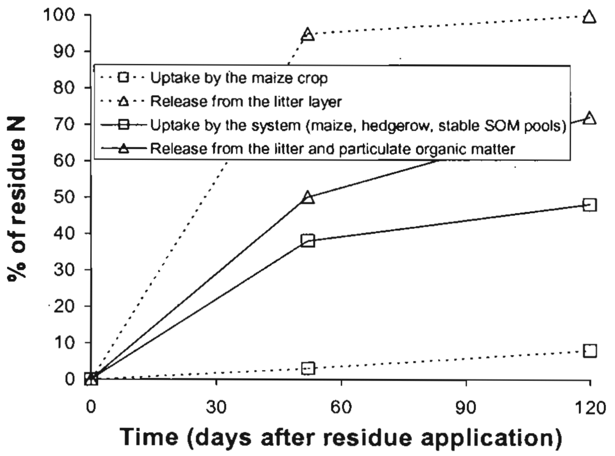

Figure 2. N released from ^{15}N labelled *Leucaena leucocephala* residues and recovered by the various components of an alley cropping system during a 120-day maize cropping season in Southwestern Nigeria. Synchrony is looked at using the 'traditional' maize and litter decomposition data and following a complete system focus. The particulate organic matter is assumed to be on the supply side of synchrony due to their high turnover (within one maize season) while the other soil organic matter fractions are assumed to be on the demand side. Source: Vanlauwe et al., 1998a.

was initiated in 1989 and various alley cropping trials were established in countries in SSA to test the performance of alley cropping systems under a wide range of biophysical environments. Most of the initial work was carried out on-station at IITA, Ibadan, Nigeria. Woomer et al. (1995) summarized the data obtained within the AFNETA framework and concluded that the system works well with maize but not with cassava, cowpea or cotton. He also observed that the ratio intercrop:monocrop yield was positively correlated with the soil extractable P level and negatively with the total N content, indicating that the system works best on N deficient soils with a relatively high P status. Aihou et al. (1999) and Tossah et al. (1999) observed that soils with a relatively fertile subsoil led to greater biomass production and N accumulation than other soils. Meanwhile, trials initiated during the earlier years of alley cropping research showed that in the long term, alley cropping systems were sustainable and yields were less variable in the presence of minimal amounts of fertilizer N, provided the trees were regularly replanted. Vanlauwe et al. (unpublished results), for instance, observed maize grain yields varying between 2500 and 4000 kg ha^{-1} (average of 2890 +/- 470 kg ha^{-1}) in a 15-year old alley cropping trial with *Senna siamea*, supplemented with 60 kg N ha^{-1} compared to sole fertilizer grain yields varying between 600 and 3300 kg ha^{-1} (average of 2080 +/- 910 kg ha^{-1}).

Whittome (1995) attempted to outline the regions in West Africa where alley cropping would potentially thrive, using the following criteria: maize-based systems, with rainfall > 1200 mm yr^{-1}, on non-acid soils and with a human population density of > 30 person km^{-1}. The outcome of this evaluation was a range of limited areas where alley cropping had potential. Most of these sites were restricted to Nigeria, obviously because of the high population density in that country. In 1996, Dvorak (1996) published a first report on the adoption potential for alley cropping. She concluded that the potential for adoption of alley cropping was limited to areas with baseline yields below 2 t ha^{-1}, but where soils are still of good enough quality to respond to application of N, and whose farmers have a flexible demand for labour. Drawbacks when evaluating alley cropping systems on farm were: (i) hedgerow biomass production and/or yield gains were usually far below results reported on-station, (ii) the cost of establishment is high, (iii) there is a time lag to realization of benefits, (iv) and the cropping system is inflexible and 'unforgiving' as the penalties for not managing the hedges properly can be high.

While it is beyond doubt that the alley cropping concept has generated an enormous amount of process work on N cycling and use, organic resource decomposition dynamics, soil organic matter dynamics, and related topics, impact at the farm level is required before a technology can be called successful. In the late nineties, Adesina et al. (1999) went back to the sites in Nigeria, Benin, and Cameroon where attempts to disseminate the technology had been implemented and concluded that despite the earlier skepticism about the adoption potential of alley farming, the actual rates of adoption were encouraging for the complex technology. In Nigeria, of the sample of 223 farmers, 93% had heard of the technology, 64% had adopted and 53% retained the technology. They observed that the technology was being adopted in sites with high pressure on land, soil fertility decline, erosion problems and fuel wood and fodder scarcity. Constraints to adoption were mainly technical and management related and included too many volunteer seeds (45% of the farmers), especially for *Leucaena*, high labour demand (40%), non-adaptability of trees (37%), and lack of knowledge (34%). Also important to note is that the technology underwent major changes by farmers to suit their circumstances and cropping systems (e.g., inclusion of a fallow phase, greater height of pruning, wider tree spacing, etc).

Summarizing the alley cropping story we conclude that (i) alley cropping is a technically sound cropping system under certain conditions related to soil fertility status, annual rainfall, and target crop; (ii) there are a wide range of socio-economic constraints to the adoption of alley cropping, (iii) alley cropping systems are currently utilized but in a modified form for a variety of reasons, and (iv) the development and evaluation of the system following the technology transfer paradigm took about 15 years (Figure 3). Especially important to note is that the impact assessment phase was not in synchrony with the phase during which the technology was evaluated with farmers. This excluded any useful feedback between both.

Mucuna Cover Cropping: Need for Benefits Beyond Soil Fertility Replenishment

When it finally became clear the alley cropping systems have limitations with adoptability, another initiative had started looking at a basket of options to improve soil fertility in the south of the Benin Republic. This basket included alley cropping, pigeon pea intercropping, mineral fertilizer, and second season *Mucuna* cover cropping (Versteeg et al., 1998). The *Mucuna* technology was not new to West Africa, as already in the 1930s, work with *Mucuna* was implemented around Ibadan, Nigeria (Vine, 1953). *Mucuna* was also observed to create large rotational benefits, e.g., increasing maize yields following *Mucuna* by up to 200% on poor soils (yielding less than 0.5 t ha^{-1} and even up to 50% on soils yielding over 1.5 t ha^{-1} maize in the control treatments (Figure 4).

Based on this initial success, screening of various species and accessions was implemented in all mandate agro-ecozones of IITA and usually *Mucuna* appeared as a best bet legume in most zones because of its consistently high proportion of N fixed (e.g., 91%) and total amount of N fixed (e.g., 242 kg N ha^{-1}) (Sanginga et al., 2001).

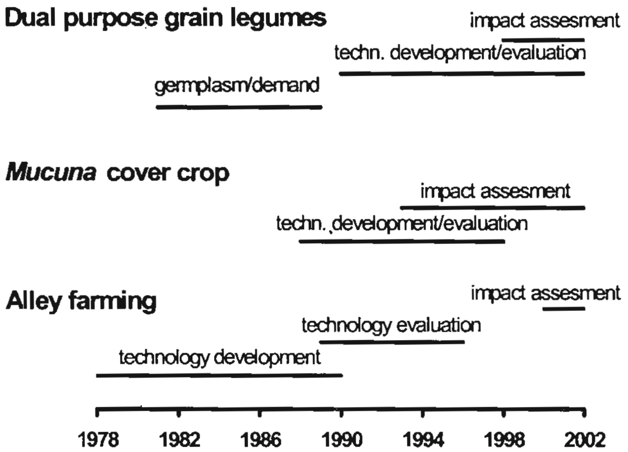

Figure 3. The various research and development strategies followed by the International Institute of Tropical Agriculture while testing various systems aiming at improving the soil fertility status.

During the evaluation of the *Mucuna* technology in southern Benin, farmers observed that the legume was very effective at suppressing one of their most serious weeds, *Imperata cylindrica*. *Imperata* takes hold as the length of fallow increases and soil fertility declines and requires a substantial amount of labour to deal with, often forcing farmers to abandon their fields. This was obviously a serious constraint to crop production in a densely populated area as is southern Benin. Evaluation with farmers also revealed their reluctance to lose a second season food crop because *Mucuna* did not yield a marketable or consumable product (Manyong et al., 1999). Farmers were calculating that the immediate opportunity cost of the lost crop was higher than the future benefits of a *Mucuna* cover crop. Efforts to deal with that constraint focussed around the creation of markets for *Mucuna* seeds, using its residues as fodder for livestock, and enhancing the edibility of *Mucuna* seeds for humans and livestock by removing toxic L-Dopa (Carsky et al., 2001a).

The adoption rate of *Mucuna* in southern Benin tripled to 8% of the farmers (amounting to 14000 farmers) between 1994 and 1996 (Figure 5), largely driven by the intensified effort of programs such as Sasakawa Global 2000 (SG2000) who bought about 15 t of seed in 1995 (Manyong et al., 1999). The decline observed after 1996 is likely related to the reduced effort of SG2000 to buy seeds and a collapse in the market (Doughtwaite, 2002). The major drivers for adoption were need for weeding (39% predicted probability) and cash income (41%) (Manyong et al., 1999), the latter likely largely driven by the market created by SG2000. Other factors were degraded fields (25%), access to extension services (24%), and land tenure security (22%). Although the rate of adoption is promising, many con-

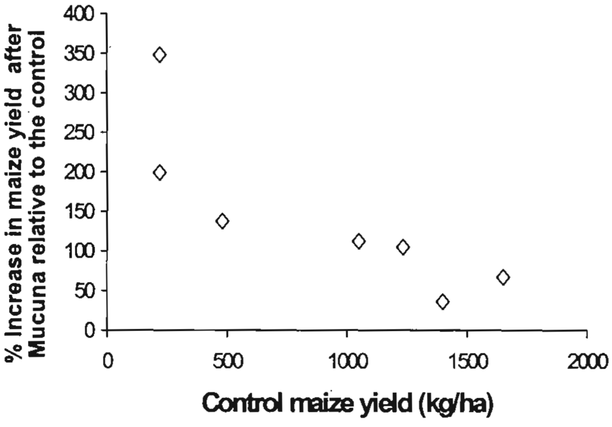

Figure 4. Proportional increase in maize grain yield after a *Mucuna* crop relative to the yields in the continuous maize control plots as related to the yields in the control plots. Data are a summary of various trials in the West African moist savanna zone. Source: Vanlauwe et al., 2001.

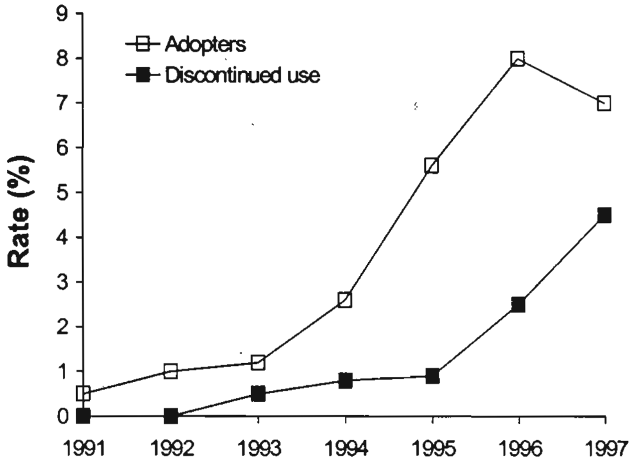

Figure 5. Dynamics of *Mucuna* fallow adoption in southern Benin (1991-1997). Source: Manyong et al, 1999.

straints are likely to halt further adoption. These include, loss of a second season (42% of farmers), insecure land property rights (19%), unavailability of seed (16%), and lack of information (12%) (Manyong et al., 1999).

In conclusion, (i) the *Mucuna* cover cropping system is a technically sound system under most biophysical conditions, (ii) as with alley cropping systems, its specific niches are determined by socio-economic considerations rather than biophysical ones (e.g., not too much pressure on land, high demand for labour due to the presence of *Imperata cylindrica* weeds), (iii) in terms of adoption, the *Mucuna* technology is known by nearly all farmers as a tool to suppress *Imperata*, but its use for soil fertility purposes is low, and (iv) it took about 10 years to conclude the above, as the *Mucuna* technology was one of the first technologies to be evaluated using farmer-participatory approaches (Figure 3). The identification of an alternative niche for this technology (weed suppression) was the result of the participatory approach followed and a complete focus on farmers' needs (Houndékon and Gogan, 1996). Impact assessment was implemented during the testing and evaluation phase and useful feedback loops led to clearer insights about the potential of *Mucuna* in the target agroecozones.

Dual Purpose Grain Legume – Cereal Rotations: Multipurpose Options for Redressing Soil Fertility Decline

While alley cropping and *Mucuna* systems were found to have specific and geographically limited niches, grain legumes such as cowpea form traditionally part of the cropping systems in most of the West African agroecozones. Also soybean (*Glycine max*) had become a major grain legume in certain areas in Nigeria mainly due to the development of local processing techniques and the creation of markets (Osho and Dashiell, 1998). Soybean production in Nigeria has been estimated at 405,000 t in 1999 compared with less than 60,000 t in 1984 (www.fao.org) and this value is expected to increase further during coming years. Sanginga et al. (1999) observed that the adoption rates of soybean varieties developed at IITA were over 70% for male and over 60% for female farmers in Benue State, Nigeria, in a period of 10 years. In that same area, soybean was for 45% of the farmers the most important source of income, leaving the second crop, rice, far behind (20%). Although improved varieties of these grain legumes have a great potential to be adopted by the farmers, the earlier-developed germplasm contributed little to improving the soil fertility status. These legumes were bred for promiscuity – or the ability to establish symbiosis with the native *Bradyrhizobia* – but their N harvest index was usually larger than the proportion of N fixed from the atmosphere, leading to net negative contributions to the soil N balance. Through interactions between the soybean breeders and soil management staff at IITA, breeders were open to develop germplasm that produced a lot of leafy biomass without giving up on high grain yields (Sanginga et al., 2001). Such varieties usually fixed more N than was exported with the grains and left a significant amount of N in the soil to be potentially taken up by a following cereal. Such a variety is, e.g., TGX-1448-2E that produced between 470 and 2080 kg of grain ha^{-1} (average of 1290 +/- 500 kg ha^{-1}), between 1000 and 5340 kg biomass ha^{-1} at peak biomass (average of 2510 +/- 1050 kg ha^{-1}), and fixed between 78 and 92% of its N (average of 84 +/- 4%) (Iwuafor et al., unpublished data) when grown on 27 farmers' fields in Northern Nigeria. Not surprisingly, maize growing after these improved soybean varieties had significantly higher grain yield (1.2 – 2.3-fold increase) compared to a maize control (Sanginga et al., 2003). In farmer-managed demonstration trials in northern Nigeria, initiated in collaboration with the non-governmental organization Sasakawa Global 2000 (SG2000), this variety yielded around 3000 kg ha^{-1} of grain (Iwuafor et al., unpublished data). These trials also successfully demonstrated that a maize crop grown after soybean can produce a good yield with a reduced quantity of N fertilizer compared to maize grown after maize. Maize following soybean and receiving 85 kg N ha^{-1} as urea yielded slightly more than maize after maize receiving 135 kg N ha^{-1} as urea. While rotational benefits may not be as high as those observed after, for example, *Mucuna*, dual purpose soybeans are to be seen as a component of an ISFM technology (Table 1) that also involved the application of sufficient fertilizer

N. Applying a limited amount of fertilizer N after a dual purpose soybean potentially leads to a more efficient use of the fertilizer N compared to a maize-maize system. This is because the soybean phase may alleviate various constraints to maize production, thus increasing the demand for N by a following maize crop (Vanlauwe et al., 2001). This phenomenon is usually referred to as positive interaction between organic resources and mineral inputs.

The multi-purpose nature of the above varieties are not only related to their capacity to produce a large amount of grain and contribute to the N balance of cropping systems but also to their ability to suppress the parasitic weed *Striga hermonthica* that affects cereal production in Africa, at an estimated value of $480 million per year for six West African countries (Sauerborn, 1991). Soybean can bring *Striga* seeds to suicidal germination and thus reduces the pressure on the following maize crop. Schulz et al. (2003) reported that the number of emerged *Striga* plants at 12 weeks after planting decreased from 0.43 to 0.14 maize^{-1} when comparing a maize mono-crop with an integrated system that included a soybean cropping phase. Large variation among soybean cultivars has been found for suicidal *Striga* germination capacity.

The dual-purpose soybean varieties have only recently been introduced to various farmer communities in Northern Nigeria, so exact information about their spread is not available at this moment. Farmers in the target areas exposed to these varieties, however, are excited, not only because of their high yields, but also because of the other traits mentioned above. Farmer-to-farmer seed diffusion is taking place and old varieties are being abandoned. They also observe the improved yields of following sorghum or maize crops. In farmer-managed trials in Northern Nigeria, that ran for 2 seasons, the highest net benefits were obtained with the rotation of TGX-1448-2E (1450 US$), followed by the local variety Samsoy 2 (1000 US$). The lowest net benefits (600 US$) were obtained with *Lablab purpureus* (Sanginga et al., 2001). Following these promising results and positive initial farmers' reactions, SG2000 has started testing soybean rotations in six states in Northern Nigeria (Iwuafor et al., 2002).

In conclusion, using resilient, multipurpose and adoptable germplasm as an entry point to curb the downward spiral of soil fertility decline has proven to be a very promising strategy with a potentially high impact on farmers' livelihoods. This is mainly driven by the fact that there is no time-lag between farmers' investments in terms of capital and labour and returns, a substantial worry about alley cropping and *Mucuna* rotations that was commonly expressed by farmers. Two factors were essential in creating the high potential of cropping systems built around dual purpose soybean: (i) the creation of the knowledge for local processing and consumption, going hand in hand with the creation of markets for soybean and soybean products and (ii) intensive interaction between soybean breeders, soil fertility management specialists, and farmers.

Cowpea in the West African Dry Savannas

In contrast with the technologies we have discussed above, cowpea (*Vigna unguiculata*) has been cultivated in West Africa since ancient times and appears to be a crop native to Africa (Purseglove, 1991). This is best illustrated by the fact that in 1999, cowpea was cultivated on about 7 million ha in West Africa, compared with less than 5 million ha for groundnut and below 1 million ha for soybean and bambara bean (Schulz et al, 2001). In lots of areas in Northern Nigeria, cowpea is the first crop to harvest after the rains have established. The crop is grown from the derived savanna to the sahel for food and fodder, although the pressure of pests and diseases usually decreases with latitude.

As with soybean, improvement of the soil fertility status in cropping systems with cowpea as a component can potentially be targeted through the introduction of more resilient and multipurpose germplasm. There are, however, fundamental differences between soybean and cowpea-based systems that need to be taken into account when devising such a strategy. Because cowpea is a traditional crop in West Africa, there is no need to create local processing skills or markets for the grains, but it also implies that seed traits such as colour, taste, or texture become an issue. Secondly, the growth cycle of cowpea is shorter than soybean, although early, medium, and late varieties are available. This gives cowpea another biophysical niche than soybean. Thirdly, cowpea is more susceptible to a wide range of pests than soybean, and requires chemical or biological control. Incorporation of traits related to multiple resistance are to be considered when breeding for dual purpose germplasm. Fourthly, cowpea nodulates in most cases promiscuously, while this trait had to be incorporated in improved soybean varieties.

Estimates for N fertilizer replacement values for cowpea range from 10 to 80 kg N ha^{-1} (Carsky et al., 2003). In a six-month growing season Carsky et al (2001b) found that cowpea during the first 2 months replaced 30 kg N ha^{-1} as fertilizer to maize during the last three months. These values are usually at

Table 3. Millet grain and total dry matter yield at harvest as influenced by millet/cowpea cropping system at Sadore (Niger). Source: Bationo and Ntare, 2000.

	Grain yield (kg ha^{-1})			Total dry matter yield (kg ha^{-1})		
Cropping system	1996	1997	1998	1996	1997	1998
Continuous millet	937	321	1557	4227	2219	6992
Millet after cowpea	1255	340	1904	5785	2832	8613
P > F	< 0.001	0.344	< 0.001	< 0.001	< 0.001	< 0.001

the higher range when residues are incorporated and at the lower range after a long dry season. Like soybean (Carsky et al., 1997), benefits can be expected to be higher after longer duration varieties. Schulz et al. (2001) reported that N harvest indices were lower and total biomass yields larger in absence of chemical treatments, potentially leading to higher N contributions to a subsequent cereal crop. Cereal-legume rotation effects on cereal yields have been reported for the semi-arid tropics (Table 3) (Bakayoko et al. 2000; Bationo et al. 1998; Bationo and Ntare 2000). In all these studies, the yield of the preceding cereal was significantly higher than in monocropping treatments. The beneficial effect of legumes on succeeding crops is normally exclusively attributed to the increased soil N fertility as a result of N_2-fixation. However, cowpea yield significantly responded to rotations suggesting that factors other than N alone contributed to the yield increases in the cereal-legume rotations.

Currently, efforts are underway to improve the germplasm of cowpea to make it more resistant to pests and diseases and adverse environmental conditions such as drought. Existing germplasm is also currently being screened for its ability to access soil P that is not readily accessible (Lyasse et al., 2002) and to trigger suicidal germination of *Striga*. Carsky et al (2000a) reported that applying P fertilizer to soybean tended to increased soybean root density and to strengthen its effect on *Striga* reduction.

The presence of cowpeas in the cropping systems in West Africa is not likely to decrease because of its high value in the region. Cowpea grain contains about 22% protein, and it constitutes a major source of protein for the resource poor farmer. Its fodder also provides an important supplement to ruminant diets. Cowpea is often the only crop that survives severe drought. Cowpea is grown primarily to supply farm household food needs but some farmers produce surpluses for sale to national and regional markets and there is high demand for cowpea in the coastal countries such as Nigeria, Togo, Benin and Ivory Coast. Thus despite the substantial potential that exists for commercialization of cowpea, the opportunities are not fully being exploited because of weak linkages between farmers and traders. The challenge is to help smallholder farmers to move rapidly beyond their subsistence needs to produce marketable cowpea that will exploit marketing opportunities to improve household food security and open opportunities for sustainable improvement in income.

Conclusions and Looking Ahead

The following conclusions can be drawn from what we presented above:

(i) Improved soil management interventions need to generate immediate benefits to the farmer beyond an improved soil fertility status, especially in areas where land is scarce. Such interventions need to address farmers' immediate and longer-term needs.

(ii) Improved germplasm of commonly-grown crops, that addresses various constraints to higher yields, is a valid entry point for targeting soil fertility depletion. Germplasm that generates multiple benefits is likely to be adopted more easily and potentially tackles several constraints simultaneously.

(iii) The role of markets in creating added value to certain crops is essential. This was demonstrated above for *Mucuna* in the southern Benin Republic, where an artificial market was created, and for soybean in Northern Nigeria.

(iv) Inclusion of improved germplasm alone will not lead to sustainable agriculture. Mineral inputs are required, very often even to allow the legume to grow properly, but also to optimally exploit the multiple benefits created by the legumes. In the same context, rotational benefits are more often than not more than just contributions of extra N.

(v) There are no panaceas. It is very important to identify the appropriate niches for specific classes of legumes, both at the macro agro-ecozone scale and the farm scale.

(vi) Regarding the research and development process itself, evaluation and impact assessment are essential components of the process. Applying participatory approaches during the earlier phases of the alley cropping story may have led to a much earlier recognition of the limitations of this technology.

(vii) Intense contact between crop breeders, soil management specialists and farmers is essential for the development of improved germplasm adapted to the biophysical and socio-economic conditions targeted. Very often, in the International as well as National Research Centres, crop improvement activities have been separated programmatically from programs dealing with natural resource management, resulting in products that are not adoptable by farming communities.

Future emphasis in legume research and development activities could be put on:
(i) It is important to increase the area cropped with legumes in order to enhance the contribution of BNF to agriculture (Giller, 2001). In this context, various classes of legumes likely occupy various niches within a farm and agro-ecozone. This is a very important consideration when targeting specific legumes for specific purposes.

(ii) Dual purpose grain and herbaceous legumes, when managed properly, do contribute N to a following cereal, although recoveries are often very low. It is important to understand the fate of the fixed N not recovered by a subsequent crop and, if lost, to understand the major loss mechanisms. All this information is required to improve the management of biologically fixed N.

(iii) Emphasizing the improvement of accepted grain legumes is likely to result in faster pay-offs compared with trying to enhance the utility of herbaceous legumes. Vast gene banks exist for the major grain legumes and these could be exploited for specific traits. Biotechnological approaches may make this easier in the near future.

(iv) A considerable amount of information is available related to the performance and rotational benefits of all classes of legumes in a wide range of biophysical environments. There is an urgent need to synthesize this information and avoid unnecessary legume screening or related activities. A platform such as the Legume Expert System (LEXSYS) (Carsky et al., 2000b) could be used as a framework for synthesizing this information.

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LEGUMES FOR SOIL FERTILITY IN SOUTHERN AFRICA: NEEDS, POTENTIAL AND REALITIES

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Abstract

Legumes have great potential for improving and maintaining soil fertility, through mechanisms such as N_2*-fixation, nutrient release from plant residues, and maintenance of soil organic matter contents. However, this potential remains largely unfulfilled. Legumes have a comparatively small role in existing cropping systems, and are often used on poor soils where a restricted supply of resources such as phosphorus means that legumes fix* N_2 *at far less than their potential rate. Filling gaps in our mechanistic understanding of these processes will allow the design of better systems, but it is essential also to consider how new technologies fit into the whole farming system. New technologies will not succeed when productivity gains are small in relation to the amount of time or other resources they require. NUANCES is a new framework for analysing trade-offs around soil fertility management in smallholder farming systems. The framework is being developed into a modular quantitative dynamic model capable of integrating crop, livestock, soil and bioeconomic models. Flows of carbon and nutrients are considered within and between heterogeneous farms, and influences of and on labour and financial budgets are explicitly included. The analysis will allow the evaluation of technologies according to criteria such as agronomic yield, nutrient use efficiency, labour productivity and contribution to soil fertility, and the assessment of tradeoffs of investment in different farming strategies and their short and long term benefits for improving soil fertility.*

Key words: NUANCES, simulation modeling, annual legumes, farming system, southern Africa, technology integration, nutrient flows

Introduction

Poor soil fertility remains a major constraint to food production in sub-saharan Africa, and thus has adverse consequences for food security and the sustainability of livelihoods. Amounts of plant nutrients in soil are generally small, and nutrient balances often negative. In the absence of thriving markets for agricultural produce, there are few means for purchasing mineral fertilisers to address crop demand for plant nutrients. Efforts have therefore focused on finding low-cost solutions, which include making efficient use of available nutrient resources (cattle manure, fertilizers, legumes) . Promising 'best-bet' technologies include use of grain legumes such as soyabean and groundnut, green manures, fodder legumes and improved manure storage (Waddington et al., 1998). Creating better connections to markets for high-value products will also benefit soil fertility by allowing the purchase of more inputs.

Nitrogen fixing legumes have great potential for inclusion in African farming systems, whether for grain or fodder, or in fallow periods either as a green manure or a tree fallow. Trees will rarely be worth including simply for their effect on soil fertility, but this may be an important additional benefit where trees are used for other or multiple functions, such as fruit, fuelwood, timber or stakes. Large amounts of nitrogen can potentially be introduced into the system through fixation by legumes (Table 1).

In reality however, legumes contribute far less than these potential amounts of fixed N_2 (Table 2.). Small areas are planted to legumes, and often these are obtaining only 25-50% of their N from N_2-fixation, resulting in overall fixation rates of 5 kg N ha^{-1} y^{-1} or less on farms in Zimbabwe. This under utilization of legumes may be due to poor market development

Table 1. Potential contribution of fixed N_2 by legumes in different systems. (Summarized from Giller, 2001)

Legume system	% N_2 fixation	N_2 fixed (kg N ha^{-1})	Time (days)
Grain legumes	60-100	105-206	60-120
Pasture legumes	45-98	115-280	120-365
Green manures	50-90	110-280	45-200
Trees	56-89	162-1063	180

Table 2. N_2 fixed on smallholder farms in Zimbabwe. *Average farm size = 3 ha. (Summarized from Chikowo et al. 2000)

Legume	N_2 fixed (kg N ha^{-1})	Area (ha / farm)	Total fixed (kg N / farm)
Bambara nut	52	0.08	4.2
Cowpea	47	0.03	1.4
Peanut	33	0.22	7.3
Pigeon pea	39	0.34	13.3

for legume products, or because legumes are grown on poor soils where growth and N_2-fixation are limited and perceived benefits are small. The aim of this paper is to examine the benefits of legume technologies for soil fertility, and to discuss how these benefits can be assessed within an integrated farming system.

Roles of Plant Residues

Plant residues from crops, mulches or green manures have two distinct roles that are in the main mutually exclusive. In the short term organic materials can, through mineralization, supply nutrients to crop plants. In the medium to long term, the accumulation of partially decomposed organic matter gives the soil better structure, improving aggregation and infiltration and decreasing run-off. Accumulated organic matter also improves the chemical properties of the soil, increasing cation exchange capacity and slowing down leaching. Medium- and long-term effects on soil nutrient supply are also possible. After the first season the rate of nutrient release from a single application of organic matter is likely to be small, but with the accumulation of organic matter the total nutrient release from slowly-turning over materials can become significant.

As an example, senescing pigeonpea leaves contain substantial amounts of N. Up to 90 kg N ha^{-1} can be added in fallen leaves (Sakala et al., 2002). However, pigeonpea leaves immobilize N for 2 months due to low N (1.8%N) and high lignin content (16%) (Sakala et al., 2000) so that no N is contributed for companion intercropped maize. After the initial N immobilisation phase, net mineralization means that substantial amounts of N are made available for subsequent crops. Following extensive review of literature data, Palm et al. (1997) developed a decision tree for allocating organic matter resources based on their nitrogen and lignin contents. Materials with high N and low polyphenol / lignin concentrations are likely to decompose rapidly and thus are suitable for direct application for short term nutrient supply. Materials with high polyphenol / lignin and low N concentrations decompose slowly without releasing N and are only suitable for surface application as mulch. Materials with high polyphenol / lignin and high N contents, or with low contents of both, may cause immobilization of available soil nutrients and should be mixed with fertilizer or higher-quality organic material before applying. This decision tree was adapted for use in discussion with farmers by Giller (2000) by translating plant quality criteria into characteristics observable in the field – green colour indicating high nitrogen content, ability to crush easily indicating low lignin content, and astringent taste indicating high tannin content.

Knowledge Gaps

Reasearch into the potential roles of legumes in African farming systems has given much insight into the biophysical processes in which they are involved and which affect them. In some cases this has been enough to develop technologies with a large benefit, and uptake by farmers has been substantial. As an example, cropping of soyabean on sandy soils in Zimbabwe has been highly productive when soil pH and phosphorus status are corrected (Mpepereki and Pompi, this volume). However, gaps still exist in our understanding of N_2-fixation under field conditions, and of the effects of legume residues on the nutrition of subsequent crops and on the amount and effects of organic matter accumulation (Table 3).

The Biggest Gap – Integration

If all the gaps in our understanding of biophysical processes were filled, systems could perhaps be designed with an optimal productivity and resource use efficiency. Ideally, legumes need to be targeted in space and time to contribute large amounts of N

Table 3. Knowledge gaps related to the use of legumes for improving soil fertility

Role	Knowledge gaps
N_2-fixation	◆ Agroecological adaptation of legumes to soils and climate ◆ Amounts of N_2-fixed in different systems and agroecologies
Residue contribution to crop nutrition	◆ Evidence for improved synchrony of nutrient release and plant uptake in the field ◆ Measurements of N leaching and gaseous losses ◆ Provision of nutrients other than N in organic resources (e.g. cations, S)
Soil organic matter accumulation	◆ Effects of organic matter quality on long-term build up of soil organic matter ◆ Trade-offs between short and long term benefits of organic resources ◆ Benefits of enhanced soil organic matter on water balances, soil erosion, nutrient use efficiency etc.

to the system in such a way that this contributes to both short- and long-term soil fertility. There is great potential for integrating livestock and residue / manure management technologies to maintain soil fertility, and in particular to make optimum use of mineral fertilizers. Often it is the effect of a technology on weeds, pests, diseases or vermin which makes or breaks it. Problems with rats and snakes make many farmers in Lampung, Indonesia reluctant to use mulches, and agroforestry legume fallows at Domboshawa were found to increase cutworm populations, resulting in almost complete loss of yield of a subsequent maize crop. Conversely, *Mucuna pruriens* can be highly effective at suppressing weeds in some environments and this has aided its adoption as a nitrogen fixing green manure (see Giller, 2001).

Creating a farm system model integrating processes such as crop rotation, livestock production and residue management is conceptually simple. Outputs from a crop model can provide inputs of crop residue to a decomposition model or stover as forage to a livestock production model and *vice versa*. Budgets can be calculated for calories, carbon, nutrients and money. Historically, agronomic models have been developed by a research group extending an existing model within the original software framework. However, developments in software technology suggest an alternative approach that allows existing models to communicate with each other and be linked as submodels (Muetzelfeldt, 1995). In such a linked model, each part of the system such as a crop field or a dairy unit can be simulated by a submodel of any level of complexity, provided that standard inputs are required and standard outputs produced. Quantitative models of pests or weeds could also be linked. Linking of all of the various components of the farm system would thus allow the exploration of opportunities for combing different types of soil fertility technologies to understand how they can contribute to overall improvement of productivity of the farm as a whole. Optimal farm systems could then be designed using techniques such as multiple goal linear programming.

Such biophysically optimal systems might however remain unadopted if they were poorly adapted to the specific needs and resources of farmers and in particular the timing of labour availability. Labour requirements are notoriously difficult to assess, particularly for new technologies, and quantification of labour supply is complicated by opportunities for alternative employment off-farm and hired labour whether paid or unpaid. External and internal value judgements about the amount of time farmers spend working in the fields also make assessment difficult. Labour constraints are generally not included in crop models, and labour is thus effectively and naively seen as a free resource. The need for agroecological models to be integrated with socioeconomic models has been identified by scientists from both disciplines.

NUANCES (Nutrient Use in ANimal and Cropping systems – Efficiency and Scales)

NUANCES (Nutrient Use in ANimal and Cropping systems – Efficiency and Scales) is a conceptual framework for analysis of trade-offs in African smallholder farming systems. Heterogeneity is a key feature of most farms, as farmers tend to concentrate resources in small areas where soil fertility is maintained while the majority of their fields are effectively mined of nutrients. The efficiency with which nutrient resources are utilized for crop production is likely to vary strongly between land of different quality, as will the potential growth of different crops or indeed of the potentially soil-improving legumes. Documenting the extent of variable land qualities within farms is therefore an important step in understanding the potential impact of different technologies for soil fertility improvement. The wealth or resource endowment of farming households also determines their capacity to invest labour and other resources in agriculture as, for example, livestock ownership is often regarded as a key indicator of wealth in rural Africa. Poorer farmers are often only able to earn income off-farm by selling their labour to the wealthier farmers which then restricts the labour they can invest in improving productivity of their own farms. Farm types will also be identified, which might correspond to different wealth classes or production systems, to capture the resource flows between farms (Figure 1). Resource flows are often mediated by livestock, and the framework thus includes livestock productivity and manure management.

Resource flow mapping approaches have provided valuable insights into the allocation of crops and nutrient resources at various scales, from fields to farms, from regions to continents. Assembling static balances for nutrients across different land units does not however allow for testing of future scenarios of how farms could be developed in future. Flows which are difficult to measure, such as leaching, are generally estimated using simple transfer functions, but these functions may not give an appropriate response to changing conditions. Biophysical models of various degrees of

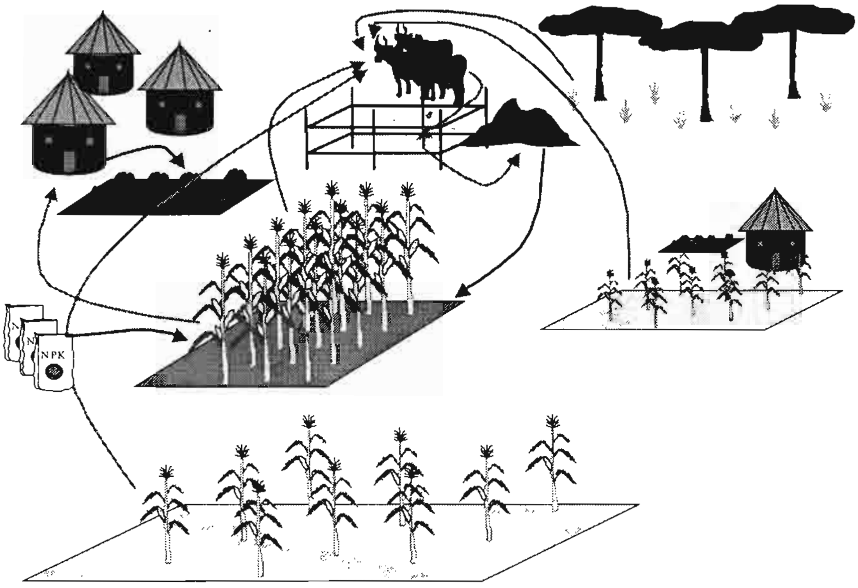

Figure 1. Resource flows within and between heterogeneous farms

complexity are however available for different flows, and ideally an appropriately complex model can be chosen for each part of the system and linked together where necessary to allow an integral analysis.

A software framework (Figure 2) is being developed to integrate existing crop, soil, livestock and bioeconomic models into a model of the whole system. This integrated model will be used to explore nutrient use efficiency and labour productivity, and tradeoffs between short and long term contributions to soil fertility, in African farming systems.

The NUANCES framework will allow the simulation of spatially and temporally complex management operations, such as crop rotation, mulching, livestock movements or manure transfer. Transfers will be possible between fields within one farm, between farms, and between the farms and rangeland. Different methods for combining labour and crop / livestock models are being considered; one idea is for management activities to be made contingent on there being sufficient available labour. The modular structure will allow different versions of submodels to be swapped in or out, depending on the detail required.

The aim is to create a model that can assist in integrating the expert knowledge of farmers and of scientists from different disciplines. The modular structure will allow the principle of 'just-sufficient-complexity' to be upheld, since simple models can be used for whichever processes are peripheral to the parts of the system being considered. As well as providing a framework for iterative experimentation and modelling, the model will shed light on which processes most affect costs and benefits and thus allow recommendations to be better targeted. NUANCES will lead to the iterative and collaborative design of more productive, sustainable systems, linking directly to policy at local and greater scales, and will facilitate the development of further rules-of-thumb for farmers.

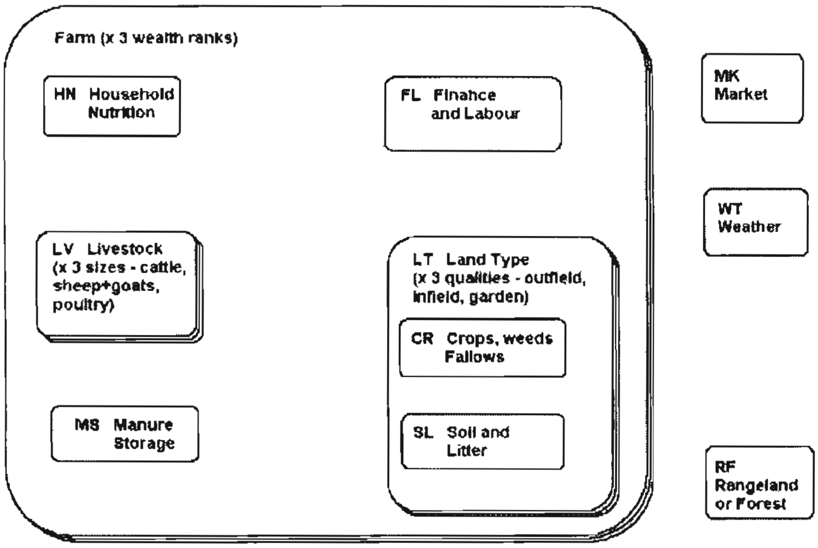

Figure 2. Modular structure and nesting of NUANCES integrated model. Submodels shown with multiple edges have multiple instances, thus each farm has three fields and each farm has fields of three different land qualities

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PATHWAYS FOR FITTING LEGUMES INTO EAST AFRICAN HIGHLAND FARMING SYSTEMS: A DUAL APPROACH

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Abstract

Food legumes have remained important components of various farming systems in Eastern Africa, but attempts to integrate fodder legumes and legume cover crops (LCCs) have been unsuccessful. Despite recognising their benefits as soil fertility restorers and providers of high quality fodder, farmers remained reluctant to integrate legumes mainly due to community/farmer- specific socio-economic determinants. This paper is based on the experiences of the African Highlands Initiative that has worked to integrate legumes in Areka in the Ethiopian Highlands. The work has tried to understand the processes of integration of legumes that have different uses, through participatory research. Areka has an elevation of 1990 masl, and an annual rainfall of 1300 mm. The area is characterised by mixed subsistence farming systems, poor access to resources, intensive cropping, land shortage and soil degradation. A participatory evaluation of the agronomic performance and adaptability of eight legumes was conducted for three consecutive years during the main and short growing seasons, accompanied by extensive data collection on socio-economic determinants. Participatory experiences showed that the selection criterion of farmers went far beyond biomass production. The major biophysical traits are performance of the species under a specific agroecology (characterised by yield, disease and pest resistance), effect on soil fertility and the succeeding crop and its compatibility within the existing cropping system. Specifically, farmers identified a firm root system, early soil cover, biomass yield, decomposition rate, soil moisture conservation, drought resistance and feed value as important criteria. The total sum of farmers' biophysical criteria showed that Mucuna *followed by* Crotalaria *should be the best fitting species, but farmers finally decided on Vetch, the low yielder, due to its fast growth and high feed value. The farmers' priority was for livestock feed rather than soil fertility. The final decision of the farmers on whether and where to integrate a food legume into their temporal and spatial niches in the system is dictated by their food habits, while for a non-food legume it depended on land productivity, farm size, land ownership, access to markets and a need for livestock feed. The potential adopters of LCCs and forage legumes were less than 7% of the farmers, while 91% of the farmers integrated new cultivars of food legumes. A strategic combination of biophysical and socio-economic determinants in the form of decision guides was suggested to facilitate the integration of legumes into farming communities, and help development agencies and researchers to easily identify potential adopters, learn about the criteria of choice and suggest an improved system of management. It may also help them to identify niches or create niches, modify the existing systems and promote the technology for wider use.*

Key words: Legumes, subsistence farmers, selection criteria, integration, decision guides

Introduction

Legumes play a pivotal role in nutrient cycling and nutrient enrichment in many subsistence-farming systems in Africa. They are considered drivers of sustainable farming because they intensify the productivity and interaction of soil, crop, livestock, people and other components. In most parts of Africa, where livestock products are unaffordable, legumes (especially bean, cowpea, pea, chickpea and faba bean) are the major sources of protein. The maize-based, banana-based and enset-based systems are supported mainly by bean and cowpea as major protein sources. Legume fodder, as crop residues or hay, is also a high value feed for milking cows, calves and draught oxen, especially during the dry season and in times of high energy demand. Legumes increase soil fertility through various mechanisms. High quality legume fodder produces a high quality manure that could improve soil fertility. Legumes can also boost the nitrogen stock in the soil through nitrogen fixation and nutrient release from their organic residues. Some legumes also release root exudates that may increase the availability of unavailable/fixed nutrients, e.g. phosphorus, through changing the rhizosphere pH and increased activity by rhizosphere biota.

The increasing interest with organic farming in the developed world and the challenge to decrease costs of inorganic inputs to maintain soil fertility in the developing world has focussed the attention of researchers and policy makers towards legume technology. Organic inputs from legumes could increase crop yield through improved nutrient supply/availability and/or improved soil-water holding capacity. Legumes offer other benefits that include providing cover to reduce soil erosion, maintenance and improvement of soil physical properties, increasing soil organic matter, cation exchange capacity, microbial activity and reduction of soil temperature (Tarawali et al. 1987; Abayomi et al. 2001) and weed suppression (Versteeg et al. 1998). There are several studies in Africa that showed positive effects of Legume Cover Crops (LCCs) on subsequent crops (Abayomi et al. 2001; Fishler and Wortmann, 1999; Gachene et al. 1999; Wortmann et al. 1994). Studies in Uganda with *Crotalaria* (Wortmann et al. 1994; Fishler and Wortmann, 1999), and in Benin with *Mucuna* (Versteeg et al. 1998) showed that maize grown following LCCs produced significantly higher yield than those without green manures, mainly through benefits of higher amounts of N and P and partly through nutrient pumping from deeper horizons. LCCs could also decrease nutrient losses by trapping a huge amount of nitrate that could be lost by leaching or denitrification if heavy pre-season rainstorms occur (Giller, 2001). However, the benefits vary with the legume species, their management, soil fertility status, the climate and the market value of the preceding crop. In some cases, integration of legumes for green manuring was not profitable when used just to fertilize cereals. Participatory experiments on *Crotalaria* in Uganda showed that a green manure did not compensate for the time it occupied in the field, although there was an increase in maize yield as an after effect (Fishler and Wortmann, 1999). In general, the type of LCC species desirable for green manuring depends on the assigned use. For weed suppression or erosion control, a species capable of rapid development of a dense soil cover is required, but if the major aim is to intercrop with a cereal, then species that grow slowly and erect are more suitable (Giller, 2001).

Despite these positive benefits, there has been relatively little success in achieving effective adoption of soil-improving cover and forage legumes in Subsaharan Africa (Sumberg, 2002, Giller, 2001, Thomas and Sumberg, 1995). This could be partly because of the absence of methodologies and tools that extensionists and community mobilizers can use to facilitate the integration of legumes. Information on legume technology is diverse and it is accumulated in patches. There is, therefore, a need to assemble and organise the available information to identify gaps and synthesize the data to develop a decision support system for farmers, researchers and policy makers to select options, niches and systems.

The objective of this paper is to explore experiences with the integration of legumes in subsistence farming systems of the East African Highlands, identify the biophysical and socio-economic determinants affecting their adoption and suggest how those various determinants could be strategically combined, processed and used to develop decision guides.

Legumes in Various Farming Systems

Although legumes are important components of various farming systems and farmers acknowledge the positive contributions of legumes, the amount of land allocated to grow them as food, fodder or cover crops is relatively small. In the upper highlands of Eastern Africa above 2700 masl, including the Ethiopian highlands, there are few legumes in most farming systems. Lentils are found as a food legume, and natural medics and trifolium as feed legumes, in proportions of < 2%. In the mid-highlands of East Africa (1000-2200 masl), both in the cereal-based and perennial-based systems, the proportion of legumes is higher (about 20-25 %), grown as intercrops, intermediate and break crops. Without the contribution of legumes in restoring soil fertility and breaking pest incidence cycles for hundreds of years in this intensively cropped agroecology, the production systems may have collapsed long ago. The proportion of the legumes decreases in the low elevations to less than 10%, because those regions are commonly too drought-prone to grow most of the traditional legume species.

In the perennial-based farming systems of Eastern Africa, the only dominant legume in the cropping system is common bean, intercropped with maize or grown sole as a second crop. However, the cultivation of beans may contribute little to soil fertility improvement (Eyasu, 2002) mainly because 1) the crop is harvested by uprooting the whole plant as it needs to be stored by hanging bundles on a trellis and kept indoors to avoid sprouting; 2) no residue is returned to the soil as pods and tops are fed to livestock while the stalk is used as feed or cooking fuel and 3) beans have the least N-fixing potential, particularly in low pH soil with low P availability.

Why is Adoption of Legume Technology so Slow?

Thus the proportion of legumes, be it food, feed or cover crops, to the various systems is very low. There are multiple factors that have affected the adoption and dissemination of legumes, which can be nested within and defined by three contextual factors i) socio-cultural, economic and political ii) agroecological and iii) management at the farm level (Sumberg, 2002).

From the food legumes perspective, three factors dictate the decision of farmers to grow or not grow legumes. First, in African subsistence farming, the food habit dictates the amount of land allocated for various crops and the type and amount of input invested per crop. Since the food habit of most of the East African Highlands is cereal-dominated, the proportion of cereal to legume consumption in the households of East Africa is about 10 to 1. For a household with five members in Kenya, on average about 500 kg of maize and 100 kg of beans is required. Similarly, for the same household size in the Ethiopian Highlands 600 kg of barley and 70 kg of pea or faba bean is required. Secondly, the fertility status of the land and the incidence of pests and diseases dictate the frequency of legumes in the cropping systems. The proportion of legumes usually increases with decline in soil productivity and increased incidence of pests and diseases. Thirdly, the market value of crops may dictate how much land is allocated for legumes. In a few cases, such as the Rift-valley of Ethiopia with beans, farmers invest land and labour to grow legumes for market. They grow legumes for the market and buy cereals for consumption at home, as the price of legumes is relatively higher than that of the cereals.

The integration of feed legumes into African farming systems has also remained low despite continuous research efforts since the 1930s. Sumberg (2002) identified several major determinants that affected integration. There is a limited tradition to grow feed legumes in the region, hence the genetic pool of legumes available for growers is limited to a few types of recently introduced germplasm. There is limited knowledge on legume management and the processing and utilization of legumes to make market-orientated products. As most of those legumes originated in the relatively favourable climates of the Andes, it became also challenging to identify high yielding, drought-resistant species to integrate into the drought-prone environments of Africa. Most importantly, because legume technology was considered gender-neutral and wealth-neutral, socio-economic dimensions were not considered during research and extension.

In recent years, there has been increased research interest across the region on the integration of legume cover crops (LCCs) into the farming systems, to help improve and sustain soil fertility. Most of the legume cover crops are known to be ideal for improving soil fertility, as they are commonly fast growing, Nitrogen-fixing, efficient in capturing and recycling nutrients and decompose easily (Jama et al. 1998). The problem of integration, however, is even worse for LCCs. This is first because the opportunity cost is much higher than the immediate benefits of LCCs. Second, most LCCs are sensitive to unfavourable environments (water stress and nutrient deficiency), and very few of them grow well in degraded corners of the farm where farmers want them to grow. Third, farmers would like to integrate legumes that have multiple benefits, i.e. for food, feed and soil fertility, while the LCCs usually address one purpose, i.e. soil fertility maintenance/ improvement through the incorporation of the green manure into the soil.

Dual Strategies for Integration of Legumes

There are two possibilities to facilitate the integration of legumes into East African Highland farming systems. Designing a new production system with a larger legume component is one option. This could be an ideal strategy to integrate legumes, as the production system will be geared towards the consumption of legumes as major production inputs. For example, a policy that prohibits free grazing and free herd movements in the Ethiopian Highlands, where free grazing is currently practised, and the introduction of fast growing feed legumes for cut and carry, would enhance the consumption of legume technology significantly. Promiscuous legumes, which are high yielding in both grain and straw, are obvious choices if the system should provide high quality manure from few animals and increased household income and food. The second option is to understand the various farming systems, identify the existing temporal and spatial niches, creating new potential niches using the existing resources (of land, water, nutrients, solar radiation and human resources) and then facilitate the integration of legumes by delivering options and acknowledging diversities.

Here I present a case study that justifies the second strategy; that of fitting the legume into existing systems by identifying the spatial and temporal niches of the existing system.

Experiences of AHI with Integration of Legumes in the Ethiopian Highlands

Characteristics of the site

The research was conducted at Areka, 430 km south-west of Addis Ababa, about 1950 masl, representative of the mid highlands, with an average land holding of less than 0.5 ha. The farming system is a perennial highly intensive Enset-based system, with a possibility of up to three crops per year. Due to a very high human population pressure (>450 people/km^2), land holdings are smaller, with fewer livestock than in the upper highlands. The average livestock holding is less than 1.5 cattle per household. Only 15% of the farmers own oxen. Sharing or hiring of oxen for ploughing and other farm operations is a traditional practice. Unlike the upper highlands, where communal land natural pasture and free grazing area is available, only crop residues, weeds and aftermath grazing are the predominant available feed sources in Areka. The cropping system is highly diversified. Different forage crops are grown around the home garden in association with coffee, Enset (*Enset ventricosum*) and fruit trees. Crop-livestock integration is strong; farmers use crop residues as a feed source, but also return the manure to the soil, applied mainly around the home garden. The farmers divided their land into several plots for various purposes. Trees are planted on valley bottoms, slopping areas, farm boundaries, in front of the house and in gully areas. Grazing land (tittering) is found in front of the house. Some plots are left for cut and carry for livestock feeding. These plots differ in soil fertility status, with a general decline in soil fertility for those plots further from houses.

Determinants of Integration of Legumes into Systems

1. Biophysical Factors Dictating Integration of Legumes

Farmers have multiple criteria to decide whether a technology would be appropriate for their circumstances, and whether to integrate those technologies into their farming practices. Although farmers were keen to learn about legume technologies in a farmers' field school and at on-farm testing sites, they demanded time to test them not only under optimum research conditions, but also under their own real sub-optimal conditions. Experiences from this site showed that for a legume to be selected by end-users, it should possess the following biophysical traits (Amede and Kirkby, 2002):

a) The biological productivity of a legume in a given agroecology is the principal factor for a legume to be considered a potential candidate to be integrated into the existing system. The most favoured candidate is the one with relatively high grain and biomass yield under variable agro-ecological conditions (of precipitation, temperature, soil fertility and variable management). The other criterion was that when farmers tested legumes for restoration of soil fertility they assume that legumes should improve the fertility status of the degraded corners of their farm. Therefore, for a legume cover crop to be selected for a short term fallow at Areka, the major biophysical criterion was whether a species can produce high biomass on degraded corner plots of the farm. Farmers were not interested to grow the LCCs in the fertile corners as they were allocated for food crops. The land they wanted improved are the border strips, the abandoned corners, steep slopes and the barren land that failed to produce a reasonable crop yield. But most of the LCCs with a strong history in improving soil fertility need relatively fertile soils to establish, produce a large amount of biomass and to fix atmospheric nitrogen. That is the reason why farmers selected *Crotalaria* for improving degraded farmlands over *Mucuna, Canavalia, Tephrosia* and vetch (Amede and Kirkby, 2002). On individual farmer's fields, *Crotalaria* was the best performing species regardless of soil fertility. Similar results were reported from Uganda (Wortmann et al. 1994). On the other hand, vetch and mucuna were the best performing in fertile corners of the farms. This did not agree with the findings of Versteeg et al. (1998), which indicated that mucuna performed better than other green manures (including crotalaria) to help recover completely degraded soils. When those seven species (crotalaria, mucuna, canavalia, tephrosia, vetch, stylosanthus, and trifolium) were planted in the driest part of the season, crotalaria followed by mucuna, performed best and produced up to 2.9 t ha^{-1} of dry matter within three months.

b) The effect of incorporation of LCCs on the grain yield of the following crop is one other very important criterion. Application of high biomass of LCCs did not necessarily guarantee high yield of the following food crop, as the quality of the organic material dictates whether nutrients accumulated in the LCCs could be released at the required time and in the required amount. Participatory experiments on the after-effect of LCCs in Uganda recorded good increases in crop yields, although the green manure did not compensate for the time it occupied the land over a three-crop cycle (Fishler and Wortmann, 1999). Moreover, how large the benefit a green manure delivers for growth of the following crop depends on the initial fertility of the soil and the amount of nutrients that the LCC contributes (Giller, 2001). In Areka, *Tephrosia* produced about double the dry matter of vetch, but maize yield under vetch was significantly higher than under *Tephrosia* (Amede and Kirkby, 2002), which could be explained by quality differences and synchrony of the demand and supply of nutrients. The most important organic quality indicators are nutrient content, lignin content and polyphenol content of the respective organic resources (Palm et al. 1997).

c) Since the opportunity cost of growing an LCC at a time when other food crops could be grown is very high, those fast-growing early maturing legumes that can grow using residual moisture should be best fitting. In this case, farmers were able to integrate them as intercrops, relay crops, and short-term fallows once the major crop is harvested.

d) Those legumes that did not strongly compete with the companion food crop for water, nutrients and light when grown in combination with food crops (e.g. maize), are the best options. Because of land scarcity, farmers may not be willing to grow LCCs as solecrops.

e) LCCs with a firm root system to reduce soil erosion (based on the strength of the plant during uprooting) were favoured by farmers with steep plots.

f) Rate of decomposition when incorporated into the soil (the strength of the stalk and/or the leaf to be broken by hand) was considered to be an important indicator to predict whether the organic resource applied can release nutrients for the preceding crop in a short period of time or not.

g) The mulching capacity of LCCs (based on the moisture content of the soil under the canopy of each species). There was a significant difference in soil water content under the canopy of the various LCCs. Higher soil water content under *Mucuna, Stylosanthus* and Vetch at Areka implied that these species may improve soil water availability through reduction of evaporative loss if grown in combination with food crops. The ground cover (%) was the highest for Mucuna (100%), and the lowest for vetch (60%). Similarly, the soil water content under mucuna was 22.5% while that under *Tephrosia* only 11%. This may have an implication for the water use efficiency of the legume and its compatibility in multiple cropping systems.

h) Drought resistance of the legume when exposed to dry spells (wilting and abscission of the leaf during warm days and extended drought periods). As food crops would occupy most of the land for most of the growing season, farmers found it very expensive to find a spatial niche for LCCs during the cropping season. The most appropriate niche they identified to plant them was the end of the growing season using residual moisture, which exposed LCCs to a terminal drought. In this case, there is little choice but to grow legumes as a sole crop.

i) Feed value of the legume (livestock preference) and ability to produce high quality feed for the dry season. This was one of the most agreeable criteria across the community, especially because of the high calf mortality during dry seasons.

j) Early soil cover. LCCs with fast mulching characteristics not only conserve water, mainly through reduction of evapotranspiration, but also keep the land easy to work with. It also reduced the kinetic effects of heavy rainfall on the soil and soil erosion.

However, the criterion of choice had different weights for farmers of different socio-economic categories. For resource poor farmers (who did not own animals or owned very few of them), legume cover crops were not first choices. Those farmers give priority to legumes with short-term benefits (food and feed legumes).

The major biophysical constraints that affect the integration of legume cover crops as perceived by farmers are presented in Figure 1. This approach would assist researchers to get feedback information on the research questions to be addressed to reduce the drawbacks of the technologies and suggest other options that could fulfil end-user require-

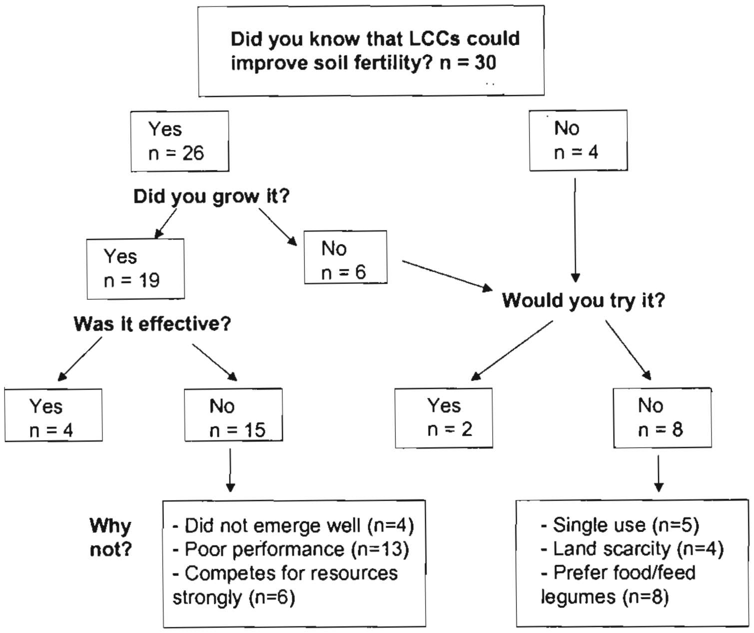

Figure 1. Schemes used for the identification of factors of adoption or non-adoption of legume cover crops in multiple cropping systems of Areka, Ethiopia (Amede and Kirkby, 2002)

ments. It would help researchers to identify the major factors of non-adoption and prioritise them in relation to socio-economic categories.

2. Socio-economic Factors Dictating Integration of Legumes

After farmers went through participatory research processes for many seasons, and tested favourite legumes in their own fields, they were asked to suggest the most important socio-economic criteria that dictated their selection of one or other legume species to be integrated into their systems.

Results from informal monitoring of farmers' activities accompanied by structured questions showed 21 different factors that affect the integration of legumes for different purposes. When farmers were asked to prioritise the most important factors that affect adoption and integration of legumes, farmers mentioned a) farm size, b) suitability of the species for intercropping with food legumes, c) productivity of their land, d) suitability for livestock feed, e) marketability of the product, f) toxicity of the pod to children and animals, g) who manages the farm (self or share cropping), h) length of time needed to grow the species, and i) risk associated with growing LCCs -- particularly the introduction of pests and diseases. None of the farmers mentioned labour demand as an important criterion. Earlier work also suggested that farm size and land ownership affect the integration of LCCs into smallholder farms (Wortmann and Kirungu, 1999). After comparing those factors in a pair-wise analysis, five major indicators of different hierarchy were identified.

1) Degree of land productivity: Farmers in Gununo associated land productivity mainly with the fertility status of the soil and distance of the plot from the homestead. The homestead field is commonly fertile due to a continual supply of organic resources. Farmers did not apply inorganic fertiliser in this part of the farm. They remained reluctant to allocate a portion of that land to grow LCCs for biomass transfer or otherwise, but grow food legumes (mainly beans), as intercrops in the coffee and enset fields. The potential niche that farmers were willing to allocate for LCCs is the outermost field.
2) Farm size: Despite very high interest by farmers to get alternatives to inorganic fertilisers, the probability that farmers may allocate land for growing LCCs depended on the size of their land holdings. For Areka, a farm size of 0.75 ha is considered large. Therefore, farmers with very small land holdings did not grow legumes as sole crops, but integrate them as intercrops or relay crops. Therefore, the potential niches for LCCs are partly occupied unless their farm is highly depleted.
3) Ownership of the farm: Whether a legume (mainly LCCs) could be grown by farmers or not depended on the authority of the person to decide on the existing land resources, which is linked to land ownership. Those farmers with insufficient farm inputs (seed, fertilizer, labour and/or oxen) are obliged to give their land for share cropping. In this type of arrangement, the probability of growing LCCs on that farm is minimal. Instead, farmers who contracted the land preferred to grow high yielding cereals (maize and wheat) or root crops (sweet potato). As share cropping is an exhaustive profit-making arrangement, the chance of growing LCCs in such contracts was almost nil. Without ownership or security of tenure, farmers are unlikely to invest in new soil fertility amendment technology (Thomas and Sumberg, 1995).
4) Livestock feed: In the mixed farming systems of Ethiopia, livestock is a very important enterprise. Farmers select crop species/ varieties not only based on grain yield but also straw yield. Similarly, legumes with multiple use were accepted by the community better than legumes solely for green manuring.
5) Market value: For a legume technology to be appraised by farmer end-users, the legume should bring an immediate and visible benefit, either direct through the generation of food or cash or indirect by making a significant and visible contribution to a secondary high value product.

The Decision Guides

In this paper, we present two guidelines for integration of legumes into multiple cropping, perennial-based farming systems. The decision trees were developed based on the following background information from the site.

1) Farmers prefer food legumes over non-food legumes regardless of the soil fertility status of their farm.
2) The above-ground biomass of food legumes (grain and stover) is exported to the homestead for feed and food while the below-ground biomass from food legumes is too small to affect soil fertility. The probability that the manure will be returned to the same plot is less as farmers prefer to apply manure to their perennial crops (Enset and Coffee) growing near the homestead.
3) The tested legumes may fix nitrogen to fulfil their partial demand (we have observed nodules in all, although we did not quantify N-fixation), but in conditions where the biomass is exported -- like with vetch for feed -- most of

the nutrient stock would be exported. Therefore, we did not expect a significant effect on soil fertility.

4) LCCs produce much more biomass when planted as relay crops in the middle of the growing season than when planted late as short-term fallows due to possible effects of end-of season drought on growth.
5) The homestead field is much more fertile than the outfield; hence those species sensitive to water and nutrients will do better near the homestead than in the outfield.

The first guide (Figure 2) is developed based on the data obtained from the farmers field and on-farm experiments, verified by on-station experiments. The overall idea is that not all LCCs fit everywhere. Some are very sensitive to the availability of nutrients and water, at least during their establishment, and others do well across environments. When farmers got the option to select among seven commonly recommended LCCs species (Vetch, *Mucuna, Crotalaria, Canavalia, Tephrosia, Trifolium, Stylosanthus*), to integrate into their systems, farmers in various socio-economic categories selected different species, planted them on different parts of their farm and managed them differently. Researchers have monitored how the farmers managed the LCCs, where they planted them, when did they plant, how long they were left to grow, how much input they invest, how was the biomass production, what benefits they get from them and what are their final decisions to integrate them into their systems. The guide, synthesised from the participatory research, has two major frames, one for legumes suitable for maintaining the fertility status of productive land and another suitable for improving the fertility status of relatively less fertile cropland. Most farmers wanted the LCCs to improve the plots that are 'addicted' to mineral fertilizers, which refers commonly to those less fertile corners of the farm, the out-fields. The guide showed that there are limited LCC options that could be used to improve degraded croplands, as the legumes themselves, except *Crotalaria*, were not able to grow under such harsh conditions. There are many more LCC options for maintaining the fertility status of the fertile corners of the farm. Vetch was suggested to be the best fitting legume for a short-term fallow. However, the guide left a space for other researchers to identify an LCC option that may fit into their specific production systems.

The second guide (Figure 3) is intended to assist farmers and researchers to identify potential legumes that could be compatible with existing spatial and temporal niches. This guide was developed based on the homestead being much more fertile than the outfield, and that the outfield is larger than the homestead field. The most important criterion at the lowest level is the presence or absence of livestock followed by who manages the farm, market access, the size of the land holding and the land quality. The factor that dictates the decision at the highest level is land productivity, which was governed mainly by soil fertility status. Growing of food legumes was the priority of every farmer regardless of wealth (land size, land quality and number of livestock). Farmers with livestock integrated feed crops regardless of land size, land productivity and market access to products. However, the size and quality of land allocated for growing feed legumes depended on market access to livestock products (milk, butter and meat). Those farmers with good market access are expected to invest part of their income into external inputs, i.e. inorganic fertilisers. Hence, farmers in this category did not allocate much land for growing LCCs, but applied inorganic fertilisers. In the homestead field, there was no land allocated for LCCs in the system, because farmers gave priority to food legumes there, to take advantage of a relatively fertile corner of the farm. The clearest spatial niche for growing LCCs is the outermost field, especially in poor farmers' fields with exhausted land and limited mar-

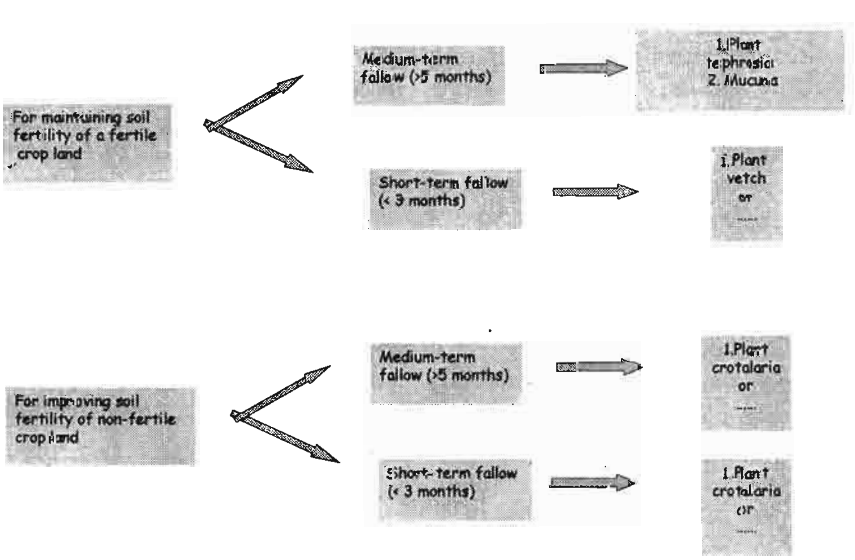

Figure 2. Decision guide that suggests various legumes for improving degraded crop lands or maintaining the fertility status of relatively fertile crop land through a short or medium term fallow

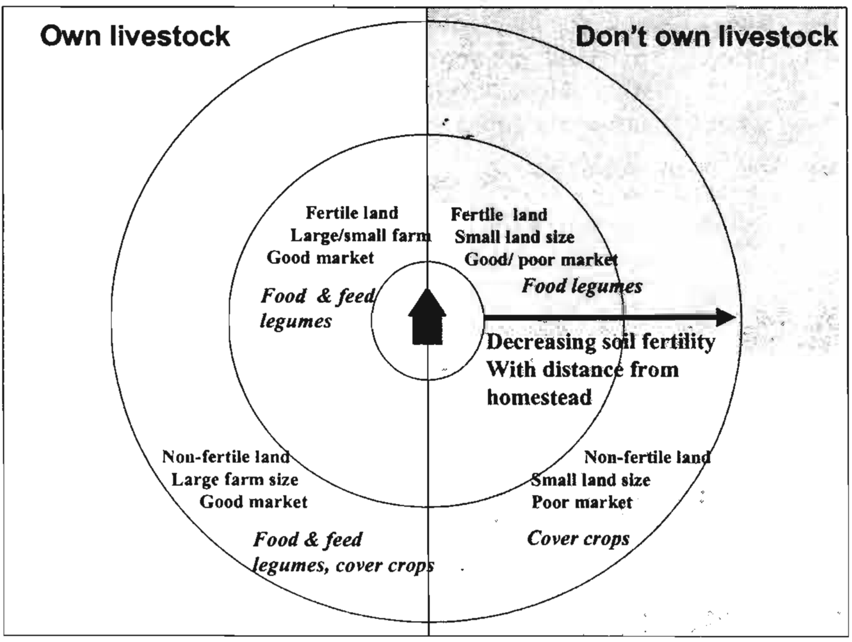

Figure 3. Guidelines for integration of food, feed legumes and legume cover crops into small scale farms, with heterogeneous socio-economic conditions

ket-driven farm products. Those categories of farmers experienced share cropping for some time, and as a result their farm was on the verge of going out of production due to unsustainable land management practices.

Conclusion

Integration of legumes into various production systems and for various clients is complex and requires a participatory approach to address both biophysical and socio-economic constraints and opportunities. The major biophysical traits that need to be addressed are adaptability of the species into that specific agroecology (which may include yield, disease and pest resistance), the effect on soil fertility and its compatibility with the existing cropping system. The most determinant socio-economic factors are land ownership, market value, farm size and trade-offs for various uses. The strategic combination of those biophysical and socio-economic determinants in the form of decision guides will help farmers, development agencies and researchers to identify potential adopters, learn about the criteria of choice, and learn about the need for improved management of the system. Moreover, it may help them to identify niches and create niches, modify the existing systems and promote the technology for wider use.

Acknowledgement
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Questions and Answers

Key Papers

To Bernard Vanlauwe, Andre Bationo et al.

Q: Where do you place improved fallows in the systems you described?
A: It is important to identify proper modes at the biophysical and socio-economic level.

Q: Promotion of mucuna is limited by its lack of utilization options due to anti nutritional factors (L-dopa). What use did Sasakawa Global 2000 put mucuna to in order to increase the adoption by farmers?
A: SG 2000 bought up mucuna seeds for further distribution to interested farmers.

Q: Markets appear to be critical for the adoption of legume technologies, as shown by the mucuna case where numbers increased from 20 to 14 000 in 10 years when Sasakawa was buying seeds. What role have markets played in the increased adoption of soyabean in Nigeria?
A: Two routes were followed to create demand for soyabean; local processing and development of private-sector-driven markets. Both were successful in creating a demand although the proportion of both mechanisms would need to be verified through IITA.

Q: It is important that we recognize the value of the word 'adaptation' in terms of developing dissemination messages. Adaptation reflects how farmers overcome complexities or constraints in the system.
A: Agricultural adaptation is limited to the complexity of the interventions aimed at.

To Ed Rowe and Ken Giller

Q: What are the incentives for organizations and individuals to share information to develop simulation tools beyond the conceptual framework of NUANCES?
A: Many people are interested to look at the broader costs and benefits of the technology or intervention that they are researching, to see whether it really is viable for the farmer. We have already seen a great willingness to share data, and models, which suggests that NUANCES is seen as useful and timely.

Q: You have indicated that soyabean leaves little residual N, not enough to support the next cereal to maturity. Where then does the observed residual effect of soyabean on maize come from? Farmers have observed and 'harvested' maize grown on the residual effect.
A: This observation, coming directly from farmers' experience, shows that the prototype soil-crop model is not predicting soya residue effects very well. This is great; the intention was just to illustrate the kind of predictions and analyses which NUANCES will provide, and the comment demonstrates the value of having better and faster feedback between model predictions and farmers' practice, so both can be improved.

To Tilahun Amede

Q: Faba beans were described as high N-fixation. What are the attributes that may account for that characteristic?
A: Firstly the seeds of faba bean are large, with a considerable nutrient concentration, good enough to support nutrient demand during the early stages of growth. This leads to a vigorous start with prolific leaves able to synthesize enough carbohydrate to support N -fixation processes. Moreover, faba bean has prolific roots that may explore nutrients like P from a wider soil space.

Q: The recommendation for outfields in the absence of livestock is to grow LCC. But earlier you presented that farmers found these were not growing well in their outfields?
A: As farmers grow mainly maize and potato in the outer fields, and apply some inorganics like DAP, the residual nutrients could be enough to support the initial start of LCCs.

Q: To what extent have the decision guides been able to predict the growing of a particular grain legume in the research areas? Were you able to quantify the decision guides, e.g. size of land holding and a specific pH that could suit each grain legume?
A: The simple guide that indicates which legume could be used for what purpose can be used across the board as they are developed based on biophysical traits. The other guides may require characterization of the socio-economic components.

PROMOTING NEW BNF TECHNOLOGIES AMONG SMALLHOLDER FARMERS: A SUCCESS STORY FROM ZIMBABWE

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Abstract

Biological nitrogen fixation (BNF) contributes significant amounts of N into both managed and natural ecosystems and forms the basis for the age-old practice of rotating legumes with other crops. Benefits of legume N fixation include protein nutrition, soil fertility improvement, savings on fertilizer costs and cash income from sale of crop surpluses. The packaging and use of superior N-fixing rhizobial strains as commercial legume inoculants is a relatively cheap cost-effective technology widely adopted by large-scale but not smallholder farmers in Zimbabwe. We report on a promotion program that used soyabean as a vehicle to convey the multiple benefits of BNF technologies to poor smallholder farmers through a multi-faceted research-extension-promotion effort. The primary objective was to strengthen rural food security of smallholder farmers through exploitation of soyabean BNF for soil fertility improvement against rising input costs. The main elements of the promotion strategy included training farmers and extension staff in technology application, demonstration of the tangible multiple benefits and facilitation of input/output marketing, all backed by a parallel program of adaptive research. The basic promotion concept used was that of creating a closed loop with four links: training (in BNF technology application), production (of soyabean), processing and marketing (TPPM). Coordination of stakeholder activities was and continues to be a critical component of the promotion effort. A conceptual framework linking various elements (BNF technology, food security, soil fertility, cash income) was used to guide and focus both the promotion and research components. The rate of adoption of soyabean BNF among smallholders has been near exponential (from 50 farmers in 1996 to more than 10,000 in 2000). This paper outlines the conceptual framework and mechanisms used in the promotion of soyabean technologies, the responses of smallholder farmers and the prospects for wider scaling up.

Key words: Soyabean, smallholder farmers, BNF, soil fertility improvement

Introduction

Nitrogen deficiency is the main limiting factor for high cereal yields in sub-Saharan Africa and yet the majority of smallholder farmers use very little mineral N fertilizer. Biological nitrogen fixation (BNF) contributes significant quantities of nitrogen (N) to both natural and managed ecosystems and offers a relatively cheap alternative source of N for resource-poor farmers. Exploitation of BNF technologies in African farming systems requires the identification of appropriate N-fixing legumes that have multiple benefits to ensure adoption by risk-averse rural communities. There is need to develop a research agenda that identifies appropriate BNF technologies (e.g. effective legume-rhizobium combinations) that can be readily adopted by farmers with immediate demonstrable benefits to ensure adoption. Such research efforts will need to be linked to appropriate extension programs that ensure that target communities benefit in tangible ways.

Traditional legumes such as groundnut (*Arachis hypogaeae*), cowpea (*Vigna unguiculata*) and bambara nut (*Vigna subterranea*) that rely on BNF and contribute residual fertility to soils are low-yielding and are often viewed as minor crops. Yields of these legumes have failed to respond consistently to inoculation with commercial rhizobial strains. Soyabean, a relatively new legume in Africa, responds well to rhizobial inoculation and fixes large amounts of N even in marginal soils (Kasasa, 2000; Musiyiwa, 2001). The multiple benefits of soyabean include soil fertility improvement, protein nutrition for humans and livestock and cash income from sales of grain and processed products. Soyabean is now grown in several parts of sub-Saharan Africa including Malawi, Nigeria, Zambia and Zimbabwe where it is making significant contributions to rural livelihoods. Due to limited inoculant production capacity in most African countries, promiscuous soyabean varieties that effectively nodulate with indigenous rhizobia have been successfully grown without inoculants demonstrating their potential for conveying the benefits of BNF to poor and marginalized communities (Mpepereki et al. 2000).

Historical Perspective on Soyabean in Zimbabwe

Soyabean was introduced into Zimbabwe (then Southern Rhodesia) in the 1930s as a green manure crop and later for forage. Large-scale commercial production started in the 1960s when a breeding program and a Rhizobium inoculant factory were established (Corby, 1967). The crop was not promoted among smallholder black farmers, most of whom had been relocated onto marginal, often sandy, soils in low rainfall areas unsuitable for soyabean production. Apart from the real agro-ecological limitations, soyabean production, with its requirement for rhizobium inoculants that need refrigeration, was considered too sophisticated for African peasant farmers who had no knowledge on how to process it for food.

After political independence in 1980, government adopted a policy of encouraging smallholder farmers to increase crop production through various inputs and marketing support programs. By the 1990s, smallholder farmers were contributing over 70% of national maize and cotton production. A soyabean BNF promotion program targeted at Hurungwe West district in northern Zimbabwe in the late 1980s boosted farmer interest, production and consumption of soyabean which all declined when project support ended in 1989 (Whingwiri, 1996; Mudimu, 1998). Smallholder farm communities however continued to face limited dietary protein sources, general declining soil fertility and poor household incomes against a background of increasing mineral N fertilizer prices, following World Bank/IMF-induced removal of government subsidies. A two-day stakeholders' workshop that was held at the University of Zimbabwe in February 1996 to examine the potential for promiscuous soyabean for smallholder farmers recommended two major activities. First it resolved that research be initiated to characterize indigenous soyabean rhizobia, the potential for promiscuous soyabean and to quantify the amounts of N fixed and the residual fertility benefits for maize grown in rotation. Secondly, it was resolved to extend soyabean technologies (the use of rhizobial inoculants and promiscuous varieties for BNF, production, processing, utilization and later input/output marketing) to smallholder farmers. A National Soyabean Promotion Task Force with representation from farmer organizations, private industry, NGOs and public institutions (research, extension, university) was formed. The Task Force was to be convened by AGRITEX with overall coordination by the University of Zimbabwe Faculty of Agriculture. The Task Force objectives included promotion of soyabean through appropriate research, training farmers in production and processing and coordinating the activities of various stakeholders.

This paper outlines the conceptual framework and mechanisms used to promote soyabean technologies, the scale of operations, feedback from farmers, constraints and opportunities and the potential for scaling up.

Conceptual Framework

The context was that of smallholder cropping systems characterized by low productivity due to low soil fertility, with N as a major limiting nutrient. Biological N fixation (BNF) was identified as a potential tool to address N deficiency in these systems. Soyabean was chosen as the candidate legume because of its high N-fixing potential and soil improving properties, food value as a protein and vegetable oil source, relatively low production costs and high market value. The place of soyabean BNF in the total food production system of a typical smallholder farm was identified. This was an essential step to ensure that the technology would address real food security concerns of farmers, a critical element for successful adoption. The conceptual framework illustrated below (Figure 1) shows the main linkage loops and benefits from soyabean BNF in an integrated maize-based crop-livestock system.

Strategies Translating the Concept into an Operational Model

For research, a proposal was written up, funds sourced and graduate students engaged to conduct research to quantify N inputs from promiscuous and commercially inoculated soyabean into the cropping system and to measure and demonstrate the residual soil fertility benefits for maize in subsequent seasons. Research was conducted to establish the prevalence and symbiotic effectiveness of indigenous rhizobia on both promiscuous and specific soyabean varieties and the adaptability of the latter to the more agro-ecologically marginal smallholder areas. Experiments were conducted both on-station and on-farm under researcher and farmer-extension

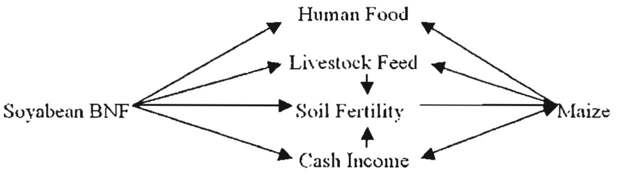

Figure 1. Soyabean BNF links to food security in a maize-based farming system (adapted from Mpepereki et al. 2001).

management respectively. This meant that researcher-managed detailed replicated field experiments were placed on a few farms selected for their representative soil types, while a larger number of simple plus/minus treatment trials were run under farmer management with extension officers monitoring them. Rhizobial inoculation, liming and basal compound fertilizers and promiscuous versus specific nodulating soyabean varieties were tested. Both farmers and extension personnel helped to set up and monitor experiments and gained valuable experience and confidence in managing a soyabean crop. Scientific data obtained was used to strengthen the extension messages that had hitherto been extrapolated from work done in large-scale commercial production under somewhat different agro-climatic conditions.

For the promotion aspect, the main strategies were: **training** of both farmers and extension staff on how to apply rhizobial inoculants, how to grow, weed and harvest soyabean; **facilitating access to inputs**, setting up technology transfer **demonstrations** that **involved farmers and extension staff**, regular **follow-ups** and **communication in local languages** at all times. Train-the- trainer workshops targeted extension staff in AGRITEX, NGO personnel and farmer leaders identified by their organizations and employed a hands-on practical approach. Topics included how to store and apply rhizobial inoculants, use of promiscuous varieties where inoculants are unavailable, how to check if nodules are effective, identification of pests and diseases and their control.

Training was consolidated by a vigorous program of field discussion days that acted as a field laboratory course for farmers and extension staff. Local traditional and political leaders were invited to field days to raise the profile of the promotion and facilitate more rapid evaluation and information dissemination on soyabean BNF technologies.

Access to inputs was facilitated by mobilizing stakeholders in agro-industries to deliberately stock inputs in rural areas where demand had been created by the training and promotion program. Introductory inputs packages containing seed, rhizobium inoculant, lime and basal fertilizer sufficient for 0.1 ha per soyabean variety were put together and distributed at a slightly subsidized cost to ensure that the crop had all required nutrients. Adequate marketing arrangements were put in place to handle all surpluses.

Soyabean as Human Food

Soyabean has up to 40% protein, 20% oil, 30% carbohydrate, 10% fibre and numerous vitamins and anti-oxidants, making it perhaps the single most nutritionally balanced food crop available today both in terms of energy and protein. Combined with maize, soyabean provides a complete diet with all essential amino acids. The potential of soyabean to reduce or eliminate the incidence of malnutrition is very significant and makes it an attractive legume to introduce across many African environments with compatible agro-ecological conditions.

The Soyabean Promotion Task Force in Zimbabwe set up a team of food scientists and extension specialists who first identified and then developed simple ways to eliminate anti-nutrition factors found in soyabean. They developed various recipes and ran numerous soyabean processing training workshops at rural service centers and train-the trainer workshops for rural women. Various women's groups subsequently adapted and developed their own new recipes compatible with local food tastes and preferences. The most significant development is that rural communities now use soyabean to substitute for many expensive grocery items that include soya milk, soya 'coffee', soya flour for making cakes, bread, pastries and nutritious soya-based relishes replacing expensive meat. Currently, research is continuing both at the University of Zimbabwe and at the Department of Research and Extension (Ministry of Agriculture, Zimbabwe) to look at the quality, nutritional value and shelf life of some of the soya-based foods being prepared by village women with a view to scaling up and commercializing production. The Nigerian experience of commercializing soyabean-based products at a local level has some important lessons for the promotion program in Zimbabwe (Sanginga, N. pers. comm.). The overall outcome of training women in processing and utilization of soyabean as food at household level has seen a huge increase in the number of families adopting the crop. With time, this should translate into significant improvements in community health and nutrition.

Soyabean as Livestock Feed

Farmers growing soyabean generate large amounts of crop residues, which contain more protein than for example, maize stover. Many are already feeding their residues and grain to livestock. The benefits to the farmers include better draught power for timely land preparation at the start of the cropping season, higher milk, meat and hides production. The manure from animals is an important soil organic amendment for resource-poor farmers who cannot afford adequate mineral fertilizers. For many African farmers, livestock represent a critical investment or "money in the bank", as they can be sold to meet food and other budgetary needs of the family.

The lowest loop on our conceptual model (Figure 1) emphasizes the link between soyabean BNF and cash income. Each soyabean harvest provides food, seed and surplus for sale. In the Zimbabwean model, the Task Force working with farmer's organizations, commodity brokers and processors put in place marketing arrangements to ensure that farmers received fair prices for their soyabean grain. The key to success has been effective load consolidation, identification of lucrative markets and affordable transport. Initially volumes were small and marketing costs very high, but as more farmers took up the crop, volumes increased allowing for economies of scale. A comprehensive study to analyze the economic potential of soyabean showed that there are '...potential benefits ... for smallholder farmers, particularly the poorer smallholders ...' in Zimbabwe (Rusike et al. 2000).

For the adoption rate to be sustained, there was need to coordinate the efforts of many stakeholders that are involved. Figure 2 illustrates the range of possible linkages that are involved in the soyabean BNF research –extension program in Zimbabwe. To facilitate coordination, a unit for that purpose was established in 2000 under the Promotion Task Force. Its major function was to provide technical backup and training to various groups engaged in soyabean production and to mobilize stakeholders. Currently stakeholders are setting up a soyabean development trust to take over coordination of all stakeholder activities in research production, processing, marketing and training in the whole country.

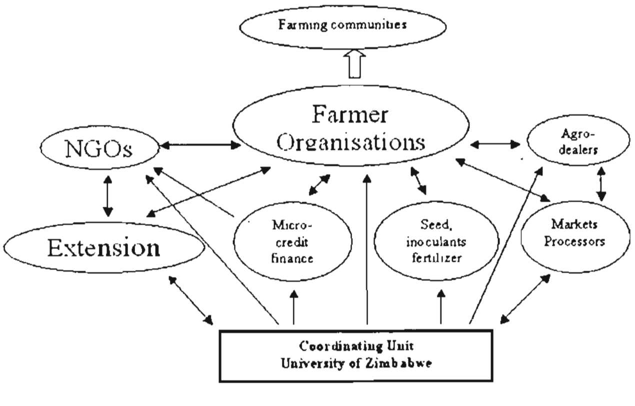

Figure 2. Coordination linkages of stakeholders in the soyabean promotion program in Zimbabwe. Key activities in the links include training, information exchange, adaptive research and movement of inputs, outputs and cash.

Outcomes

In general the research-extension program has successfully introduced and brought benefits of soyabean BNF to thousands of smallholder families in Zimbabwe. Promiscuous soyabean has enabled farmers with no access to commercial inoculants also to adopt soyabean. Up to 50% of soyabean produced in Hurungwe district in northern Zimbabwe in the last four seasons (1998 –2001) was promiscuous, while in Zambia and Malawi promiscuous Magoye still forms the backbone of smallholder soyabean production (Javaheri, 1996). Promiscuous soyabean forms the bulk of varieties planted in Nigeria. Below we summarize results from various research initiatives undertaken within the conceptual framework described to illustrate the kinds of information being generated.

Quantities of N fixed by promiscuous and specific soyabean varieties under field conditions were measured (Table 1). In demonstrating the residual soil fertility benefits of rotating maize with soyabean, yields of both grain and stover were quantified.

Yields of maize following soyabean were significantly higher than those of maize after maize, demonstrating significant residual fertility effects of soyabean (Table 2). Residual effects ensure sustainable food production in a soyabean maize rotation. Soya-

Table 1. Nitrogen yields from promiscuous and specific (improved) soyabean varieties at Hotera smallholder farm, Hurungwe, Zimbabwe, 1997

Soybean variety	% N derived from fixation		Fixed N (kg/ha)	
	- Inoculation	+ Inoculation	- Inoculation	+ Inoculation
Magoye	91	90	73	58
Local	90	90	57	58
Roan	91	88	63	66
Nyala	92	82	46	58
s.e.d	3.8		15.8	

'Magoye' and 'Local' are promiscuous; 'Roan' and 'Nyala' are specific commercial varieties. (Adapted from Kasasa et al. 1998).

Table 2. Maize yields over two seasons following soyabean in a sandy loam soil in a smallholder farm, Hurungwe, Zimbabwe, 1998-99

Soyabean variety (96/97)	Soyabean biomass incorporated (t/ha)	Maize yields (t/ha)	
		97/98	98/99
Magoye (prom)	5.4	2.3	1.2
Local (prom.)	4.9	2.1	1.4
Roan (spec.)	3.2	1.8	0.9
Nyala (spec.)	2.8	1.4	0.8
Maize control	Nil	0.19	0.2

Prom - promiscuous; Spec. - Specific

bean residual fertility effects on maize have been demonstrated under farmer management, boosting adoption of soyabean BNF by smallholder farmers. Mineral fertilizer inputs (e.g. Cu, Mg, P, K) will continue to be required to prevent nutrient mining of soils. Extension messages must continue to emphasize the critical importance of inorganic fertilizer amendments.

An important benefit of soyabean BNF has been the boost in household incomes from grain sales by farmers (Table 3). A critical element in the promotion program was the consolidation of loads so that economies of scale have enabled the relatively small production by each farmer to be sold on the lucrative commodity exchange as part of a large batch. Thus the conceptual model for promoting BNF includes produce marketing as a key element.

A study of the economic potential of soyabean showed that the crop was most profitable for the poorest farmers as it had lower input costs but gave the highest return on investment (Rusike et al. 2000). Poor farmers who adopted soyabean for the first time between 1997 and 2001 have testified that they earned more money from soyabean sales than from any other crop that they have ever grown (Table 4). The significant boost in family dietary protein availability (Table 4) is a critical element of household food security, a key benefit of BNF among rural communities where poor nutrition among the HIV-infected is contributing to the high death toll from AIDS related illnesses.

Table 3. Soyabean grain sales by smallholder farmers from four locations over 4 marketing seasons in Zimbabwe

Location	Amounts sold (metric t)			
	96/97	97/98	98/99	99/2000
Guruve	6.2	53	153	210
Kazangarare	58	280	475	580
Sadza	0.5	3.5	7	10.2
Senge	0.2	6	11	18.1
Total sold	64.9	342.5	646	818.3

Only sales facilitated by the Soyabean Promotion Task Force are reflected; farmers also used other marketing outlets.

Table 4. Grain, protein and cash returns from soyabean for Tapera smallhold farm in Zimbabwe (1998)

Soyabean variety	Total grain yield (kg/ha)	Protein from 15% seed retained (kg/ha)	Cash from 70% grain sold (US$ equiv)
Magoye	2100	126	471
Local	1900	114	302
Roan	2800	168	496
Nyala	3100	186	560

Average smallholder planting: 0.4 ha; average yield: 0.8 t/ha; average price: US $360/t (2001).

Conclusions

Our experiences with developing and implementing a research-extension model for promoting BNF technology among peasant farmers in Zimbabwe offers lessons for similar initiatives in developing countries. Previous experiences of promoting promiscuous soyabean in Nigeria (N. Sanginga, pers. comm.), Malawi and Zambia (Mpepereki et al. 2000) also point to the need for integrated approaches that address both the scientific-technological and socioeconomic aspects in a holistic way (closing the loop). Demonstration of multiple benefits of N-fixing soyabean, use of promiscuous varieties, training women in home processing, adapting soyabean to local diets and facilitating input/output marketing (all carried out in the context of a clear conceptual framework with stakeholder participation), have resulted in rapid adoption of soyabean by thousands of smallholder farmers, thereby strengthening their food security in a sustainable way. An integrated program of adaptive and applied research to support the soyabean BNF promotion initiative has provided a scientific basis for a technical backup service to adopting farmers. The success of such a promotion program depends on the number of actual and demonstrable benefits to the smallholders and the commitment of all stakeholders to implement its various facets in a coordinated way. Marketing, both in terms of inputs and outputs, is a key driving force for soyabean BNF technology adoption. More BNF grant funds must go into activities that directly benefit farm families than project personnel salaries and per diems. Legume BNF can make a difference to rural livelihoods.

Acknowledgements

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RESPONSE OF BEAN (*PHASEOLUS VULGARIS*, L.) CULTIVARS TO INOCULATION AND NITROGEN FERTILIZER IN ZAMBIA

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Abstract

Bean is an important component of the diet of people of Zambia, and many farm households grow it for subsistence and barter in their communities. However, grain yields are low, typically 500 to 700 kg ha^{-1} with local cultivars and without supplemental nitrogen fertilizer application. Many soil and plant factors have been investigated to explain these low yields, but there is still limited information on the contribution of soil fertility, variety and inoculation to improvement in bean yields. A field study was conducted to evaluate the response of bean cultivars to applied nitrogen fertilizer and to inoculation with native and introduced rhizobium strains. The experiment was set up as a 5 x 5 factorial design comprising 25 treatment combinations of five common bean cultivars and five nitrogen sources (3 strains and 2 nitrogen fertilizer levels). The treatments were replicated four times and arranged in a randomized complete block design at Mount Makulu Central Research Station, Chilanga, Zambia. The data collected included nodule count, dry nodule weight, dry shoot weight, total nitrogen content in shoots and grain weight. The amount of nitrogen fixed by the inoculated crop was estimated by the difference method, using wheat as the non-fixing control crop. The results show that a combination of some strains with some cultivars tested is as effective as applying nitrogen fertilizer to the crop. An effective strain such as TAL1383 increased grain yield by 38.2% with some cultivars compared to the average grain yield of the other four strains with other cultivars. The local strain isolated from nodules of common beans grown locally was comparable to introduced strains in Mbala and Lundazi cultivars. The reduction in biological nitrogen fixation (BNF) by inorganic nitrogen application was more with the Lundazi cultivar than other cultivars. The native rhizobia strains at the trial site were as effective as the introduced strains. This study has shown that optimization of the effect of inoculation lies in identifying and matching bean cultivar to Rhizobium strain. Therefore, because of strain/cultivar specificity, it may be advisable to develop a broad-spectrum inoculum for use with bean cultivars in Zambia.

Key words: N_2-fixation, N fertilization, rhizobium strains, common bean

Introduction

Beans are produced for both domestic consumption and sale in Zambia. Some bean leaves are consumed as a vegetable, and only cultivars with palatable leaves are consumed; other cultivars have tough textured leaves. The major production areas in this country are the high rainfall areas of Northern, Northwestern, Luapula Provinces and medium to high rainfall areas of Eastern and Central Provinces. In other provinces, production of beans is on a small scale.

Most farmers prefer to grow local cultivars for their colour and taste. However, average grain yields of local cultivars are exceptionally low (500 –700 kg ha^{-1}) even under commercial production (Annual Report, 1978). Beans experience a deficient in nitrogen, which results in poor yields (Lupwayi and Mkandawire, 1996).

To improve bean yields, in the absence of effective rhizobia, it is recommended to apply nitrogen fertilizer. However, most resource-poor small-scale farmers are unable to afford N fertilizers. The cheaper option, therefore, is to exploit Biological Nitrogen Fixation (BNF) through inoculation with Rhizobia, and use bean genotypes that respond well to inoculation. Lupwayi and Mkandawire (1996) made similar observations to other researchers, that inoculation with some strains of rhizobia increased yield in common beans.

Some factors may cause failure of applied inoculum to increase grain yield. According to Weiser et al. (1985), soil pH, low phosphorus, high levels of exchangeable aluminium and manganese, poor nutritional status, and water stress may limit nodulation and nitrogen fixation. Further, high levels of applied N or soil N can inhibit nodulation (Munyinda, personal communication). Nodulation and N_2 fixation is also influenced by climatic factors such as light (Antoninew and Sprent, 1978), temperature (Rennie and Kemp, 1981) and cultural aspects such as planting density (Graham and Rosas, 1978).

In Zambia, very little research work has been conducted on the inoculation of common bean. A great deal of research work has been biased towards soyabean. Although there are numerous bean cultivars and native rhizobia strains, these have not been identified and exploited. Therefore, extensive screening of bean landraces for N_2 fixation is required throughout Zambia.

The objectives of the study were a) to evaluate the response of some cultivars of common bean to inoculation using native and introduced rhizobia strains, b) to identify effective strain/cultivar combination for optimal N_2 fixation and c) to evaluate the response of common bean to nitrogen fertilizer application.

Materials and Methods

The field experiment was conducted during the 2001/2002 cropping season at Mt. Makulu Central Research Station located 15° 32'S 20° 15'E near to Lusaka, Zambia. The station received 617.5 mm annual rainfall, though normally the area receives between 800 and 1000 mm rainfall annually.

The land used for the trial had not been previously planted to any legume. Sorghum was grown during the immediate previous cropping season (2000/2001). Before planting, soil samples were taken at random for analysis to establish the initial fertility status of the site. The initial physical and chemical characteristics of the soil at the trial site are given in Table 1.

The experiment was set up as a 5 x 5 factorial design comprising 25 treatment combinations of five common bean cultivars/varieties and five nitrogen sources (3 inoculum strains and 2 nitrogen fertilizer levels). The treatments were replicated four times and arranged in a randomized complete block design.

Each treatment plot measured 3 m x 1.5 m, with four crop rows spaced at 50 cm apart. The harvest area for grain yield was a sub-plot of 2 m x 1 m, and the two outer rows were used for sampling. Each plot was isolated from the adjacent plot by a border of 0.5 m.

Table 1. Initial physical and chemical characteristics of the soil used

Texture	Sand Clay Loam
pH $CaCl_2$	7.2
Organic Carbon	1.37%
Total Nitrogen	0.09%
Available Phosphorus	13 mg kg^{-1}
Potassium	0.84 cmol (+) kg^{-1}
Calcium	42.8 cmol (+) kg^{-1}
Magnesium	2.1 cmol (+) kg^{-1}
Zinc	11.0 mg kg^{-1}
Iron	98 mg kg^{-1}
Manganese	456 mg kg^{-1}

Five bean cultivars were evaluated; three landraces (Mbala, Solwezi and Lundazi) and two improved varieties (Carioca and Pembela). An improved wheat variety (Coucal) was used as a reference crop for N_2 fixation. Two exotic rhizobia strains (CIAT 899 and TAL 1383), one local isolate and native rhizobia at the experimental site used as a control were evaluated. Nitrogen was applied at two rates of 0 and 100 kg N ha^{-1}. The nitrogen was applied as a split, 20 kg N ha^{-1} at planting as compound D (N P K S: 10:20:10:10) and 80 kg N ha^{-1} as urea at 25 Days After Sowing (DAS).

The beans were planted in rows 50 cm apart and 10 cm within the row. The planting depth was approximately 4–5 cm deep, and one seed per station. Wheat was grown in adjacent plots to the beans and it was drilled in rows 50 cm apart. Weeding was carried out by hand hoeing in all the plots at 17, 28 and 45 DAS.

Five plants from the discard rows of each plot were randomly sampled at 50% flowering or 5-6 weeks after sowing. After thorough washing the nodules were detached, counted and then dried in an oven at 65°C for 48 hours to obtain nodule dry weight. The shoots were dried in the oven at 70°C for 48 hours to obtain shoot dry weight.

The Nitrogen Difference Method by Hansen (1994) was used to determine the amount of nitrogen fixed. The fixed N was calculated from:

N_2 fixed = Nl - Nnf
where :
Nl is the N accumulated by the fixing legume and
Nnf is the N taken up by the reference crop.

The data were analyzed using the Genstat statistical package. The means were separated using the Duncans multiple range test.

Results and Discussion

Response to Inoculation

The results show that nitrogen sources had a significant ($P<0.05$) effect on nodule numbers (Figure 1). Pembela had a significantly lower number of nodules ($P< 0.05$) than other cultivars. Pembela had only a third of the nodule number compared to the average of the other four cultivars.

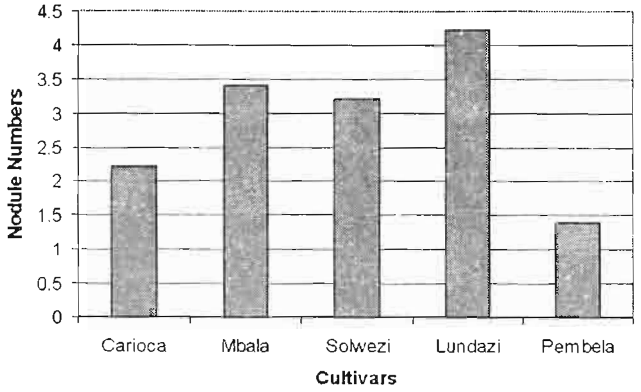

Figure 1. Nodule number for bean cultivars following inoculation and fertilization

Results of percent nitrogen content are presented in Figure 2. There was a significant interaction between nitrogen source and variety/cultivar. The highest percent nitrogen content was obtained from the inorganic nitrogen source followed by CIAT 899. All the cultivars responded to inorganic nitrogen application except Lundazi. All the varieties also responded to CIAT 899 except Mbala, but the response was greater with Carioca and Lundazi than with the other three cultivars.

Results of nitrogen fixed by cultivars are presented in Figure 3. There was a significant difference ($P < 0.05$) between cultivars and nitrogen sources. CIAT 899 was more effective than other strains across all the varieties except Mbala, but it was most effective with Carioca and Lundazi. Pembela only responded to TAL 1383.

The native rhizobia at the trial site were as effective as CIAT 899 with Solwezi and Pembela. Carioca was less sensitive to the reduction of BNF by inorganic nitrogen. The reduction in BNF by inorganic nitrogen was more in Lundazi than other cultivars. Deibert et al (1978) reported that nitrogen levels above 45 kg ha^{-1} inhibited nitrogen fixation in soybeans, and the trend was the same in Lundazi. This result suggests that if Lundazi is to be grown with inoculum, the levels of inorganic N in the soil should not be excessive (greater than 100 kg N ha^{-1}).

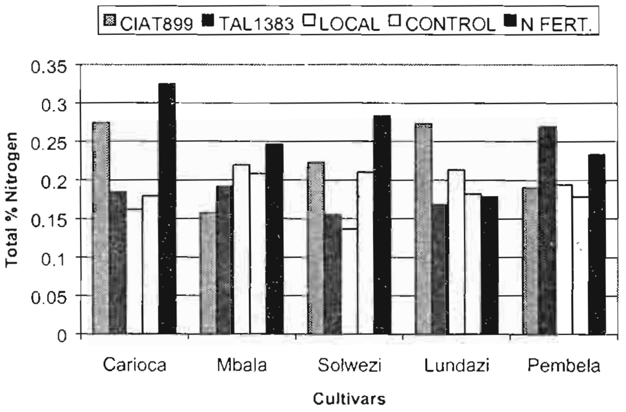

Figure 2. Effect of N source on % N of bean cultivars

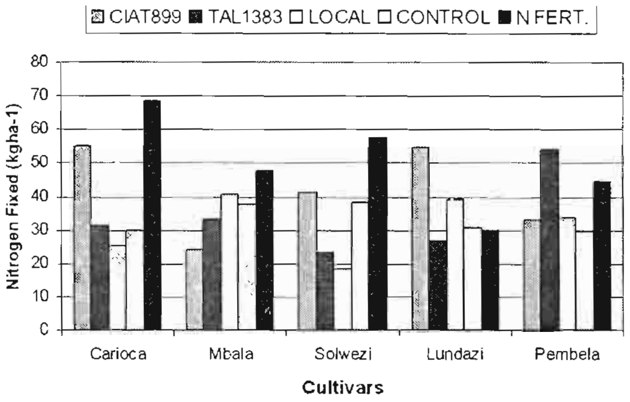

Figure 3. Nitrogen fixed by bean cultivars following inoculation and fertilization

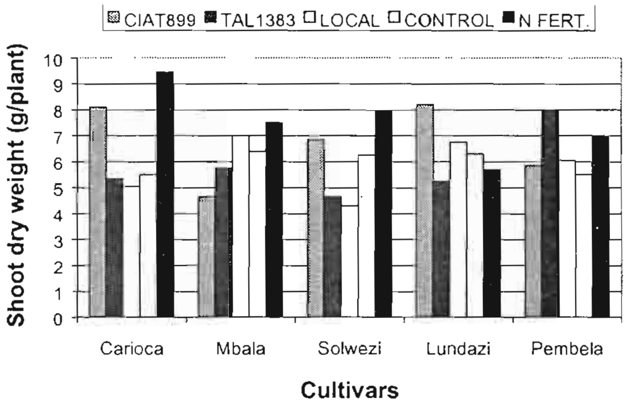

Figure 4. Effect of N source on shoot dry weight of bean cultivars

Effect of inoculation on yield

Results of the shoot dry weight and grain yield are presented in Figures 4 and 5. There was a response of shoot dry matter to nitrogen across the varieties. CIAT 899 was more effective than other strains in increasing dry matter yields across varieties. The effect was more for Carioca, Solwezi and Lundazi, than in Mbala and Pembela. This effect was comparable to the application of inorganic nitrogen. The local isolate was as effective as the introduced strains in Mbala and Lundazi, and in Mbala it was even more effective than CIAT 899. The native rhizobia strains at the trial site were as effective as the introduced strains in Mbala, Solwezi and Lundazi. TAL 1383 was specifically selective to Pembela.

There was a significant yield increase ($p < 0.05$), with application of inoculum and inorganic nitrogen fertilizer. The increase was greatest in Lundazi with inorganic nitrogen application and least in Pembela. Overall TAL 1383 was more effective than other strains in increasing grain yield across the cultivars, and it was even more effective in Lundazi

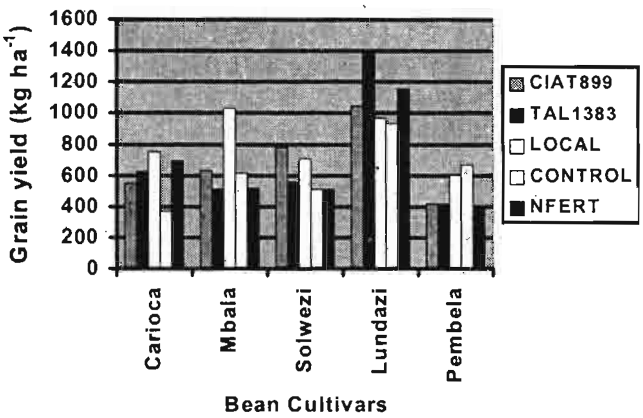

Figure 5. Effect of N source on grain yield of bean cultivars

where it showed a 38.2% increase in grain yield. CIAT 899 and the local isolate were comparable in Mbala and Lundazi. In Pembela, the native rhizobia strains at the trial site were as effective as other strains in increasing grain yields.

Conclusion

The response to inoculum was variable and was specific to cultivar, strains and level of inorganic nitrogen. The local isolate was comparable to introduced strains in Mbala and Lundazi. The native rhizobia at the trial site applied to cv. Solwezi were as effective as the other strains. Lundazi in association with native strains was very sensitive to the reduction in BNF by inorganic nitrogen. Therefore, it is important to carry out soil analysis to establish soil nitrogen status. Careful selection of cultivars and strains is also important. The right combination of strains with some cultivars was as effective as applying nitrogen fertilizer to the crop. The right legume cultivar and inoculum strain combination thus provides an opportunity for increasing bean yields in Zambia. This study has demonstrated the importance of strain cultivar specificity.

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ROLE OF PHOSPHORUS AND ARBUSCULAR MYCORRHIZAL FUNGI ON NODULATION AND SHOOT NITROGEN CONTENT IN GROUNDNUT AND LABLAB BEAN

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Abstract

*Rotations with legumes have been suggested as a means to increase cereal production in low-input agriculture in Zimbabwe, as cereal yields are currently limited by nitrogen (N). However, N_2 fixation by legumes is often phosphorus (P) limited. Soil available P explained 67% of the variation in nodule numbers when groundnut was grown on a wide range of soils collected from subsistence farmer's fields in southern Zimbabwe. P applications on a luvisol and vertisol in Tsholotsho, south-western Zimbabwe, can significantly increase nodule mass, aboveground biomass and total N in residues of groundnut (*Arachis hypogaea *L), lablab bean (*Lablab purpureus*) and pigeonpea (*Cajanus cajan *(L) Millsp.). However, P fertilizers are often beyond the economic means of subsistence farmers. The success of the legumes therefore, will strongly depend on their ability to utilize the P already in the soil. Arbuscular mycorrhizal fungi (AMF) are components of most natural ecosystems and form a symbiosis, arbuscular mycorrhiza, with approximately 80 percent of all terrestrial plants. The fungi can increase plant P uptake by increasing the surface uptake area. We have shown in a pot trial that by enhancing the AM colonization through an inoculation with AMF in a luvisol from Tsholotsho, nodule number and N content of the shoot significantly increased in groundnut and lablab bean. This study indicates that by exploring the biology of the agro-ecosystem, beneficial effects could be obtained by optimizing the mutualistic interactions between the plant, bacteria and fungi. Ways to enhance AMF inoculum potential in the fields of subsistence farmers are currently being tested and are discussed.*

Key words: Arbuscular mycorrhiza, rhizobia, phosphorus, groundnut

Introduction

A majority of subsistence farms in Zimbabwe occur on communal land. Maize (*Zea mays*) is grown as a staple, often on nutrient depleted sandy soils low in organic matter (Grant 1967, 1981, 1985). Inorganic fertilizers, once subsidized by the government, are scarce in rural areas and often beyond the economic means of subsistence farmers (Mapfumo and Giller, 2001). With declining maize yields due to nitrogen (N) limitations (Snapp, 1998), there has been renewed interest by researchers in using N_2 fixing legumes in intercropping and rotational cropping systems to increase soil fertility (Snapp et al., 2002; Ma et al., 1998), a common practice in much of southern Africa prior to the introduction of mineral fertilizers (Howard reprinted in Small Farmer's Journal, 1999).

Groundnut (*Arachis hypogaea* L), cowpea (*Vigna undiculata* (L) Walp.) and bambara groundnut (*Vigna subterranean* (L) Thou.) are currently grown for huan consumption and animal feed in Zimbabwe. However, their capacity to improve soil fertility might be limited for at least two reasons. First, they are all grain legumes where much of the N is translocated to the seeds and removed from the field at harvest. Second, optimal N_2 fixation might be limited by phosphorus (P), as soil P availabilities are generally low in the old, highly weathered soils of sub-Saharan Africa (Warren, 1992; Buresh et al., 1997; Giller, 2001).

In a previous experiment we have shown that when groundnut was grown on a wide range of soils collected from subsistence farmer's fields in southern Zimbabwe, nodule numbers differed by an order of magnitude. Further, soil available P explained 67% of this variation (Besmer et al., unpublished), suggesting the importance of this element for nodulation and N_2 fixation. Applications of P (40 kg P_2O_5/ha) to two soils from Tsholotsho, a luvisol and vertisol (Moyo, 2001), both low in P, significantly ($p<0.05$) increased nodule mass and amount of N in residues of lablab bean (*Lablab purpureus*), pigeonpea (*Cajanus cajan* (L) Millsp.) and groundnut (Besmer et al., unpublished). However, since legumes are considered low value crops, few subsistence households are willing to invest in expensive P fertilizers. The success of the legume and of the subsequently grown maize crop therefore, will largely depend on the ability of the legume to utilize the P already in the soil.

Arbuscular mycorrhizal fungi (AMF) colonize roots of about 80% of terrestrial plant species and can increase plant P uptake by increasing the surface uptake area (Koide 1991). Synergistic effects on legumes are frequently seen when both symbionts (the rhizobia and the fungi) are present (Goss and de Varennes, 2002; Sanginga et al., 1999; Fitter and Garbaye, 1994). Both nodule number and dry weight usually increase after mycorrhizal colonization (Reddy and Bagyraj, 1991), which is often explained by increased P uptake by the fungi. While mycorrhizal fungi are components of most natural ecosystems, their abundance and efficacy can be severely retarded by common agricultural practices such as fallowing, soil disturbance through tilling and weed management, and prolonged cultivation of non-host plants (Boswell et al. 1998; Kabir et al., 1997; Douds et al. 1995; Harinikumar and Bagyraj, 1989).

The objective of our work was to understand the role of AMF for legume performance in subsistence farmers' fields, and to determine if an enhanced AMF abundance can promote nodulation and N_2 fixation. In this paper we discuss the results of two pot experiments. In Experiment 1, the effect of an altered AMF abundance on nodulation and shoot N content on groundnut was determined by enhancing the AMF abundance through an inoculation with a common AMF, or by reducing the indigenous AMF abundance through a fungicide application. In Experiment 2, the abundance of indigenous fungi was enhanced and the effects on nodule number, nodule mass and shoot N content were determined on lablab bean. Groundnut was chosen since it is a common legume grown by the subsistence farmer in Zimbabwe, and lablab bean because it is a green manure crop and therefore has a higher potential to improve soil fertility.

Material and methods

General

The soil used in both Experiment 1 and Experiment 2 was a Tsholotsho luvisol (from Simeon Moyo's farm) where legume P limitations had been demonstrated previously. The pH of the soil was 6.2 (1:2 V soil: V water), and available P was 1.2 ppm (Olsen). Soil was collected to a depth of 15 cm in December 1999, for Experiment 1, in April 2001 for the inoculum production part of Experiment 2, and in November 2001, for the inoculation part of Experiment 2. For Experiment 1 the soil was collected randomly from the field where plants were currently grown and no fertilizers had been added, and for Experiment 2 from areas where maize had been grown the previous year without fertilizer additions.

Experiment 1

Groundnut (var. Falcon) was planted on December 28 1999, in 1.6 L pots and grown for 6 weeks in soil amended with P [2 g single superphosphate pot^{-1} (19% P_2O_5)], AMF (2000 spores pot^{-1} of *Glomus intraradices*, Schenk and Smith), a fungicide Benomyl (200 mL of 0.1% solution added one day prior to planting), or control consisting of non-sterile soil. No additional fertilizers were added and the plants were watered as needed. At harvest, nodule numbers were determined along with shoot N and P concentrations and AM colonization using standard procedures (Brundrett et al., 1996; Watanabe and Olsen, 1965; Jensen 1962).

Data were analyzed using a one-way ANOVA and transformed where appropriate. When transformation failed to generate data that fulfilled the underlying assumptions, data were analyzed using nonparametric tests.

Experiment 2

Production of AMF and control inoculum

Maize was planted in the soil in July 2001, and grown for three months to enhance the abundance of indigenous AMF. Control pots consisted of maize grown in sterile soil that had been given spore washings containing soil bacteria and fungi but lacking AMF. The plants were fertilized six times with Peters fertilizer 15-0-15NK plus micronutrients (at a N concentration of 100 ppm) and amended with 0.15 g/L $MgSO_4$ and 5 mg P/L as KH_2PO_4. After three months the maize plants were allowed to wilt, and dry soil and cut root pieces served as a source of inoculum, which consisted of AMF spores, external hyphae and colonized root pieces. The control roots were non-mycorrhizal.

Inoculation experiment

Lablab bean (var. Rongai) was planted on 3 November 2002, in pots amended with either 200 mL control inoculum or 200 mL of AMF inoculum, and grown for 7 weeks and watered as needed. At harvest, nodule number and weight were recorded, AM colonization determined and shoot N and P concentration measured (Brundrett et al., 1996; Watanabe and Olsen, 1965; Jensen 1962). Data were analyzed using a one tailed paired t-test where +AMF and control pairs shared the site origin from the field.

Results

Experiment 1

Enhancing AMF in the test luvisol significantly increased AM colonization compared to the control (Table 1). This resulted in a doubling in nodule numbers and a significantly higher N content in the shoot. There was a strong beneficial effect of P on the number of nodules, which resulted in almost a doubling in N content in the shoot. However, interestingly, P was more efficient than a fungicide in lowering the AM colonization. Fungicide applications did not differ significantly from the control in any of the variables measured.

Experiment 2

Enhancing the indigenous AMF abundance resulted in a significantly higher AM colonization, nodule mass and N concentration in the shoot (Table 2). There were no significant differences between control and +AMF in shoot weight and shoot P concentration.

Discussion

Many factors need to be considered when trying to optimize the soil fertility benefits of legumes. Differences in residue quantity and quality among legumes grown under various conditions need to be documented, and factors limiting legume performance need to be established. We have shown here by exploring the biology of the agro-ecosystem that beneficial effects could be obtained by optimizing the mutualistic interactions between the plant, bacteria and fungi. Nodule number and mass in groundnut and lablab were significantly enhanced by a higher abundance of AMF when the legumes were grown in a low P luvisol. This resulted in more N in the shoot tissue, a key element for optimizing maize production.

Beneficial effects of AMF on nodulation have been documented before (Goss and de Varennes, 2002; Ahiabor and Hirata, 1994; Reddy and Bagyraj, 1991) and have often been linked to the increased P uptake provided by the fungi. However, even though AM colonization levels were higher in the +AMF treatment in our experiments, shoot P levels were not significantly increased. If the AMF effect is P mediated, should this not be reflected in an increased shoot P content? One possible answer to this is that the amount of P needed for optimal nodulation is an order of magnitude lower than for optimal growth of plants (Gates and Wilson, 1974). Since available P in the luvisol soil in this experiment was very low, it is possible that the small amount of additional P taken up in the +AMF treatments remained in the roots and promoted nodulation. In that case, differences would not be detected in the shoot tissue. Analyses of nodule P contents in lablab are currently underway to address this issue. Further, unlike many previous experiments, the control plants in our experiments were mycorrhizal, so differences between +AMF and control plants were likely to be smaller than what is normally presented when the control plants are non-mycorrhizal.

Table 1. Effect of P, enhanced AMF and a fungicide on groundnut grown in a luvisol soil collected from a subsistence farmer's field in Tshlotshlo. Different superscripts indicate a significant ($p < 0.05$) difference between means, n = 5.

Treatment	Shoot DW (g)	Nodule (per plant)	AM (%)	P content (mg shoot^{-1})	N content (mg shoot^{-1})
Control	1.0 ^{bc}	75 ^{c}	25 ^{b}	1.1 ^{b}	27 ^{c}
AMF	1.2 ^{ab}	144 ^{b}	57 ^{a}	1.9 ^{b}	36 ^{b}
Fungicide	0.7 ^{c}	43 ^{c}	13 ^{bc}	0.9 ^{b}	20 ^{c}
Phosphorus	1.3 ^{a}	290 ^{a}	1 ^{c}	6.9 ^{a}	46 ^{a}

Table 2. Effect of enhanced indigenous AMF on lablab bean. Control consisted of non-sterile soil collected from a subsistence farmer's field in Tsholotsho. Different superscripts indicate a significant ($p < 0.05$) difference between means, n = 10.

Variable	Control (non-sterile soil)	+AMF (non-sterile soil + AMF)
Shoot DW (g)	3.3^{a}	3.6^{a}
Nodule mass (mg plant^{-1})	48.6^{b}	202.1^{a}
Shoot N concentration (%)	1.8^{b}	2.2^{a}
Shoot P concentration (%)	0.11^{a}	0.11^{a}
AM colonization (%)	54.0^{b}	74.5^{a}

We are not proposing large-scale inoculation projects as an outcome of these results. Rather, the abundance of indigenous fungi should be increased. In temperate agro-ecosystems, it has been shown that fungal abundance is affected by tillage and fallow practices (Boswell et al. 1998; Kabir et al., 1997; Douds et al. 1995; Harinikumar and Bagyraj, 1989), but little is currently known about the effects of common management practices by subsistence farmers in the semi-arid tropics. Based on this, AMF responses to tillage timing and fallow period are currently being investigated on subsistence farmers' fields. It is important to remember though, that even if AMF abundance is increased through a change in current management practices and beneficial effects on legume performance observed, it is not a sustainable substitute for P fertilizers. Whatever P is brought from the soil in harvestable products or animal feed need to be replenished. Nevertheless AMF can contribute to a better utilization of the P applied to the system, thereby reducing the amounts and frequency of P application in a sustainable agro-ecosystem.

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SOYABEAN YIELD RESPONSE TO DIFFERENT RHIZOBIAL INOCULATION RATES ON SELECTED SANDY SOILS IN ZIMBABWE

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Abstract

The recommended rhizobial inoculation rate for soyabean (Glycine max *(L)) seed in Zimbabwe of 80 g (10^8 cells g^{-1}) inoculant for 100 kg seed has generally resulted in unreliable nodulation on the sandy soils that predominate in most smallholder areas. In this study, it was hypothesized that a higher seed inoculation rate would improve soyabean grain yield in the smallholder sector. The trial was set up during the 2001/2002 season in two districts, Guruve and Goromonzi, to determine appropriate inoculation rates for maximum soyabean grain yield on sandy soils of the smallholder sector in Zimbabwe. Two soyabean varieties, Solitaire and Storm, were inoculated with a commercial rhizobial inoculant containing* Bradyrhizhobium japonicum *(strain MAR 1491) at the following rates: 80 g inoculant per 100 kg of seed (the recommended rate), and 2, 3, 5 and 10 times that recommended rate. Seeds were sown at the rate of 100 kg ha^{-1} in 5 m x 3.6 m field plots arranged in a randomized block design, with each inoculation rate replicated four times. Eight weeks after planting, whole plant samples were dug up from the guard rows of each plot and checked for nodulation. Plants were harvested from 3 m x 3 m net plots at maturity to determine seed and stover yields. Results showed a significant increase in grain and stover yields as well as primary root nodulation with increased inoculation rates for both varieties ($P<0.05$). The grain yield of variety Storm doubled with a ten-times increase in inoculation at the Majuru site and a five-times increase at Kanonama. Findings from this study suggest that an inoculation rate of five times that currently recommended would result in maximum grain yield of soyabean grown on sandy soils in Zimbabwe.*

Key words: Soyabean, Inoculation rate, Nodulation, Seed yield

Introduction

Nitrogen remains the single most limiting nutrient for crop growth in Zimbabwe (Thompson and Purves, 1981). Exploitation of biological nitrogen fixation through seed inoculation offers a unique opportunity to harness "free" fertilizer from a relatively low-cost technology (Mpepereki, Makonese and Giller, 2002). Seed inoculation technology contributes to soyabean productivity and to improving the nutritional quality of grain.

High soil temperatures (Giller, 2001), nutrient deficiencies (Beck and Muns, 1984; Watkin, O'Hara and Glenn, 1997 and O'Hara, 2001), low levels of soil moisture (Boonkerd and Weaver 1982), low pH (<5.5), low clay and organic matter (Dudeja and Khurana, 1989; De Mallora and Izaguirre, 1994) adversely affect rhizobial survival. These conditions are characteristic of most sandy soils in the smallholder (SH) sector of Zimbabwe.

The recommended rhizobial seed inoculation rate for a commercial soyabean crop in Zimbabwe is 80 g (10^8 cells g^{-1}) for 100 kg seed, which is enough seed to plant one hectare. This rate was extrapolated from research specifically designed for large-scale commercial (LSC) sector cropping conditions (Whingwiri, 1996) where soils are loamy to clayey with a high water-holding capacity, along with optimum organic matter, pH and nutrient levels. Use of this rate in the SH sector resulted in unreliable soyabean nodulation and poor grain yield (Davis, 1994) because the harsh soil environment negatively affected rhizobia survival.

The adequacy of the current recommended inoculation rate under SH cropping conditions has been questioned (Davis, 1994). We hypothesized that a higher seed inoculation rate would improve soyabean grain yields under SH cropping conditions, hence we set up an experiment to determine an inoculation rate that would result in maximum soyabean grain yields on sandy soils in Zimbabwe.

Materials and Methods

The trial was set up during the 2001/2002 cropping season in Goromonzi District of agro-ecological region (AER) 2 and Guruve District of AER 3. Average rainfall in AER 2 (705-1000 mm) and 3 (650-800 mm) is suited for soyabean production. Two weeks before planting, soils were sampled (from 0-30 cm depth) in Guruve (Mrs. Kanonama's field) and Goromonzi (Mr. Majuru's field). Both fields were last planted with soyabean in the 1998/1999 cropping season. Maize (*Zea mays*) was grown at both sites during the 2000/2001 season. Cotton (*Gossypium hirsutum*) and common beans (*Phaseolus vulgaris* (L).) were grown at Majuru and Kanonama respectively during the 1999/2000 season. Soil texture was determined using the hydrometer method and organic matter content (%C) by the Walkley-Black method (Nelson and Sommers, 1996). Total soil nitrogen was estimated using the Kjeldahl method (Bremner, 1996). Exchangeable bases were determined using ammonium acetate as the extracting agent (Summer and Miller, 1996). The most probable number (MPN) technique (Vincent, 1970) was used to quantify indigenous rhizobial populations in the soils. The density of *Bradyrhizobium japonicum* (strain MAR 1491) in the commercial inoculants was estimated by plate counts on Yeast Extract Mannitol agar.

Five inoculation rates (the recommended inoculation rate (0.8 g kg^{-1}seed), 2, 3, 5 and 10 times that rate) were tested in this experiment using two soyabean varieties, Storm (determinate) and Solitaire (indeterminate), that nodulate with specific rhizobial strains. Seeds were sown at 100 kg seed per hectare in 5 m x 3.6 m plots that were arranged in a randomized complete block design with four replicates. Basal fertilizer, Compound L (5% N, 18% P_2O_5, 10% K_2O and 0.25% Boron) and lime were applied at rates of 150 kg ha^{-1} and 500 kg ha^{-1} respectively. The crop was weeded at 2 and 6 weeks after sowing. The uninoculated plots were weeded first, then other plots were weeded, taking precautions to avoid cross-contamination by wiping feet, hands and hoes with commercial methylated spirit (10% methanol) before weeding a different plot. Whole plant samples (12) from the guard rows of each plot were dug up and checked for nodulation 8 weeks after sowing. The number of nodules, nodule colour and nodule dry mass (70°C for 24 h) were determined. Plants were harvested at maturity from 3 m x 3 m net plots. Pod number, grain and stover yield, and seed weight of 100 seeds were determined. Analysis of variance of treatment means was done using the GENSTAT statistical package. The expected value (EV) concept (Singleton et al., 1992) was used to express yield increases in monetary terms. [EV = Y (increase in yield resulting from inoculation) x Pr (price of the crop) x P (the probability of obtaining a yield increase under the defined conditions)].

Results

Rainfall amount during the 2001/2002-season rainfall was low at both the Kanonama (416 mm) and Majuru (307 mm) site. Rainfall distribution was poorer at Majuru. Soils at both sites were sandy (<7% clay) and acidic (pH<4.8 0.01M $CaCl_2$) with low organic carbon (0.49 and 0.52%) and total nitrogen (0.02 and 0.03%). The exchangeable bases were low, K^+ (< 0.2 cmol$_+$ kg^{-1}) while Ca^{2+} and Mg^{2+} were less than 1 cmol$_+$ kg^{-1}. Available P was slightly higher at the Kanonama site (Table 1). The indigenous rhizobial population were lower at the Majuru (71 cells g^{-1}) than at the Kanonama site (479 cells g^{-1}) (Table 1).

Inoculants used in this trial contained 4.1 x 10^{8} cells g^{-1}. Hence, for the five inoculation rates used in this study, the rhizobial populations ranged from approximately 7.5 x 10^{4} to 7.5 x 10^{5} cells per seed.

Site x variety x inoculation rate interaction was significant ($P<0.05$) for nodule counts on the primary root (taproot and crown). Nodules on the primary root of variety Storm significantly increased as inoculation was increased from the recommended (0.8 g kg^{-1}) to the highest rate used (8 g kg^{-1}) at Majuru and to 2.4 g kg^{-1} seed (three times the recommended inoculation rate) at Kanonama (Figure 1). Primary root nodulation on variety Solitaire was not significantly different at the 5% level of probability.

Upon dissection to inspect the nodule colour of five nodules from five plant samples, 40-50% of the nodules on Solitaire were observed to be ineffective while 80-100% of the nodules on Storm were effective and the number of effective nodules increased with inoculation rates for both varieties. Soyabean at Kanonama had more ineffective nodules than at Majuru.

There was a positive trend of increased nodule dry matter (DM) with increased inoculation rates. Nod-

Table 1. Rhizobial populations, physical and chemical characteristics of two soils from two smallholder sector fields

	Texture	MPN	pH	pH	%N	%OC	Ca^{2+}	Mg^{2+}	K^+	P
			($CaCl_2$)	(Water)			––(cmol/kg)––			(ppm)
Kanonama	sandy	479	4.79	5.41	0.028	0.52	1.63	0.43	0.19	26.7
Majuru	sandy	71	4.21	5.11	0.021	0.49	0.82	0.47	0.11	21.3

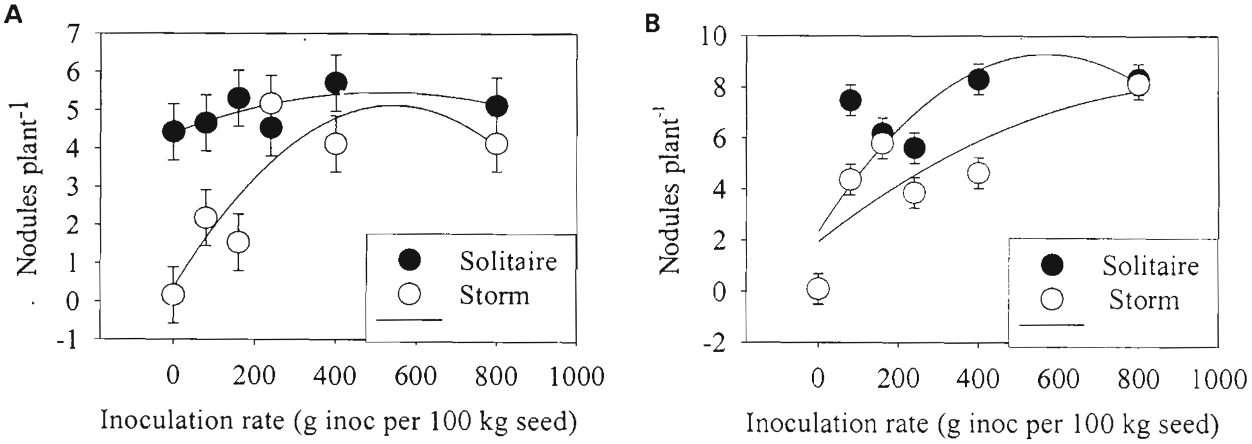

Figure 1. Nodulation on the primary root of two soyabean varieties, Storm and Solitaire, at (A) Kanonama and (B) Majuru as affected by the rate of inoculation

ule DM did not significantly differ with increased inoculation rate at the 5% level of probability but was always higher than the uninoculated control. There was no site x inoculation rate x variety interaction for the nodule DM. Nodules formed on Storm were heavier than those formed on Solitaire at all inoculation rates (Table 2).

Table 2. Nodule dry mass per plant (mg) for two soyabean varieties, Storm and Solitaire, as affected by the rate of inoculation

Variety	Inoculation rate per 100 kg seed					
	0	80	160	240	400	800
Solitaire	37.5	110	112	106.3	118.8	95
Storm	76.5	135	136.5	125	137.5	151.2

s.e.d - 9.4 LSD (5%) - 18.9

Pod count generally increased with increased inoculation for both varieties at both sites (Table 3). When the inoculation rate was increased from 80 g to 400 g per 100 kg seed, pod count of variety Solitaire increased by 47% at Kanonama and by 125% the at Majuru site. For variety Storm, the number of pods per plant increased by 111% at Kanonama and by 25% at Majuru.

Grain yield followed a similar trend with pod count, as inoculation rates were increased. Doubling or trebling the rate of inoculation did not significantly increase grain yield.

Table 3. Pods count for two soyabean varieties, Storm and Solitaire, at two sites Kanonama and Majuru as affected by the rate of inoculation

		Inoculation rate per 100 kg seed					
Site	Variety	0	80	160	240	400	800
Kanonama	Solitaire	14	19	19	20	28	26
Kanonama	Storm	9.3	18	22	27	38	39
Majuru	Solitaire	9	8	11	15	18	12
Majuru	Storm	9	12	13	12	15	18

s.e.d - 2.43 LSD (5%) - 4.84

Solitaire grain yields at both sites and those for variety Storm at Kanonama were highest at 5 times the recommended rate (4 g kg^{-1} seed). At Majuru, the grain yields for variety Storm increased up to the highest rate used (8 g kg^{-1} seed). Solitaire yielded less than Storm at Kanonama, with the reverse occurring at Majuru (Figure 2). There was a positive and significant relationship between inoculation rates and grain yields (r=0.94) and this was significant for both varieties at both sites.

Stover yields increased by 64% for variety Solitaire and 76% for Storm when the inoculation rate was increased to ten times the recommended rate (Table 4). Variety x inoculation rate interaction was significant for stover yields ($P < 0.05$).

The current market price of soyabean is ZW$ 60 kg^{-1}. Assuming the probability of obtaining a yield increase under SH conditions is 1 (an assumption made on the basis of poor rhizobial survival on sandy soils), the value added by inoculating soyabean at rates resulting in maximum grain yields is shown in Table 5. These results show that it is more profitable to grow variety Storm at both sites. High inoculation rates resulted in variety Storm yielding a crop with 53% and 64% more value than variety Solitaire at Kanonama and Majuru respectively (Table 5).

Discussion

The present inoculation rate of 80 g inoculant per 100 kg seed was shown to be insufficient for maximum nodulation and failed to result in the highest seed yields on the sandy soils in the SH sector. Doubling and trebling the recommended rate of inoculation did not result in the highest grain yields. Maximum grain yields were realized only when the inoculation rate was increased by five times. Grain

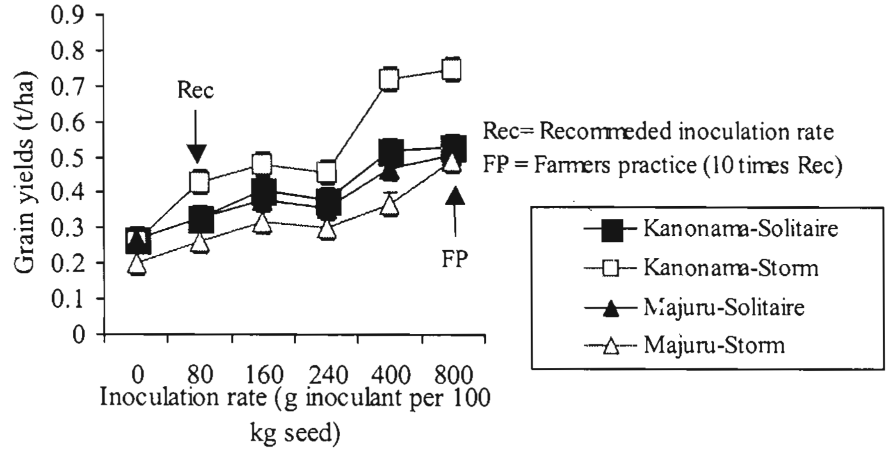

Figure 2. Grain yield of two soyabean varieties planted at two sites, Kanonama and Majuru, and inoculated at five different rates

Table 4. Stover yield (t/ha) for Storm and Solitaire soyabean as affected by the seed inoculation rate

	Inoculation rate per 100 kg seed					
Variety	0	80	160	240	400	800
Solitaire	1.89	2.23	2.64	3.02	3.1	3.65
Storm	0.9	1.83	2.28	2.55	2.99	3.22

s.e.d = 0.16 LSD (5%) = 0.23

Table 5. Value added to a soyabean crop by inoculating seed at 4 g kg^{-1}

Site	Variety	Yield increase (t/ha)	Expected Value Added ZW$/ ha
Kanonama	Solitaire	0.19	11 400
Kanonama	Storm	0.29	17 400
Majuru	Solitaire	0.14	8 400
Majuru	Storm	0.23	29 400**

** Expected value calculated using a rate of 8 g kg^{-1} seed

yields from a ten times and five times increase in the rate of inoculation were not significantly different at the 5% level of probability. The variety Storm at Majuru was exceptional as yield continued to increase and it was highest when ten times the recommended inoculation rate was used. This yield increase could be attributed to improved nodulation that resulted in a good crop stand that allowed for more reproductive nodes and hence more pod and grain yield. Therefore, as well as increased grain yields, increased inoculation rates resulted in a better canopy cover, which would smother weeds reducing the need to handweed.

Grain yields of Storm were higher than Solitaire at Kanonama. This could have been due to high-energy wastage through ineffective nodulation having resulted in reduced grain yields for the variety Solitaire. The grain yields of Storm were less than those for Solitaire at Majuru, possibly due to the different growth habits that made the two varieties respond differently to poorly distributed rainfall. Storm, because of its determinate growth habit, was severely affected by the long dry spell experienced during the first eight weeks of the year, while Solitaire (which is indeterminate) was able to fully 'revive' its flowering and grow with the later rains.

Low amounts of rainfall [Kanonama (416 mm) and Majuru (307mm)], clay and organic carbon and the high temperatures experienced in the 2001/2002 season negatively affected rhizobial populations. Thus while the recommended inoculation rate is higher than internationally recognized guidelines (>10^{1} cells seed^{-1}) (FAO, 1991), high rhizobial populations increased the chances of infection under the harsh SH soil environments where rhizobial survival and persistence was poor (*http://www.ianr.unl.edu/pubs/fieldcrops/index.htm*).

The high native rhizobial populations at Kanonama could have been because of an inoculated soyabean crop having been grown in this field in the 1998/99 season. Mpepereki and Makonese (1998); Sanginga, et al., (1996) reported higher counts of rhizobia in soils where legumes have been grown. Common bean, which is promiscuous for nodulation (Giller 2001), was grown in this field in the 1999/2000 season and could have hosted rhizobia, thus improving their persistence. However, this relatively large population of indigenous rhizobia was ineffective in fixing nitrogen. This could be because the rhizobia lost their nitrogen fixing genes or became less effective over time resulting in them fixing less nitrogen even though they remained good nodulators (*http://www.urbana-labs.com/benefit.htm*). Andrade ·and Hungria (2002) reported that high temperature and low soil moisture may contribute to undesirable changes in rhizobia, including plasmid deletions, genomic rearrangements and reduced diversity. Inoculation response was not eliminated as the use of 'fresh' rhizobia could have out-competed most indigenous rhizobia which could have become 'weak' (Gardner, Pearce, and Mitchell, 1985). Poor inherent soil N levels, added to the low mineral N additions (7.5 kg ha^{-1}), meant the crop had to depend on nitrogen fixation to meet its N-demand.

Increased nodulation on the primary root with increased inoculation rates has been reported to be evidence of an inoculation response (Zapata, Danso, Hardarson and Fried, 1987). Differences in nodulation between the sites emphasized that inoculation response is site specific (Singleton and Tavares, 1986). The nodulating pattern of the two varieties tends to suggest that variety Solitaire is less specific than variety Storm as it had a relatively high nodule count in the absence of inoculation. Because Solitaire has an indeterminate growth habit, like the popular promiscuous variety Magoye, it could be that the indeterminate growth habit is related to promiscuity. At the sites used in this study, the indigenous rhizobia population was ineffective in fixing N as evidenced by the poor grain yield in the uninoculated control. However, in the presence of effective indigenous rhizobial populations, Solitaire could be grown without inoculation.

Wadisirisuk and Weaver (1985) reported that nodule DM is related to N-fixation capacity. Nodules formed on Storm increased with inoculation rate and had a higher DM than those on Solitaire. This could have partly contributed to increased nitrogen fixation and grain yield for Storm.

Pod count was significantly related to grain yields (P=0.03) and increased with inoculation rates. This result is in agreement with Jayapaul and Ganesaraja (1990) who stated that an increase in plant nitrogen increases pod count. The seed weight of 100 seeds did not differ for the different inoculation rates, possibly due to the poor rainfall that could have affected seed setting.

In the SH sector, pieces of land allocated to soyabean are small (0.1 ha), with seed requirements of about 10 kg. Available inoculant sachet sizes (80 g) result in farmers inoculating their soyabean at rates almost ten times higher than recommended. This could be the reason why dramatic yields in response to inoculation were reported in the first phase of soyabean promotion in Zimbabwe (Mpepereki et al., 2002). Results from this study suggest that the recent introductions of inoculant sachets allowing inoculation of small quantities of seed at the recommended rate will result in a yield decrease.

As farmers become more confident in growing soyabeans and realizing they can make profits, they are increasing its area planted. Of the 5 million ha opened for resettlement, about 30% are virgin sandy soils. If 150 000 ha (10%) of the sandy soils are used for soyabean production, a five times increase in the rate of inoculation will increase the demand for inoculants above what the factory can supply. The inoculant factory in Zimbabwe currently produces 120 000 sachets in a year which are for the 75 000 ha of soyabean grown nationwide, 10 000 ha of which was in the SH sector.

Conclusions

This study has shown that the recommended inoculation rate of 0.8 g inoculant kg^{-1} seed is insufficient for maximum nodulation, soyabean seed yields, seed nitrogen and stover yields on sandy soils in Zimbabwe. A rate of 8 g kg^{-1} seed, currently being used by farmers is uneconomic for soyabean production on sandy soils. Generally, the inoculation rates of 4 g kg^{-1} seed were observed to result in maximum seed yield.

Recommendations

Judging from its current capacity (120 000 sachets per year), the inoculant factory in Zimbabwe would not meet the increased inoculant demand if the inoculation rates were to be increased five times. Assuring a higher seed inoculation rate by increasing the number of viable cells per sachet could be an option. While this could increase the number of cells in an inoculant sachet, intensifying competition for available nutrients, increasing cell mortality, there is need for further research to ascertain this. Use of granular inoculants could also be considered for the harsh SH cropping environments. Improving the soil environment for better rhizobia survival by reducing soil acidity and increasing soil organic matter could enhance rhizobial survival in the soil, eliminating the need for high inoculation rates. This could allow farmers to benefit from high yields at reduced inoculation rates.

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SURVIVAL AND PERSISTENCE OF INTRODUCED COMMERCIAL RHIZOBIAL INOCULANT STRAINS IN SELECTED SMALLHOLDER FIELD ENVIRONMENTS OF ZIMBABWE

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Abstract

The persistence of an introduced rhizobial inoculant strain in smallholder field environments of Zimbabwe was determined at two sites with no history of soyabean production in Goromonzi district. An inoculated soyabean crop was introduced in the first season using Magoye, Solitaire and Viking soyabean varieties. There was a positive response to inoculation in the first season (2000/2001) with inoculated plants having higher nodule numbers, grain yields and total nitrogen contents than the uninoculated plants ($p < 0.05$). Re-inoculation of previously inoculated plots in the following season (2001/2002) however did not result in an increase in nodulation or yields of soyabean indicating that the rhizobial strain introduced in the first season persisted into the second season. In a separate experiment to determine the persistence of an inoculant strain over many seasons, soils that had been last inoculated in the years 1996, 1998, 1999 and 2000 were sampled from three districts and assessed for rhizobial population sizes in the greenhouse. Rhizobial numbers were correlated with soil properties and the occupying strains identified.

Results indicated that rhizobial numbers were positively correlated with soil pH, clay percent and organic carbon, with numbers significantly increasing at pHs above 5.5. Rhizobial numbers decreased with year since last inoculation, with populations as high as 10^3 cells /g of soil being obtained in fields last inoculated in the year 2000 and less than 30 cells /g of soil in fields last inoculated in 1996. The rhizobial strain MAR 1491 (USDA 110) was obtained in most fields with a history of rhizobial inoculation.

Key words: Rhizobia, persistence, soyabean, inoculation

Introduction

Soyabean, a crop previously restricted to the large-scale farming sector of Zimbabwe, has been promoted to smallholder farmers through first the Soyabean Promotion Programme from 1986-89 then more recently through the Soyabean Promotion Task Force from 1996 to the present (Rusike et al., 2000). Soyabean production requires the use of rhizobial inoculants to attain optimum nodulation and high yields. Commercial rhizobial inoculants are however not readily available for use by smallholder farmers. This is because marketing channels for rhizobial inoculants to smallholders were not sufficiently developed to match their demand.

A solution to the problem of limited inoculant availability could be the use of promiscuous soyabean varieties such as 'Magoye' that readily nodulate with indigenous rhizobia and hence do not require rhizobial inoculation (Mpepereki et al., 1999). These varieties are however not available on the local market, they produce lower grain yields and their pods readily shatter compared to specific soyabean varieties (Kasasa, 1999). The locally available commercial specific soyabean varieties on the other hand require rhizobial inoculation to obtain high yields. Since the use of rhizobial inoculants in smallholder field environments is a relatively new technology, little information is available on the survival and persistence of an introduced inoculant strain in field soils. Persistence of an inoculant strain would obviate the need for inoculation each time soyabean is cropped thereby allowing for sustained productivity. The objective of this study was therefore to assess survival and persistence of introduced rhizobial inoculant strains in field soils. It was hypothesized that inoculant strains survive and persist poorly in smallholder field environments due to unfavourable soil conditions of low soil pH, poor clay and low organic matter amounts.

Materials and Methods

Persistence of an introduced rhizobial inoculant strain over one season was assessed by setting up an experiment on two field sites in Goromonzi district. The first site Mudzivare, is a sandy soil with a low soil pH of 5 and poor nutrient status. The second site, Majuru, has a contrasting clay soil with a slightly higher pH of 5.8 and favourable nutrient amounts. Three soyabean varieties, namely Magoye (promiscuous variety), Solitaire and Viking (specific varieties) were planted on 5 x 5 m plots set up in a completely randomized design replicated four times. Treatments included inoculated and uninoculated field plots in the first season (2000/2001). In the second season (2001/2002), half of the previously inoculated plot was reinoculated while the other half remained uninoculated. The control plots that were not inoculated in the first season remained uninoculated in the second season. Data on nodulation was collected at eight weeks after planting (WAP) while grain and total dry matter yield in the different inoculation treatments was assessed at physiological maturity. An analysis of variance of treatment means was determined using GENSTAT.

Persistence of an inoculant strain over many seasons was assessed under greenhouse conditions. Soil samples with a previous history of rhizobial inoculation were collected up to a 20 cm depth in October 2001 from Guruve district. The fields had last been inoculated in the 1996, 1998, 1999 and 2000 growing seasons. Populations of rhizobia in each soil were quantified using the most probable number method with the variety Solitaire as the trap host. Serial dilutions of each soil were done using a base dilution of 10. Three plants were planted per pot and inoculated with 1ml of soil inoculum. Plants were scored for nodulation at 6 WAP. Data on nodulation, inoculation volume and number of replicates used was fed into the MPNES computer programme and populations of rhizobia in the different soils estimated. The rhizobial strain occupying nodule sites was identified with the enzyme–linked immuno sorbent assay. Population sizes of rhizobia were then compared with soil properties using regression analysis.

Results

Number of nodules in different inoculation treatments at 8 WAP for three soyabean varieties. Although inoculation of the specific varieties Solitaire and Viking resulted in increased nodule numbers, yields and total N amounts in the first season, reinoculation of the same varieties in the second season did not result in increased nodulation at both sites (Table 1). No significant differences in nodule numbers in the different inoculation treatments were recorded for the promiscuous variety Magoye. More nodules were also obtained from the clayey Majuru site than from the sandy Mudzivare ($p < 0.001$).

Grain and total dry matter yield in different inoculation treatments

Re-inoculation of the different soyabean varieties in the second season also did not result in increased grain and total dry matter yields at both sites (Figure 1). An exception was Viking, which gave a positive response to re-inoculation for total dry matter yield at Mudzivare. The grain yield obtained at this site was however very low when compared with the total dry matter yield.

Changes in rhizobial populations in inoculated fields over time

An assessment of persistence of rhizobia over many seasons showed that the rhizobial strain used in inoculant production persists in smallholder fields since a good rhizobial count was obtained from fields last inoculated as far back as 1998 (Table 2). Rhizobial populations were positively correlated with soil pH, clay and organic carbon contents. The year since last inoculation also strongly influenced rhizobial numbers, with numbers decreasing with increasing year since last inoculation ($p < 0.001$). As many as 10^3 rhizobial cells / g of soil were obtained in fields last inoculated in the year 2000 while less than 30 cells / g of soil were found in fields last inoculated in 1996. The strain MAR 1491 was detected in most previously inoculated fields and in one instance both MAR 1491 and 1495 were

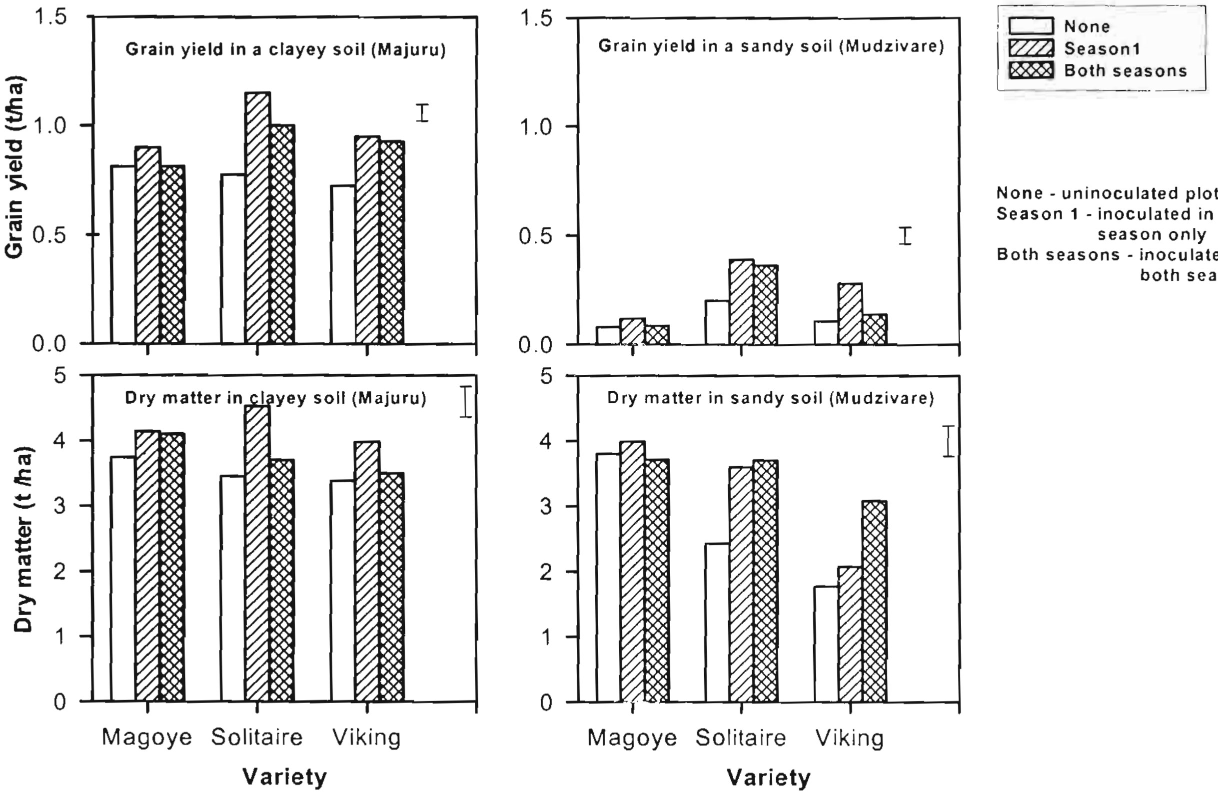
Table 1. Number of nodules at eight WAP in different inoculation treatments at two sites in Zimbabwe

Variety		Majuru			Mudzivare	
	-inoc	inoc $_{s1}$	inoc $_{s2}$	-inoc	inoc $_{s1}$	inoc $_{s2}$
Magoye	7	7	8	3	1	2
Solitaire	2	14	7	0	2	1
Viking	3	8	5	0	1	1
sed			0.639			

inoc – no inoculation
Inoc $_{s1}$ – inoculation in season 1 only
inoc $_{s2}$ – inoculation in both seasons
sed – standard error of differences of means

Table 2. Changes in rhizobial population in inoculated fields from Guruve district over time

Site No.	Year last inoculated	Rhizobia cells/ g soil x 10^3	Soil pH in water	% Clay	% C	rhizobial strain	
						1491	1495
1	2000	4.5	5.9	32	2.3	+	–
2	1999	3.0	6.1	29	0.9	+	+
3	1998	0.44	6	36	0.79	+	–
4	1996	0.029	6.6	24	1.3	+	–
5	Control	0.01	5.5	23	0.8	–	–



None - uninoculated plots
Season 1 - inoculated in first season only
Both seasons - inoculated in both seasons

Figure 1. Grain and total dry matter yield at Majuru and Mudzivare in the second season

identified. Fields with no history of rhizobial inoculation (controls) had none of these strains.

Discussion

Although soyabean responded to inoculation in the first season of cropping through increased nodule number and yields, re-inoculation in the second season did not result in a similar increase. This indicates that rhizobial strains introduced in the first season persisted into the second season. Mapfumo (2000) noted that legumes often responded to inoculation during the first year of introduction into new areas but not in subsequent years on the same piece of land. The initially low population of indigenous rhizobia may necessitate the use of commercial inoculants but as high populations of effective rhizobia build up in the soil, the need for inoculation may be obviated in subsequent years.

The response to rhizobial inoculation through increased nodule numbers and yield for the specific varieties Solitaire and Viking and not the promiscuous Magoye correspond with results obtained by Kasasa (1999) where significantly higher nodule numbers were obtained after inoculating specific soyabean varieties. Studies by Mpepereki et al. (1999) revealed that promiscuously nodulating soyabean varieties such as Hernon 147 and Magoye nodulate and fix nitrogen well in fields with no history of rhizobial inoculation, hence no significant changes were observed after inoculating Magoye in either season. More nodules at the clayey Majuru site than the sandier Mudzivare can be explained by the observation that a high clay soil gives rise to many small nodules because of a better moisture retention capacity while sandier soils result in larger but fewer nodules due to their poor water retention capacity (Mapfumo, 2000). The very low amount of grain produced at Mudzivare in comparison with its total dry matter yield is a result of mid season dry spells experienced at flowering resulting in reduced grain production.

Results from the greenhouse experiment showed that rhizobial strains persist in smallholder fields and that inoculation history and pH strongly influence the populations. This trend is consistent with work covered by Mpepereki and Makonese (1995) where soyabean rhizobia were not detected in fields with no history of legume cultivation. They similarly observed that cowpea rhizobia were lowest in communal areas that were generally acidic, sandy and with low nutrients. Acidic soils of pHs below 5 are known to be detrimental to rhizobial survival and are unfavourable for soyabean–rhizobia symbiosis (Tattersfield, 1996). In this experiment, a rise in soil clay and carbon content resulted in increased rhizobial populations. Chatel and Parker (1972) noted that heavy textured soils formed micro aggregates, which afforded some protection to rhizobia against high temperatures. Rhizobia also survive saprophytically in the absence of a legume host, therefore organic carbon is an essential source of energy required for their growth and survival. The rhizobial strain MAR 1491 was found in most inoculated field soils since it is the most widely used strain in soyabean inoculant production in Zimbabwe. In some soils, the strain MAR 1495 was also found because it was once used in combination with MAR 1491 during inoculant production. The uninoculated field controls had none of the tested strains because they have no history of rhizobial inoculation.

Conclusion and Recommendations

Rhizobial inoculant strains survive in smallholder field environments for at least three seasons, so re-inoculation of previously inoculated fields is not beneficial to the farmer. Inoculation when introducing a soyabean crop in a new area for the first time is essential. Thereafter, a second soyabean crop grown after rotation with a cereal does not require inoculation since a significant population of rhizobia will still be present in the soil. Rhizobial survival can be further enhanced by raising soil pH and organic matter content and in soils with high clay amount. Re-inoculation may therefore need to be more frequent in sandy soils.

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INTEGRATING ORGANIC RESOURCE QUALITY AND FARMER MANAGEMENT PRACTICES TO SUSTAIN SOIL PRODUCTIVITY IN ZIMBABWE

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Abstract

Maintenance of soil fertility on smallholder farms in Southern Africa is almost entirely dependant on locally available organic resources, with mineral fertilizers only dominating in exceptional cases for relatively wealthy farmers. The exploitation of nitrogen-fixing legumes for soil fertility purposes, be it in the form of residues from grain or green manure legumes, is not widespread in Zimbabwe smallholder farming systems.. In a newly initiated study in three agro-ecological regions in Zimbabwe, we focus on the differential effects of organic resource quality and quantity on the manifestation of soil fertility gradients and subsequently on crop yields as influenced by farmer management practices. Both Master/Innovator farmers and poor farmers are targeted in the exploration of the within-farm soil fertility gradients (usually giving rise to high yielding 'rich' and low yielding 'poor' fields) observed under different management regimes. Preliminary results showed that mineral fertilizer was the most common nutrient source used by over 85% of the farmers from three identified farmer groups (Class A - Master farmers, Class B – Innovator farmers and Class C – Resource poor farmers). Livestock manure and woodland litter featured as common organic nutrient sources in Zimuto, while in Chinyika and Chikwaka, less than 50% of the farmers used these as additional nutrient sources. As a result of frequent organic nutrient source usage, soil organic carbon contents of the rich and poor fields of Zimuto was significantly higher than from the other two agro-ecological regions ($p < 0.05$) with values reaching 11.5 mg C g^{-1} soil (rich field) and 8.5 mg C g^{-1} soil (poor field). The bulk of the tested soil had very little total nitrogen (< 1 mg N g^{-1} soil). Although the chances of building soil organic matter (SOM) under granitic sands in Zimbabwe are slim, understanding the influence of organic resource management on SOM dynamics, short-term N availability and mineral fertilizer use efficiency is critically important. Target farm sites serve to complement long-term experiments in explaining the interaction between organic resource management and crop yields. In addition to these preliminary results, the principles and approaches of the study are also discussed in this paper.

Key words: Organic resource quality, soil organic matter, mineral fertilizer

Introduction

Marked differences in soil fertility levels and nutrient balances can often be observed for the different fields within one smallholder farm. These within-farm soil fertility gradients have a major impact on overall farm productivity, yet their dynamics are often poorly understood. Several reasons could be attributed to this high variability, although inherent soil properties, micro-climatic conditions and farmer management practices may be obvious determining factors (Mapfumo and Giller; 2001; Sanchez and Jama, 2002; Smaling et al., 1997). Farmer management of fields varies with time of planting, type of crop planted, type and quality of added inputs (including access to cash for purchasing inputs) and the efficiency with which nutrients are used. Most smallholder farmers in Zimbabwe recognize the importance of soil fertility and its conservation. There is also general knowledge among both scientists and farmers that the application of organic residues improves the physical conditions of soil, although information as to why this happens is still often very limited (Sanchez et al., 1989; Palm et al., 1998).

Agricultural activities and maintenance of soil fertility in a smallholder farming community is almost entirely dependant on locally available resources. However, given the present scenario where traditional strategies for sustaining soil and crop productivity have been outpaced by the growing human population, a diminishing natural resources base, and the downward spiral of many national economies, the question of resource availability has become topical. The big question is: *what options are available to the smallholder farmer for soil amelioration?* Annual woodland litterfall may be as much as 5 t ha^{-1} and measured annual litter collections in Masvingo, southern Zimbabwe, by Nyathi and Campbell (1993), ranged from 0.2 to 1.2 tonnes per household. In reality, most communal areas are in a severe state of deforestation. Livestock manure, cattle manure in particular, is a traditional source of plant nutrients and can be one of the cheapest sources of organic fertilizer in many smallholder communities

(Mugwira and Murwira, 1997). However, use of manure is a privilege for owners. Cereal and legume residues are available to many but their uses as soil ameliorants is not widespread as these are usually fed to livestock or even burnt in some cases to prepare land for the next growing season.

Mineral fertilizers are accepted as a way to increase productivity (Piha, 1993), but the extent to which farmers can depend on this input is constrained by the low purchasing power of the majority of farmers (Ashworth, 1990). Mineral fertilizers are often purchased in amounts inadequate to replace those nutrients lost annually in harvested produce. Where ecological conditions are not particularly favourable for farming or the soil has been degraded, using mineral fertilizers alone may be insufficient (Smaling et al., 1997). The foregoing discussion indicates the critical need to increase the efficiency with which the little available nutrients should be used. Consequently, nutrient outflows from individual farm holdings have progressively become much higher than inputs supplied in both organic and mineral nutrient sources. This paper discusses preliminary results of a recently initiated study "Managing soil organic matter for improved nutrient use efficiency on smallholder farms in Zimbabwe – the NUESOM Project" which aims at addressing the role of organic residue quality and quantity on soil organic matter (SOM) dynamics in smallholder farmers' fields under different management systems in Zimbabwe. The study is part of a larger collaborative research effort by the African Network (AfNet) members of the Tropical Soil Biology and Fertility (TSBF – CIAT) on " Soil Organic Matter Dynamics for Sustainable Cropping and Environmental Management in Tropical Systems: Effect of Organic Resource Quality and Diversity" (Mapfumo et al. 2001a). The study aims to answer the following questions:

(i) Can the reason for crop yield success be attributed to grain legume rotations, litter and livestock manure applications and /or simply efficient mineral fertilizer management techniques?

(ii) Do legumes play a role in the superior fertility status or productive capacity of soils often observed on Master and/or Innovator farmer's fields?

(iii) What is the comparative advantage of legumes in these circumstances given the current state of knowledge on legume technologies?

This paper discusses the preliminary results of this research.

Materials and Methods

Study sites

Three communal areas in different agro-ecological regions of Zimbabwe, namely Chikwaka in Natural Region (NR) II (31°30'E and 17°40'S; 80 km northeast of Harare), Chinyika in NR III (32°25'E and 18°15'S; 250 km east of Harare) and Zimuto in NR IV (30° 52'E and 19°50'S; 320 km southeast of Harare) were chosen for the major part of the study. Natural Region II is a sub-humid zone that receives summer rains of between 700 - 1000 mm of rainfall, NR III receives rainfall of between 650 and 750 mm with relatively high temperatures and infrequent, heavy fall of rain while NR IV is a semi-arid area in which annual rainfall is between 450 and 650 mm and is subject to frequent seasonal droughts (Vincent and Thomas, 1961). Chikwaka and Zimuto have a long history of settlement (over 70 years of settlement) while Chinyika is a resettlement area first cropped by smallholder farmers less than 20 years ago. Farming systems in all the three areas are maize-based, with strong crop-livestock interactions. These sites were found to be representative of dominant soil types found in most parts of the country in addition to rainfall regimes. Although the overall focus of the project is on-farm, replicate on-station experiments were established at Domboshawa Training Centre (NR II) located about 30 km north of Harare (31°19'E and 17°36'S) and Makoholi Research Station in NR IV (about 280 km south of Harare (30° 45'E and 19°47'S) for detailed measurement on the influence of C quality on SOM formation.

Selection of farm sites

On-farm sites that have been systematically and consistently managed by known groups of farmers were chosen for field monitoring and experimentation. Gathered information based on farmer participation, key informant interviews and literature on biophysical and socio-economic characteristics of the respective farming systems, was used to classify farmers according to resource endowment and competence in farming. The focus was on the farmers' history of organic matter management. Detailed key informant interviews conducted in the three study sites revealed that farmers basically fell into three groups: Class A – Master Farmers; Class B – Innovator Farmers; and Class C – Resource-poor Farmers (Table 1).

Field surveys

Participatory rural appraisal (PRA) techniques helped to identify the range and determine the quantities of organic resources available to smallholder farmers. Particular attention was paid to C inputs in relation to general soil fertility management practices. Focused group discussions, priority-ranking, transect walks and informal interviews constituted the major PRA tools. Six replicate sites across farms, two from each class (Table 1) were selected in each Natural Region for further investiga-

Table 1. Classification of smallscale farmers of Chikwaka, Chinyika and Zimuto according to key informants

Class	Description	Resource endowment
Class A	• The **Master Farmer** class • Undergo all training as recommended by AREX • Training is on-site and involves crop and animal production including general farm management	• livestock (at least 2 cattle) • plough • scotchcart • adequate accommodation whether galvanized iron sheets, asbestos or grass. • Small livestock (chickens/ goats)
Class B	• Group contains the **Innovator Farmers** • Group comprises mostly the eager-to-learn type farmers • Maximize production through informal consultation with AREX Officers and/ or other farmers • Generally do not attend training sessions	The majority has the same resources as Master farmers. The remainder normally have at least: • some livestock • a plough • a scotchcart • adequate accommodation
Class C	• The group includes farmers who take time to adopt a technology • The majority of the members are resource constrained/ resource poor	Usually those who don't or have little of: • livestock • plough • scotchcart • have little or no ambition to learn or know what is happening in the local environment. • rarely attend training meetings

tions bringing the total number of farm sites to 36. The farm owners assisted in identifying appropriate field sites with attributes that included:

- a known history of organic matter applications (at least 5 years)
- fields with no external C application in the past 5 years
- type of predominant management systems including mineral fertilizer applications, organic matter management (cereal or other stover, livestock manure, green manures, woodland litter, compost or household waste, termitaria) and legume/cereal intercrops or rotations.
- distinct soil textures.

The 36 sites reported here are part of a total of 120 field sites being investigated in the three Natural Regions for the same attributes. Transect walks and informal interviews were conducted with the selected farmers to help identify the different productivity capacity of their fields. We specifically identified the indices that the farmers used to classify the yield potential of their fields. Some of the productivity indices for rich and poor fields included:

a) high yielding (Rich) fields

- high crop performance
- crops respond well to additional nutrient inputs
- heavy soils usually with a high humus content
- islands of termitaria present
- soils do not easily dry out.

b) low yielding (Poor) fields

- poor crop performance despite external nutrient inputs
- very light (sandy) free draining soils
- low humus content.

Data on maize yield estimates in the rich and poor fields were also collected during informal interviews with the selected farmers.

Soil sampling and analyses

The key question was whether the local indices for productivity could be given a scientific meaning. To answer this, soils were collected for analysis from the top 20 cm of the rich and poor fields before the onset of the 2002-2003 rainy season. At least ten auger samples were collected from each field site, bulked in a bucket and then thoroughly mixed to give one composite sample that was sub-sampled for laboratory analysis. These soils were analyzed for total organic C and N using methods described by to Anderson and Ingram, (1993). The C and N data from the rich and poor fields from the three Natural Regions were subjected to a Two-sample T-Test for mean comparisons (Minitab Inc., 2000).

Results

Maize yields

Maize yields were higher in Chinyika compared to Zimuto and Chikwaka (Table 2). Yields of up to 7.0 t ha^{-1} were realized by Class A farmers in Chinyika. Average yields from rich fields were highest in Chinyika (5.1 t ha^{-1}) followed by Chikwaka (3.5 t ha^{-1}) and Zimuto had lowest yields of 2.7 t ha^{-1}. In all the three regions, yields from rich fields were in the order of Class A > Class B > Class C. However, differences between yields from poor fields of the three identified farmer groups within each NR in the three study sites were insignificant ($p > 0.05$). Comparing the three agro-ecological regions, average yields from the poor fields also followed the same trend with Chinyika having the highest yields (1.3 t ha^{-1}) followed by Chikwaka (0.9 t ha^{-1}) and Zimuto with the lowest yields (0.5 t ha^{-1}).

Nutrient sources

All host farmers in Chikwaka applied mineral fertilizer to their rich fields with at least half of them also applying livestock manure to the same fields (Table 2). Two out of the six poor fields did not receive mineral fertilizer. In Chinyika, there appeared to be a strong dependency on mineral fertilizer by all, including Class C farmers. Only one Class C farmer failed to apply any external nutrient to his fields, although he still managed to achieve relatively good

Table 2. Average maize yield estimates and farmer management of fields perceived as rich and poor fields in the three agroeco-regions in Zimbabwe

Agro-region	Farmers' name and Class	Field status	Average maize yields	Farm management		
				Mineral fertilizer (kg ha^{-1})	Organic fertilizer	Legume rotations
NR II Chikwaka	Mr G2 – Class A	Rich	5.0	150 D*; 100 AN[1]	7.0 t ha^{-1} manure	Groundnut (4 years)
		Poor	0.9	0 D; 100 AN	0	None
	Mrs K – Class A	Rich	4.0	0 D; 0 AN	6.0 t ha^{-1} manure	None
		Poor	0.8	150 D; 100 AN	0	None
	Mr M1 – Class B	Rich	3.7	150 D; 100 AN	6.0 t ha^{-1} manure	Groundnut (3 years)
		Poor	2.0	150 D; 150 AN	0	Soyabean/ runnerbean
	Mrs M2 – Class B	Rich	2.5	150 D; 150 AN	0	None
		Poor	0.2	150 D; 100 AN	0	None
	Mrs C – Class C	Rich	1.5	150 D; 100 AN	0	Groundnut (5 years)
		Poor	1.0	150 D; 100 AN	2.0 t ha^{-1} manure	Groundnut intercrop
	Mr G1 – Class C	Rich	4.5	0 D; 0 AN	0	None
		Poor	0.6	150 D; 100 AN	0	None
NR III Chinyika	Mr C1 – Class A	Rich	7.0	200 D; 200 AN	5.0 t ha^{-1} manure	None
		Poor	1.0	200 D; 200 AN	0	Groundnut (2 years)
	Mr C2 – Class A	Rich	6.0	150 D; 100 AN	4.5 t ha^{-1} manure	Soyabean (3 years)
		Poor	2.0	150 D; 100 AN	0	None
	Mr M1 – Class B	Rich	6.5	200 D; 200 AN	2.5 t ha^{-1} groundnut stover	Groundnut (2 years)
		Poor	0.7	200 D; 200 AN	0	None
	Mr M2 – Class B	Rich	4.5	200 D; 200 AN	0	None
		Poor	1.5	200 D; 200 AN	0	None
	Mr W – Class C	Rich	2.5	0 D; 0 AN	0	None
		Poor	0.5	0 D; 0 AN	0	None
	Mr Z – Class C	Rich	4.0	150 D; 100 AN	0	Groundnut/bambara (4 yrs)
		Poor	2.0	150 D; 100 AN	4.5 t ha^{-1} manure	Groundnut/bambara (4 yrs)
NR IV Zimuto	Mr M1 – Class A	Rich	3.7	100 D; 100 AN	0	None
		Poor	0.2	0 D; 100 AN	4.5 t ha^{-1} manure	None
	Mrs M2 – Class A	Rich	3.0	100 D; 100 AN	2.5 t ha^{-1} manure	None
		Poor	0.6	100 D; 100 AN	2.5 t ha^{-1} manure	None
	Mrs C – Class B	Rich	2.5	0 D; 200 AN	2.5 t ha^{-1} composted litter	Groundnut/cowpea/bambara intercrp
		Poor	0.4	0 D; 200 AN	4.0 t ha^{-1} manure	None
	Mr Z – Class B	Rich	2.7	100 D; 100 AN	0.4 t ha^{-1} litter/ 2 t ha^{-1} manure	Groundnuts (2 years)
		Poor	0.4	0 D; 100 AN	1.0 t ha^{-1} manure	None
	Mrs N – Class C	Rich	2.0	50 D; 100 AN	0.7 t ha^{-1} manure	None
		Poor	0.3	50 D; 100 AN	0	None
	Mrs T – Class C	Rich	2.1	0 D; 0 AN	2.5 t ha^{-1} manure	Bambara (2 years)
		Poor	0.8	0 D; 0 AN	0.9 t ha^{-1} manure	None

* D = Compound D fertilizer (7% N; 14% P_2O_5; $7K_2O$); [1] AN = Ammonium Nitrate (34.5%N

maize yields (about 2.5 t ha^{-1} from the rich field). Manure usage in Chinyika was far lower than that in Zimuto and Chikwaka. Only one farmer (Class B) used legume stover as a soil ameliorant in Chinyika. In Zimuto, organic nutrient resource usage was more widespread with livestock manure and woodland litter being the common sources among the three farmer classes (Table 2). Most of the farmers who used organic fertilizers did not apply basal Compound D fertilizer. However, except for one resource-poor farmer, farmers in Zimuto applied the recommended rates of between 100 and 200 kg ha^{-1} ammonium-nitrate fertilizer to both their rich and poor fields.

Grain legume adoption

Less than half of the 18 interviewed farmers in the three study areas grow grain legumes in their fields. In Chikwaka, groundnut rotations in rich fields range from 1 in 3 to 1 in 5 years. Only one Class B farmer had tried to rotate maize with soya and runner beans in his poor field. In Chinyika, legume rotations included groundnut, bambara nut and soyabean on a two to four year cycle for all the three farmer classes, and only one Class B farmer utilized groundnut residues for soil fertility purposes. In Zimuto, only two farmers (Class B and C) grow legumes in 2-year rotations (Table 2). Another Class B farmer intercropped groundnut, cowpea and bambara nut with maize in their rich field.

Soil carbon and nitrogen

Soil organic carbon content of the soils from the rich fields in Chinyika ranged from about 4.5 (Classes B and C fields) to 8.2 mg C g^{-1} soil (Class A farmer) while that from the poor fields ranged from 3.2 (Class B farmer) to 8.3 mg C g^{-1} soil (Class A farmer). In five out of six cases, organic carbon was consistently higher in the rich than the poor fields (Figure 1a). The only exception observed was that of a Class C farmer whose poor field had about 2.5 mg g^{-1} soil more C than his rich field. Total soil nitrogen was less than 1 mg N g^{-1} ranging from 0.5 to 0.8 mg N g^{-1} soil in Chinyika. There was little difference in the soil nitrogen contents between rich and poor fields in Chinyika for all the farmer classes (Figure 1b). In Zimuto, soil C contents ranged between 2.0 (Class B farmer) and 11.5 mg C g^{-1} soil (Class A farmer) in rich fields and between 2.0 (Class C farmer) and 8.2 mg C g^{-1} soil (Class A farmer) in poor fields (Figure 2a). Unlike the Chinyika case, soil nitrogen was relatively higher in Zimuto, with results ranging from 0.6 to 1.2 mg N g^{-1} soil (Figure 2b). In all the selected field sites, the nitrogen content of the rich fields was higher than that of the poor fields regardless of farmer class.

Discussion

Ownership of resources was the key attribute differentiating farmer classes. When it came to farm management, the more resource-endowed Class A farmers had more soil fertility options at their disposal. The biophysical characterization of the smallholder farming systems has shown that nutrient sources accessible to farmers in the different agroecosystems were highly heterogeneous and varied in quantity. There was a general appreciation of the role of organic nutrient sources in soil amelioration in the three Natural Regions, particularly livestock manure. However, it was Class A farmers who frequently used mineral fertilizers for crop production although they could afford to use other available resources. Although there was widespread use of manure among all classes, the survey also showed that application of woodland litter, composted household waste and crop residues to field crops was deemed experimental by the innovator farmers (Class B) and was also perceived as an option for resource poor farmers. In many instances, manure, when available, was preferentially applied to the rich fields particularly by the Class A farmers. This

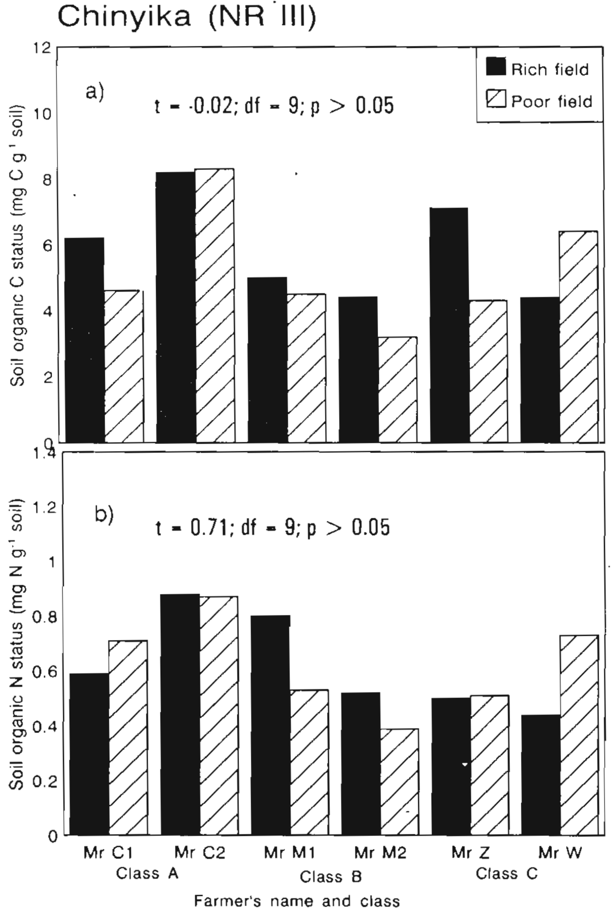

Figure 1. Pre-season soil organic carbon (a) and nitrogen (b) contents of rich and poor fields belonging to six three different farmer groups in Chinyika, Zimbabwe

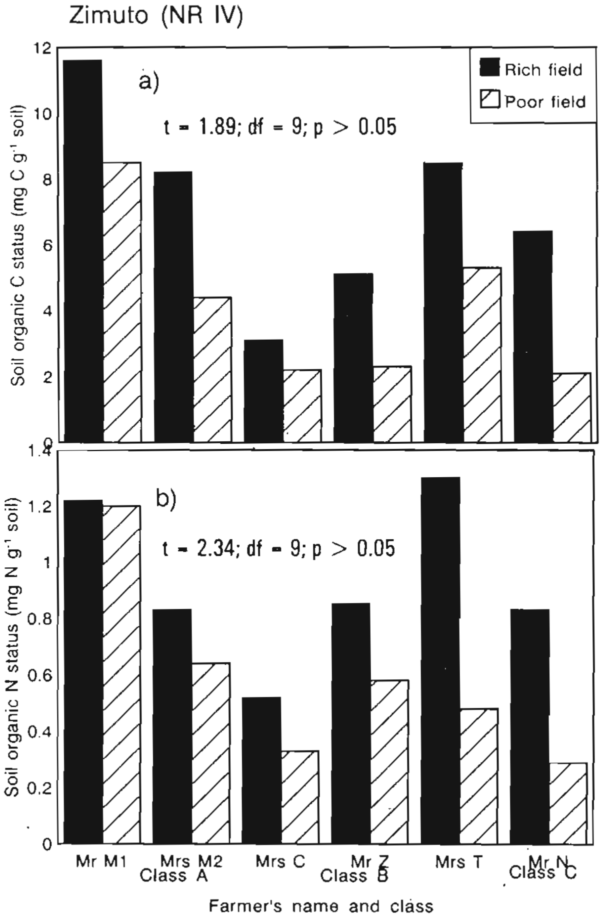

Figure 2. Pre-season soil organic carbon (a) and nitrogen (b) contents of rich and poor fields belonging to six three different farmer groups in Zimuto, Zimbabwe

implied that most farmers prefer to invest their labour inputs where returns are already favourable, thus apparently following a nutrient concentration strategy - the poorer or less productive the field, the less applied. The ameliorative role of manure to soil was not a new concept to the smallholder farming community where cattle manure was viewed as a common and significant soil fertility input in maize systems (Tanner and Mugwira, 1984; Mugwira and Murwira, 1997). Livestock manure applications to soil have been known to increase soil pH, infiltration rates, water holding capacities and decrease bulk densities (Grant, 1967; Murwira, 1993).

Preliminary results from this study have revealed that cultivation of grain legumes for food is at a low scale in all the three Natural Regions, be it as rotations or intercrops while exploitation of legumes for soil fertility management is virtually non-existent. While information on the role of leguminous plants in replenishing soil fertility is available (Sanchez, 1995; Giller, 1998; Mapfumo, 2000), these results suggest that the strategies to translate this valuable information to the smallholder farming community need diversification. Currently there is a general belief among smallholder communities that legumes are a women's crop (Mapfumo et al., 2001b) and this belief coupled with poor extension methods and over emphasis on cereal production, have led to reduced legume cultivation. Application of leguminous residues in arable farming systems provides a ready supply of N to growing crops. While very few farmers appreciate the role of grain legume residues in soil amelioration, some results have shown that in cereal cultivation, N contributions from legumes can be as high as 250 kg N ha^{-1} yr^{-1} (Giller, 2001). However, in poor sandy soils, reported values have mostly been less than 30 kg N ha^{-1} (Mapfumo, 2000). It is imperative to note that the impact of legumes on soil productivity may not only be restricted to N contributions, which has been the major focus of previous work on organic input research. The quantity and quality of C supplied by many of these organic materials may also play a significant role in soil productivity. Information of the role of decomposable C on nutrient release and soil amelioration from high quality organics including legume residues is not well documented (Kirchmann and Bergquist, 1989). This information is essential in guiding farmers and land-managers to optimally use their organic resources, both in the short and in the long term. Legume residues are most beneficial in providing nutrients in the short-term, an option more likely to be appealing to most smallholder farmers (Palm et al., 2001). In the wake of diminishing resources, the growing of legumes and utilizing their residues may be a realistic way of increasing soil available C in sandy soils. This study aims to address the practicalities of these issues. Are we as researchers doing enough to promote soil organic matter build-up in our inherently poor soils? Participatory experiments with farmers in Murewa (NR II) suggested that *Cajanus cajan* (pigeonpea) could be successfully grown by farmers yielding very high biomass of up to 23 t ha^{-1} in 2 years (Mapfumo et al., 2001).

While it is difficult to make conclusive statements based on these preliminary results, a few lessons can be drawn. In Zimuto, use of organic fertilizers in arable farming showed that soil C reserves could be improved judging from the relatively high contents of soil organic C, compared to the soils in Chinyika where mineral fertilizer usage takes precedence. Although cultivation in Chinyika is barely 20 years old, soil C and N are already depressed probably stemming from the heavy dependency on mineral fertilizer with little or no organic inputs. We therefore conclude that there is merit to develop strategies for the use of organic inputs, to not only improve the soil organic C status, but also crop yields through efficient nutrient uptake. The term organic fertilizer should be given a new meaning for the smallholder environment to not only mean manure but crop residues as well. For the non-owners of cattle, the window of opportunity rests with the growing of legumes with the N-rich stover being retained in the field.

It is imperative to investigate how nutrient availability is related to the quantity and quality of C supplied in organic resources used by farmers in the medium- to long-term if combined use of organics and mineral fertilizer is to be optimized.

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Questions and Answers

Rhizobium, N Fixation and Microbiology

To Sheunesu Mpepereki and Ishmael Pompi

Q: How did you handle marketing among smallholder farmers?
A: In Zimbabwe, lucrative markets exist for soyabean, e.g. for oil expression and livestock feeds. Smallholder farmers come together in groups to consolidate their harvest into large enough loads for transport to market. Contracts have been negotiated with buyers to accommodate all smallholder crops. The Soyabean Promotion Task Force has played a coordination role that has been progressively passed on to farmers' own organizations. Private buyers have supplied weigh scales.

Q: Is inoculation a full component of the soyabean technology or do farmers often grow soyabean without inoculation?
A: Yes inoculation is the key technology being promoted. The inputs package contains seed, inoculant, lime (for acid soils), base fertilizer and fungicides (for rust disease). No farmer will plant soyabean without rhizobia inoculants if they can help it. Some plant promiscuous varieties. Unfortunately, there is no breeding program for promiscuous varieties in Zimbabwe.

Q: Where does the soyabean fit within the whole farm system given soil fertility gradients?
A: In Zimbabwe soyabean is planted in outfields, often not the most fertile fields. Farmers are encouraged to grow soyabean in the more fertile fields to enhance yields and income from sales.

Q: What is the percentage of smallholder farmers adopting soyabean production technology in Zimbabwe?
A: Adoption rates have been near experiential. Numbers increased from a few hundred to over 10 000 in three growing seasons (1996 – 1999). Area planted has increased from about 240 ha (1995) to 44 000 ha in 2000. In one communal area, Kazangarure, with about 3000 families, AGRITEX estimates over 98% have adopted soyabean BNF technology over a four year period (1997 – 2000).

Q: To what extent could you have soil residual effects of the inoculants in the field?
A: Residual effects of inoculants depend on the survival and persistence of inoculation strains. In heavy soils (with high clay and organic matter content), rhizobia strains survive and are effective for up to three seasons or more if the legume is grown in a regular rotation. Survival and persistence are poor in sandy soils where the legume requires to be inoculated every time it is planted.

To Friday Sikombe, et al.

Q: What were the optimum levels of nitrogen fertilizers and inoculation for bean yields?
A: The optimum levels of nitrogen recommended were 100 kg N ha^{-1} which is called the Lima recommendation. For the inoculum, the optimum level is two 250g-packets of inoculant per hectare.

Q: The pH of the soils at your site was 7.2. What could have been the effects on N- fixation? You also applied N-fertilizers at two rates; 0 and 100 kg N ha^{-1}. Don't you think that 100 kg N ha^{-1} was rather too high and could have suppressed nodulation? Do you think we have farmers who can apply fertilizers at this rate?
A: The pH 7.2 had no effect on N- fixation. The level of 100 kg N ha^{-1} is the Lima recommendation. This level did not affect nodulation except with the cultivar, Lundazi. It is true that small-scale farmers are unable to apply fertilizer nitrogen at this rate. The option, therefore, is to exploit Biological Nitrogen Fixation (BNF) through inoculation with Rhizobia, and the use of bean genotypes that respond well to inoculation.

C: A rate of 100 kg N/ha is certainly too high for a legume. Its effect would be to limit nodulation and N fixation in the beans.

To Ylver Besmer, et al.

Q: Did you quantify the AMF inoculants, e.g. spore numbers? And is the intervention one that farmers can introduce and manage?
Why lab lab? Does it have any utility value for farmers or a chance of being integrated into the cropping system?
Quantities of N from groundnut appear extremely low, contrary to common knowledge that the residues of groundnut have high amounts of N. How do you explain this?
How did you account for litterfall by pigeonpea in calculating N input?
How was the control for trapping the AMF treated?

General Discussion

C: Recovery of legume N may be low in a subsequent cereal crop but a substantial part often remains in the SOM pool, which may build soil fertility and benefit future crops.

C: The N recovery of leguminous tree rotations with maize is 10-20% and subsequent recovery is 3-5%. However we need fertilizer equivalencies of organic based technologies and these should be presented in extension manuals.

C: In relation to the recovery of N from soyabean residues by a subsequent maize crop. Results from work carried out at CIAT (1993-98) on the Colombia Savannas on an Oxisol in the humid tropical lowlands (150 masl, >2600 mm rainfall) using ^{15}N techniques found 10–20% recovery of N from soyabean residue by a subsequent maize crop. A substantial amount was lost by leaching (>50%). N recovery was <50% that of N fertilizer under these conditions. However, conditions are very different in this region than in Colombia and the amount of N recovery from legume residues, the amount lost through various pathways, and the amount that remains in soil to build soil fertility is very much dependent on factors such as soil biophysical properties, climate, etc. So there is no single answer to the question.

C: Leaving legume residues on the soil surface as a mulch rather than incorporating into soil has the potential to preserve nutrients in the biomass for release later when the crop is planted. The practice is consistent with conservation minimum tillage practices.

C: The value of grain legumes in improving soil fertility should not only be seen from a chemical point of view but also from benefits on soil physical properties.

ADDING A NEW DIMENSION TO THE IMPROVED FALLOW CONCEPT THROUGH INDIGENOUS HERBACEOUS LEGUMES

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Abstract

Opportunities for harnessing biological nitrogen fixation of non-cultivated herbaceous legumes in order to improve soil productivity on smallholder farms in Zimbabwe were explored in a study initiated in December 2001. Over 30 indigenous legume species were jointly identified with farmers across three agro-ecological regions, ranging from sub-humid (800 mm annually) to semi-arid (<650 mm). A Gwezu Smell Technique, based on the odour released from freshly harvested legume roots, greatly enhanced the capacity of farmers to participate in the identification process. The legume diversity was highest in Chinyika Resettlement Area where cropping had been going just over 20 years. This was contrary to the loss of diversity in old Communal Areas where dominance of clean weeding practices for over 70 years has led to depletion of the weed seed bank. Legume contribution to the total above ground biomass ranged from 3% in 1-year fallows under semi-arid conditions to 88% in a field abandoned soon after crop establishment under sub-humid conditions. The latter case indicated an opportunity for manipulating legume populations to increase their contribution. Overall, total fallow productivity did not exceed 3.2 t ha^{-1} due to extreme conditions of poor soil fertility, where soils had generally <10% clay with ~ 0.4% organic C, < 3 ppm available P and pH (H_2O) between 4.8 and 6.0. Evaluation of the fallowed sites suggested that most of the fields fallowed by farmers are often too poor for any meaningful cropping using the currently available low cost soil fertility technologies. Based on results from this exploratory study, this paper introduces the concept of indigenous improved fallows, Indifallows, as an alternative option for integrated management of soil fertility by smallholder farmers. Indifallows involve the use of self-regenerating and well-adapted indigenous herbaceous legumes to improve the quality and productivity of natural fallows, and thus minimizing labour and establishment costs for poor households.

Key words: Indigenous herbaceous legumes, natural fallows, improved fallows, indigenous improved fallows, indifallows

Introduction

Challenges for enhanced soil fertility management

Over the past two decades, researchers and farmers in sub-Saharan Africa have developed numerous technologies to combat low and declining soil fertility under different agro-ecosystems. Technologies based on agroforestry, livestock manures, N_2-fixing grain legumes and green manures have been tried to improve both the quantity and quality of nutrient resources available to farmers (Giller and Wilson, 1991; Mugwira and Murwira, 1997; Waddington et al. 1998; Mapfumo et al. 1999). Although some of these technologies have shown great potential, the target farmer groups have often failed to adopt them, partly due to the costs involved in the adoption process (e.g. purchase of seed or inoculum, raising seedlings, and particularly meeting labour demands). Studies have generally revealed strong relationships between socio-economic and soil fertility management factors, demonstrating the complexity of the soil fertility problem. For instance, studies by Carter et al. (1993) and Scoones et al. (1996), showed that farmers aim not only to minimize the costs of inputs but also the risk associated with adoption of new technologies. Wealth-ranking exercises in these studies have indicated that poorer households are more risk averse than their wealthier counterparts and most often depend entirely on traditional technologies (e.g. natural fallowing) and locally produced resources for soil fertility management. In the wake of increasing population pressure and land shortages, the main challenge is to enhance the diversity and accessibility of these locally derived nutrient resources, and minimize the costs associated with their management in order to reach the poorest farmers. Use of any particular type of nutrient resource is seldom a matter of choice but determined mainly by availability (Mapfumo and Giller, 2001). There is therefore a need to promote those soil fertility management options that optimally exploit the dominant ecological and/or biological processes in the given agro-ecosystems. Despite the advocacy for integrated nutrient management and ecological approaches to agriculture (e.g. Giller and Cadisch, 1995; Breman, 1998), little or no research work in Zimbabwe and other parts of Southern Africa has focused on natural weeds as an organic nutrient resource that can be exploited by smallholder farmers for their management of soil fertility. This study, therefore, focused on self-regenerating N_2-fixing indigenous legumes. These legumes are considered an under-utilized component of an organic resource pool that may be readily available to smallholder farmers in many parts of Africa. Assessing and manipulating the diverse N_2-fixing herbaceous legumes in local agro-ecosystems provide a good starting point to meet these challenges. Based on results of a study initiated in December 2001, this paper explores the concept and scope for indigenous fallows (Indifallows). The general objective was to make an appraisal on the potential for indigenous legumes to contribute towards combating the problem of poor soil fertility which underlies rural poverty in Zimbabwe and other parts of Africa.

The Indifallow concept

The Indifallow concept is based on harnessing biological nitrogen fixation (BNF) of herbaceous annual legumes native to or naturalized under given agro-ecological environments in order to improve the N economy of natural fallows at minimal establishment and management costs. While it is traditional practice to fallow unproductive land, effectiveness of fallows as a means for soil fertility restoration has often been compromised by the reduction in fallow periods as land becomes limiting and also the poor quality of the plant biomass generated in the fallowing phase. Efforts to improve the quality of fallows through agroforestry tree crops such as *Leucaena*, *Sesbania* and *Acacia* spp. have often been hindered by high establishment costs and lack of immediate benefits to the farmer (Cook and Grut, 1993; Kwesiga and Coe, 1994; Snapp et al. 1998). Through use of self-regenerating and well-adapted indigenous annual legumes, constraints related to seed costs and availability, nursery management and biomass management are minimized. Thus a focus on BNF of indigenous herbaceous legumes will not only help to provide a basis for integrating weeds as a potential source of N and soil organic matter in cropping systems, but also to improve and maintain the biodiversity in smallholder agro-ecosystems. Most studies on weed management in smallholder farming systems have been concerned with the adverse effects of weed competition on moisture and nutrient uptake by crops, and the labour costs involved in managing the weeds. As a result, the strategy has been to eradicate weeds, mainly by depleting the seed bank (weed plants are killed before flowering). Clean weeding, which involves maintenance of weed-free fields until the end of the cropping season, is a common practice among smallholder farmers in Zimbabwe. This is still driven by extension recommendations based on 'green revolution' technologies. Although this weed management approach has become a tradition, it may compromise the long-term sustainability of these cropping systems through loss of bio-diversity and reduced organic matter inputs. It also leads to the dominance of pernicious weeds that are by definition difficult to control by hand weeding and cultivation. An analysis of 'green revolution' technologies in sub-Saharan Africa has shown that they are largely incompatible with the socio-economic environment on smallholder farms (Quiñones et al. 1997). It is imperative that the current weed management regimes be revised to match the demands for integrated nutrient management and reduce labour requirements. This may reduce the burden on women and children who usually provide labour for key agricultural activities such as weeding and seedling establishment and transplanting in agroforestry. Technologies with minimal labour demands are likely to be particularly appropriate for the poorest farmers who are often women in single-headed households, or families where key members providing labour have been lost due to AIDS. As we explore the feasibility and merit of indifallows from a soil fertility perspective, the key question is whether such legumes do exist in smallholder farming systems and under what soil conditions.

Study Sites

The research was conducted in three communal (smallholder) areas found in different eco-zones of Zimbabwe, namely Chikwaka (31° 30′ E; 17° 40′ S) in Natural Region II, Chinyika (32° 25′ E; 18° 15′ S) in NR III and Zimuto (30° 52′ E; 19° 50′ S) Communal Areas in NR IV. Natural Region II receives over 750 mm of rainfall annually between November and March while NR's III and IV receive 650-750 mm and 450-650 mm of unimodal rainfall per annum respectively. The soils in all sites are granite-derived sand to loamy sands, Haplic Lixisol/Arenosols according to the FAO classification. The sites were mainly chosen based on their being representative of most smallholder farming areas. Chikwaka and Zimuto are old Communal Areas where cultivation by smallholders has been going on for over 70 years. The average household landholding in Chikwaka and Zimuto was 3 ha, while in Chinyika, a resettlement area established in 1982, the landholding was 6 ha per household.

Materials and Methods

The study used farmer participatory approaches, complemented with laboratory-based analyses of soils and plant materials. At least two participatory rural appraisal (PRA) workshops were held at each study site to discuss broader issues of soil fertility management and local knowledge of leguminous plants. Farmer involvement ranged from identification of the legumes, and their niches, to seed collection. Members of the local community leadership that included councilors, headmen and resident national extension officers organized and participated in transect walks during the initial legume identification exercise.

Transect walks and legume identification using the *Gwezu* smell technique

Transect walks were conducted in all study sites. Based on the physical slope, farmers identified three main field positions, namely, topland, midslope and the relatively moist bottomland positions. During the transect walk, particular attention was paid to cropping patterns (including crop types), weed status of the fields, and occurrence of naturally growing herbaceous legumes. General discussions ensued during the course of the walks and details of cropping history and predominant weed species were specifically discussed with farmers whose fields were surveyed. Farmers were generally able to distinguish legumes from non-leguminous plants by considering mainly fruit morphology and likening them to traditionally grown leguminous crops such as groundnut (*Arachis hypogaea*), common bean (*Phaseolus vulgaris*) and cowpea (*Vigna unguiculata*). Because identification was done when most of the species were not yet fruiting, applicability of this approach was limited. To aid this process, the research scientists then came up with an identification approach based on the human sense of smell, hereinafter called the *Gwezu smell technique*. The researchers discovered that freshly harvested roots of all the identified legumes invariably had a distinct smell characteristic of an immature groundnut pod. An immature groundnut pod is known as *Gwezu* in Shona (Karanga dialect), a Zimbabwean vernacular language. Plants were also uprooted, and presence of root nodules was considered indicative of a legume, taking care to differentiate true root nodules from the galls caused by root-knot nematodes. The field-identified legumes were then taken to the National Herbarium laboratory of the Zimbabwe Ministry of Lands, Agriculture and Rural Resettlement, for botanic identification.

Measuring species diversity and abundance

Transect walks and PRA group discussions resulted in three possible scenarios for legume sampling to determine the diversity and abundance of the legume species: Scenario I - natural grazing areas that have not been cultivated for more than five years; Scenario II - fields that had not been cropped in the current season (first season of fallowing); and Scenario III - cultivated fields in which only the first weeding had been done. After further consultation with farmers, it was decided that measurement of species abundance be focused on the latter two scenarios since grazing by livestock would affect measurements under natural grazing areas. Consequently, the emphasis on Scenario I was only on determining species diversity. Individual plant samples were collected by farmers, field assistants and researchers enclosed in polythene bags, and put in cooler boxes for transportation to the National Herbarium for identification. For Scenario II, only those fields that were free from livestock disturbance during the cropping season were sampled. The only exception to the sampling protocol was at Mr Zindoma's farm where a maize field abandoned soon after crop emergence due to lack of fertilizer inputs was additionally included.

Sampling and analyses of plants and soils

Sampling for Scenarios II and III was done by using a network of 4 m x 4 m grids that were made out of metal pegs and twine. The grid network was spread over the desired field area and four replicate grids randomly selected for sampling. For each replicate sampling grid, all legume plants belonging to the same species were uprooted, checked for nodulation and put in a khaki sampling bag after cutting off the roots from just above the soil line. Non-leguminous plants were collectively sampled from 2 randomly located grids of 0.5 x 0.5 m^2 drawn from within the 4 x 4 m^2 grid. In each agro-region the process was repeated at each of the selected 10 farm sites where fields meeting desired criteria were found. All plant samples were oven-dried to constant weight at 60°C and then measured for dry mass. The dried samples were then ground in a Wiley Mill to pass through a 1 mm sieve. Determination of N, P and K concentrations was then done using the methods given by Anderson and Ingram (1993).

Soils were sampled from the respective field sites by collecting 15 sub-samples from the 0 – 20 cm depth per field site using a spade. The sub-samples were mixed thoroughly in a clean polystyrene bucket, after which a 1 kg composite sample was withdrawn and put into a polythene bag for laboratory analysis. The soils were analyzed for texture, pH, organic C and plant available P according to methods by Anderson and Ingram (1993).

Seed collection

Seed collection was considered an important entry point for farmer involvement, and would enhance farmers' capacity to identify the legumes. No specific assignment was given to individual farmers. All volunteers made collections for more than one species, taking into consideration the spatial distribution, time differences in reaching maturity and the differences in growth patterns among the different species.

Results

Species diversity and abundance

Thirty-three indigenous herbaceous legume species, mainly of the genera *Crotalaria, Indigofera* and *Tephrosia,* were identified among the three agrozones. Using the *Gwezu* smell technique, participating farmers and field assistants were able, not only to identify the legumes, but also to collect seed. The highest number of 28 legume species (Table 1) was recorded in Chinyika resettlement area. Ten of the total of 33 species were only present in Chinyika and not in the other two Communal Areas, while a further 10 species were commonly found in all areas. There was a critical lack of information on indigenous names for the diverse legumes identified. Farmers attributed this to fact that these species were generally not rated as problem weeds, neither were they used as a source of food at household level. They were therefore unlikely to be given specific names because of their little economic importance. Seed collection by farmers was feasible for all species except *Alysicarpus ovalifolius.*

Table 1. Species of indigenous herbaceous legumes identified to grow as weeds on smallholder farms in three agro-ecological regions in Zimbabwe

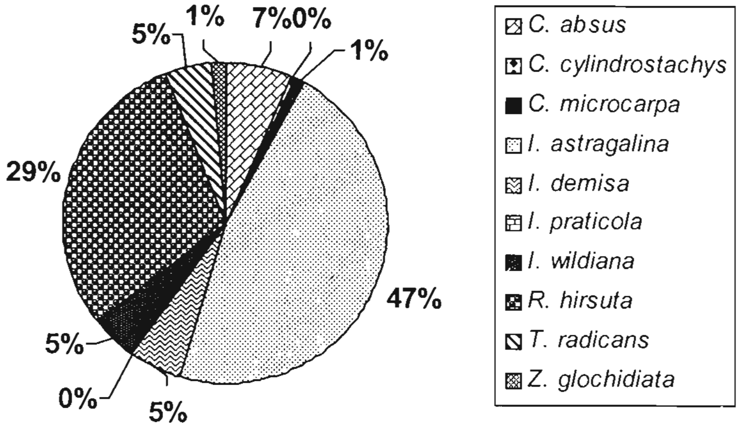
Legume species	Agro-ecological region (NR) and site		
	NR II: Chikwaka	NR III: Chinyika	NR IV: Zimuto
Alysicarpus ovalifolius	NI	I	NI
Eriosema ellipticum	NI	I	NI
Crotalaria cylindrostachys	I	I	I
C. glauca	NI	I	NI
C. laburnifolia	I	NI	I
C. microcarpa	I	I	I
C. ochreleuca	I	I	NI
C. pisicarpa	NI	NI	I
C. rhodesiae	I	NI	NI
C. sphaerocarpa	I	I	NI
Chamaecrista absus	I	I	I
C. mimosoides	I	I	I
Indigofera antunesiana	NI	I	NI
I. astragalina	I	I	I
I. brachynema	NI	I	NI
I. demisa	I	I	NI
I. flavicans	NI	I	I
I. nummularifolia	NI	I	NI
I. praticola	I	I	NI
I. vicioides	I	I	NI
I. wildiana	I	NI	NI
Macrotyloma daltonii	NI	I	I
Neonotonia wightii	I	I	I
Rothia hirsuta	I	I	I
Stylosanthses fruticosa	NI	I	NI
Tephrosia acaciifolia	NI	I	NI
T. longipes	NI	I	I
T. lurida	NI	I	NI
T. purpurea	NI	I	NI
T. radicans	I	I	I
T. reptans	I	I	NI
Vigna vexillata	NI	NI	I
Zornia glochidiata	I	I	I
Total number of species identified	**18**	**28**	**15**

I – identified; NI – not identified in the area; NR II – 750 mm annual rainfall; NR III – 650-750 mm; NR IV – 450-650 mm

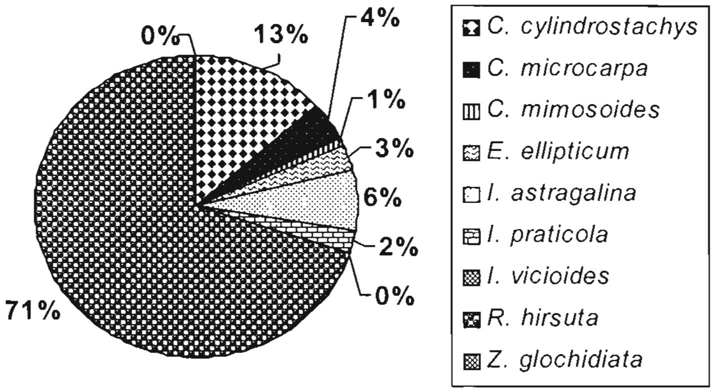
Because of a severe drought that started mid-way through the growing season, the determination of species abundance under cropped areas was rendered impossible. Weeds failed to germinate after the first weeding due to lack of moisture. Results on legumes species abundance were therefore only available from fallowed areas (Scenario II). *Rothia hirsuta* was the most dominant species in Chinyika where it constituted 71% of total legume biomass, while *Indigofera astragalina* was predominant in Chikwaka contributing 47% (Figure 1a and b). *Crotalaria pisicarpa,* predominated in semi-arid Zimuto where it contributed 39% to the total legume biomass, followed by *R. hirsuta* with 32% (Figure 1c). Apart from *R. hirsuta* and *I. astragalina* which featured prominently across all agro-regions, there were significant differences in the abundance of species from one region to another. For instance, *Crotalaria cylindrostachys* only featured prominently in Chinyika while the most significant amounts of *Zornia glochidiata* biomass were measured in Zimuto (Figure 1). At Mr Zindoma's additional field site (outside the regular sampling domain), there was a dense natural stand of legumes dominated by *C. cylindrostachys* with legumes contributed up to 88% of the above ground biomass (Figure 2), suggesting populations of the existing species are highly dynamic within a single growing season depending on soil management.

No observable patterns in species distribution across catenary positions were apparent in all areas during transect walks. The only notable exception was the growth and abundance of *Vigna vexillata* and *Zornia glochidiata* in bottomland positions (seasonally waterlogged or *dambo* fields) where the rest of the species were excluded. While the former was only restricted to dambo fields, the latter also occurred on topland and mid-slope positions down the catena.

a) Chikwaka



b) Chinyika



c) Zimuto

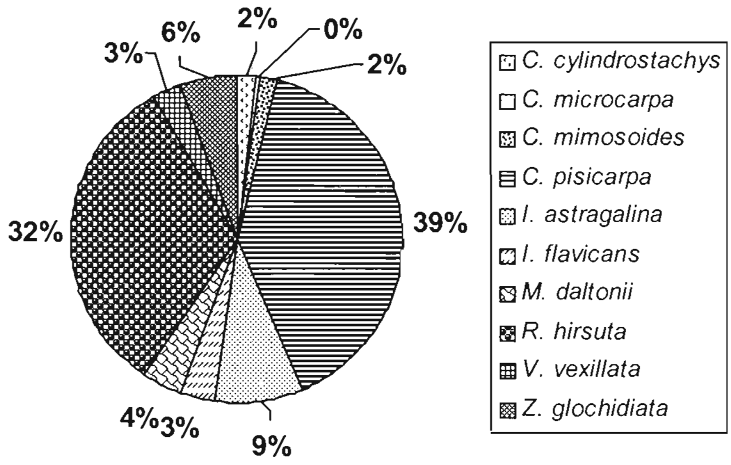


Figure 1. The relative abundance of legume species, expressed as % of total legume biomass per unit area, identified in communal areas falling under different agro-ecoregions in Zimbabwe

Productivity of the legumes on abandoned infertile soils

Most of the identified species were adapted to much depleted coarse sandy soils with organic C averaging less than 0.4% and mean available (Olsen) P levels below 3 ppm (Table 2). About 89% of all the soils sampled had less than 10% clay. The pH was slightly acidic in Chinyika but in the strongly acidic range, for Zimbabwean soils, in Chikwaka and Zimuto. Overall, legumes contributed a maximum 12% of the total biomass harvested under high relative rainfall conditions (average 800 mm yr^{-1}) in Chikwaka, and as low as 3% in semi-arid Zimuto (Figure 3). The total biomass productivity was highest in Chinyika Resettlement Area, with slightly over 3 t ha^{-1}, while Zimuto had no more than 0.75 t ha^{-1}. Plant productivity was evidently reduced by drought in the second half of the season.

N, P and K contents of identified species

There were high variations in the tissue N, P and K concentrations of the legumes across the three study areas. About 12 out of the 35 sample entries across sites had more than 2% N (Table 3). In general there were more entries with high tissue N concentration from the semi-arid area than from the other two regions. Surprisingly high total N values of 5.02 and 5.88% were measured for *C. laburnifolia* and *T. purpurea*, respectively, both of which were sampled in Zimuto. The number of samples with relatively high concentrations of P and K was generally high in Chinyika.

Discussion

The Gwezu Smell Technique for identification of legumes by farmers

Participatory research is often constrained by lack of a common tool for assessing or evaluating technologies. In several instances, there is a technical language barrier between farmers and researchers. The Gwezu Smell Technique provides an identification tool that can be shared by researchers and farmers. The technique is easy and accessible to all farmers, and could therefore provide an opportunity for them to distinguish and utilize legumes in their own environments. It could be combined with other assessment tools such as physical inspections for nodulation and nodule colour development used in the field for legume N_2-fixation appraisals. There is, however, a research challenge to identify the chemical substance responsible for giving this characteristic smell.

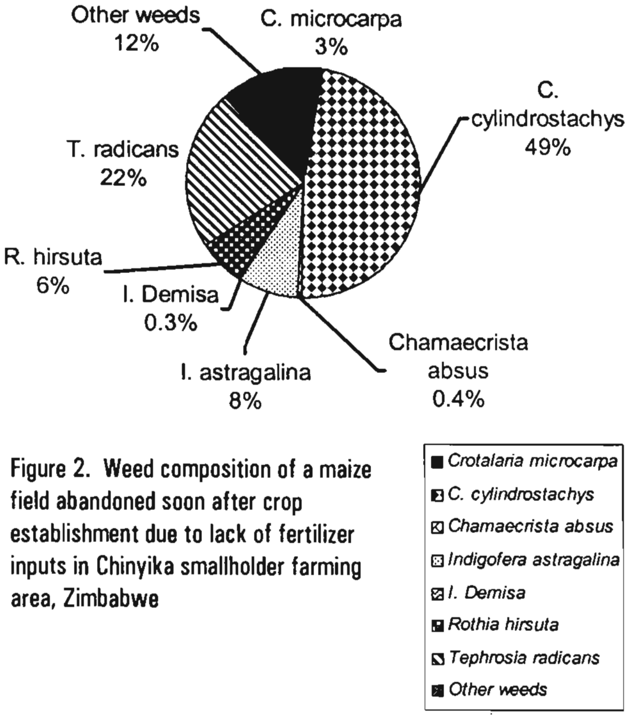


Figure 2. Weed composition of a maize field abandoned soon after crop establishment due to lack of fertilizer inputs in Chinyika smallholder farming area, Zimbabwe

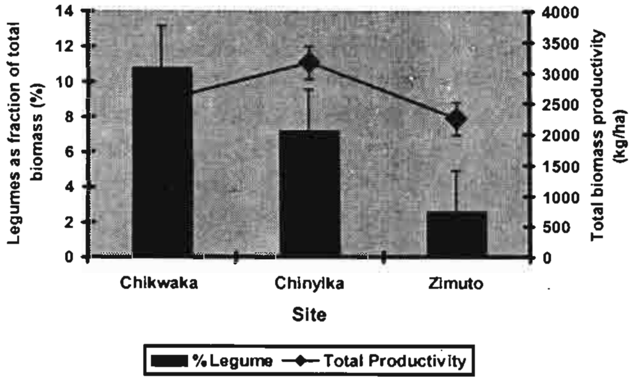


Figure 3. Legume biomass contribution to total biomass product under a one-year natural fallow in smallholder farming areas across three agro-ecological regions in Zimbabwe

Table 2. Major soil characteristics for selected fallowed field sites on which indigenous herbaceous legumes were naturally growing in smallholder areas of Zimbabwe

Areas and Agro-region	Farmer's Name	% Clay	% Sand	pH (H_2O)	Olsen P (ppm)	% C
Chikwaka	Kaseke	6	85	4.8	3	0.40
NR II	Mutawu	6	87	5.5	1	0.33
	Tafirenyika	6	83	5.3	1	0.32
Chinyika	Majaji	9	78	5.8	3	0.41
NR III	Razio	13	75	6.0	1	0.49
	Zindoma	7	82	6.0	3	0.52
Zimuto	Madhava	4	81	5.0	1	0.40
NR IV	Makonese	8	81	5.3	< 1	0.35
	Mudzikisi	7	85	5.5	1	0.17

NR = natural (agro-ecological) region

Legume diversity and adaptability

Diversity of legumes was higher in the relatively new resettlement area of Chinyika, where smallholder cropping has been taking place for about 20 years, than in the old smallholder farming areas of Chikwaka and Zimuto where cultivation had been going on for over 70 years. The trend on legume diversity contrasted with the pattern in biomass productivity, which showed a decline in legume biomass from Chikwaka (~12% of total), a high rainfall area, to Zimuto (~3%) a semi-arid area. This suggests a loss of legume diversity in the old communal (smallholder) areas of Chikwaka and Zimuto, and we attributed this to continuous depletion of the seed bank due to continuous cultivation coupled with clean weeding approaches. However, the 88% contribution by legumes to total biomass productivity in an abandoned field suggests that boosting the population density can enhance the legume contribution. Total biomass productivity was highest in Chinyika where legume diversity was also highest, although this study provides no basis to determine if the two parameters were related. Diversity measurements were taken across different soil fertility gradients and niches while biomass measurements were restricted to the fallowed sites where soils were predominantly infertile.

While the granitic sandy soils in Zimbabwe and other parts of Southern Africa are well known for their low pH (Grant, 1981; Anderson et al. 1993), the levels of soil C and plant available P were indicative of a severe state of soil nutrient depletion. It was therefore no surprise why farmers fallowed the respective field sites. Although the biomass productivity was low, it was evident that these legumes grew and nodulated relatively well under conditions where most cultivated annual legumes are usually constrained (Giller, 2001). The low overall biomass productivity in the study was largely attributed to the poor fertility of the soils and low rainfall received during the study. Less than 50% of normal rainfall was received across the regions, with less than 10 mm received in the second half of the season. Based on current results, it remains unclear whether soil fertility status, particularly P could influence legume species composition and productivity. However, 12 of the identified species showed tissue N concentration ≥ 2% suggesting their potential for N inputs into the soil. The high variability in N, P and K tissue concentrations suggest there is scope for harnessing selected species with high capacity for accumulation and cycling of the respective nutrient elements. Only those species adaptable to low levels of soil available P have a strong potential for use in Indifallows.

An ideotype for an Indifallow legume

The results of the study allow us to identify a number of key criteria that legume weeds should fulfill, which can be used in future selection work in other areas, namely:

Table 3. N, P and K concentrations (means of ≥ 5 samples) of indigenous legume species sampled from fields fallowed for a single growing season in three smallholder farming areas across different agro-regions in Zimbabwe

Species	Nutrient Concentration[1]								
	Chikwaka (NR II)			Chinyika (NR III)			Zimuto (NR IV)		
	%N	%P	%K	%N	%P	%K	%N	%P	%K
Alysicarpus ovalifolius	-	-	-	1.53	0.04	0.73	-	-	-
Chamaecrista absus	1.19	0.11	0.77	-	-	-	-	-	-
C. rotundifolia	2.12	0.08	1.75	-	-	-	-	-	-
C. mimosoides	-	-	-	1.45	0.07	1.44	1.45	0.05	0.48
Crotalaria cylindrostachys	1.63	0.09	2.11	2.09	0.09	2.33	1.77	0.06	1.79
C. laburnifolia	-	-	-	-	-	-	5.02	0.12	1.04
C. microcarpa	2.09	0.08	1.71	1.99	0.18	2.19	2.81	0.11	1.14
C. pisicarpa	-	-	-	-	-	-	2.67	0.08	1.14
Eriosema ellipticum	-	-	-	1.62	0.05	0.99	-	-	-
Indigofera astragalina	1.95	0.08	0.89	1.62	0.14	2.16	1.18	0.04	0.33
I. demisa	1.81	0.10	1.28	-	-	-	-	-	-
I. flavicans	-	-	-	-	-	-	1.71	0.05	1.29
I. praticola	-	-	-	1.74	0.13	1.14	-	-	-
I. vicioides	1.41	0.07	1.75	2.59	0.11	1.24	-	-	-
I. wildiana	2.38	0.10	0.84	-	-	-	-	-	-
Macrotyloma daltonii	-	-	-	-	-	-	1.66	0.06	1.14
Rothia hirsuta	1.59	0.09	1.72	1.91	0.10	2.44	1.66	0.06	1.02
Tephrosia longipes	1.32	0.05	0.33	-	-	-	-	-	-
T. purpurea	1.76	0.04	0.43	-	-	-	5.88	0.04	0.73
T. radicans	2.22	0.07	1.19	-	-	-	-	-	-
Vigna vexillata	-	-	-	-	-	-	1.65	0.06	1.40
Zornia glochidiata	2.72	0.09	1.14	1.59	0.17	1.45	2.27	0.08	0.96
Other weeds (mostly grasses)	0.75	0.07	0.73	0.63	0.07	1.35	0.69	0.05	0.59

[1] Each value is a mean of four samples; NR = natural (agro-ecological) region; (-) implies a missing value due to absence of particular species in the sampling framework

1. Abundant seeding to allow ready propagation and ready seed collection to reinforce populations.
2. A long-lived seed bank.
3. Rapid establishment and growth.
4. Adaptation to poor soils with restricted availability of phosphorus.
5. Good N_2-fixing potential in terms of spontaneous nodulation with indigenous rhizobia, good nodulation potential and high N concentrations in the shoots.
6. Easy to remove by hand pulling or hoeing should weeding be required.

The legumes that best fit these characteristics are largely annuals, biennials or short-lived perennials.

Opportunities for Indifallows in smallholder farming systems

The potential for Indifallows lies in the existence of a diversity of annual legumes that can grow in their mixtures with little demand for management of interspecific competition. Unlike agroforestry improved fallows and annual green manures, which are often constrained by conditions of poor initial soil fertility, establishment costs and high labour demands, the most significant cost variables for Indifallows are likely to be seed collection and sowing. The fact that seed collection for most of the identified species by farmers themselves was feasible is indicative of the potential to manipulate legume densities in the stands, once the population dynamics are understood. We consider Indifallows as a technology for those poor and vulnerable farmers for whom current research and development initiatives have failed to draw their participation. These poor groups often lack minimal cash requirements to invest into currently available soil fertility technologies. The challenge, however, is that of developing strategies for integration of these legumes into existing cropping systems, and defining the practical domain within which the technology can work. The existence of regional research networks such as the TSBF-CIAT African Network (AfNet) and Soil Fertility Network for Maize-Based Cropping Systems in Southern Africa (SoilFertNet) provide an opportunity for a wider development and testing of Indifallow technologies on a regional basis.

Conclusions

Several conclusions were drawn based on this exploratory study. Results showed that smallholder farming systems across different agro-ecological regions in Zimbabwe contain sufficient diversity of indigenous herbaceous legumes to warrant more strategic research on Indifallows as a component of integrated soil fertility management. However, there are indications that that current clean weeding practices recommended for these farmers may be contributing to loss of agro-biodiversity in farming systems. Most of the dominant species were evidently tolerant to poor fertility soils with low P and pH levels, yet it was apparent that most of the soils on fields fallowed by farmers in Zimbabwe are too poor to support any meaningful cropping using the currently available low cost soil fertility technologies. Although there is still need to establish why farmers have not significantly exploited these resources over time, we advocate for a paradigm shift in weed management approaches towards enhancement of agro-biodiverse smallholder farming systems. There is scope for wider networking and collaboration on development of Indifallow technologies in the sub-regions in Africa.

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SCREENING OF SHORT DURATION PIGEONPEA IN MATABELELAND

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Abstract

Pigeonpea is a new crop fcr the semi-arid tropics of Zimbabwe that offers substantial benefits to rural households. These benefits include soil fertility enhancement, improved household nutrition and income diversification. To identify adaptable varieties for farmers, ICRISAT-Bulawayo conducted screening trials for 10 short duration determinate and 12 short duration indeterminate pigeonpea varieties on heavy clay (Matopos site) and sandy (Lucydale site) soils during the 2001/2002 rainy season at Matopos Research Station.

At each site, pigeonpea varieties were planted in a randomized block design with three replicates. The crops were planted on 10 (Matopos) and 11 (Lucydale) December 2001. Agronomic data included date of planting and emergence, days to 50% flowering and maturity, plant height, grain yield and woody biomass yield.

Total rainfall for the season (October 2001 to June 2002) was close to the long-term average, with 537 mm at the Matopos site and 427 mm at Lucydale. However, it was poorly distributed, and crops effectively received 124 mm at Matopos and 133 mm at Lucydale from the date they were planted until harvest. Generally, varieties planted on the clay outperformed those planted on the sand because of a more favorable soil water balance. Determinate pigeonpea planted at Matopos flowered and matured earlier and on average yielded more grain compared to the crop at Lucydale. The earliest maturing determinate varieties on both soils (average 114.5 days on sand) were ICPL 86012 and ICPL 87105. However, the grain yield for these two varieties (744 kg/ha and 841 kg/ha respectively) was lower than the highest yielding determinate varieties, ICEAP 00781 (1058 kg/ha), ICEAP 00535 (902 kg/ha) and ICEAP 00536 (849 kg/ha), which matured at about 116 days. The earliest maturing indeterminate varieties for both soils were ICPL87091 (114 days) and ICEAP00718 (140 days). For the indeterminate types, earliness was associated with highest grain yield ICPL87091 (829 kg/ha), ICEAP 00721 (682 kg/ha) and ICEAP 00718 (641 kg/ha), but these were much lower yields than from the best performing determinate varieties.

Key words: Short duration pigeonpea, early maturity, high grain yield, screening, benefits

Introduction and Background

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is a multipurpose drought tolerant grain legume crop (Kimani et al., 1994) that offers substantial benefits to many smallholder farming systems that dominate the semi-arid tropics (SAT) of Africa and Asia. These benefits include improved household nutrition, fodder and browse, soil fertility enhancement, and income diversification (Holden, 1993; Karachi and Zengo, 1998; Mapfumo et al, 1998).

Over the last 30 years, the area cultivated to pigeonpea has increased substantially, as have the countries that now produce it. Traditionally, pigeonpea production in the semi-arid tropics was principally confined to the Indian subcontinent. However, over the last 25 years the efforts of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and other organizations have ensured that the crop is now widely grown in the SAT of Asia, Africa and the Caribbean under a wide variety of cropping systems (Kollipara et al, 1994). In Africa, considerable amounts of pigeonpea are produced in Kenya, Malawi and Zambia, with varieties such as ICP 9145 having been cultivated in Malawi since 1987 (Reddy et al, 1993). Pigeonpea is also an important grain legume crop for smallholder farmers in Tanzania (Mligo et al, 2001). Despite the increased cultivated area in many countries of sub-Saharan Africa, few studies have been done on the adaptability of pigeonpea in Zimbabwe, through efforts by the Department of Research and Specialist Services in the late 1980s. Those that have been done were confined to the higher rainfall areas of the country. Dzowela et al (1995, 1997) carried out trials on pigeonpea to establish its potential as livestock fodder in Domboshava and Makoholi Zimbabwe whilst Mapfumo et al (1998) investigated the potential contribution of pigeonpea to soil fertility in Domboshava and Murewa communal lands during the 1996/97 cropping season. Consequently, ICRISAT-Bulawayo conducted screening trials for 10 short duration determinate and 12 short duration indeterminate pigeon pea varieties on heavy clay (Matopos) and sandy (Lucydale) soils during the

2001/2002 rainy season. Short duration varieties were selected to suit the weather conditions of the region that is characterized by low and unpredictable rainfall patterns. This paper summarizes results for the 2001/2002 season.

Materials and Methods

Site Characteristics

Matopos. The Matopos site is 1344 m above sea level, with flat land on the lower slope within the Matopos Hills. The soil at the site is classified as the Matopos 3E.4 using the Zimbabwe Classification system (Pellic-Eutric Vertisol), which describes an imperfectly drained vertisol derived from igneous/metamorphic rocks. The soil is deep (130 cm+) and is water-saturated for short periods every year. It is mostly made of black clay with a granular structure in the top layers. This soil is fertile with 100% base saturation and a high cation exchange capacity (CEC) (Moyo, 2001). Prior to the 2001/2002 cropping season the land had been planted to millet breeding trials that had received 300 kg ha^{-1} basal Compound D fertilizer.

Lucydale. The Lucydale site is 1378 m above sea level, located on a gently undulating plain. The soil type at the site is described as a Eutric Arenosol 5G.2 (Zimbabwe Classification) that is a typical moderately deep to deep well-drained fersiallitic soil derived from granite. The soil is excessively well drained. The tops layers of the soil are coarse-grained sand and loamy sand with apedal structure. The soil has a slightly acidic pH 5 in the top layers. This soil is less fertile compared to the Matopos soil and has a base saturation of 60% in the top layer (Moyo, 2001).

Experimental Design

At each site, 10 determinate and 12 indeterminate varieties were planted. The selected fields at both Matopos and Lucydale were previously under millet breeding trials. Prior to planting the pigeonpea, both sites received a basal dressing of 300 kg ha^{-1} Compound D and the soil was ploughed using a tractor drawn disc plough to a depth of 0.20 m.

The design was a complete randomized block design with three replicates. The determinate pigeonpea plot size was 5.0 m x 2.0 m, with a between row spacing of 0.5 m and within row spacing of 0.2 m. The indeterminate plots were 5.0 m x 3.0 m in size with a row spacing of 0.75 m and plant-to-plant spacing of 0.3 m. These are recommended plant densities for the Matopos elevation.

The Matopos plots (both determinate and indeterminate) were hand planted on 10 December 2001 and the Lucydale plots were planted on 12 December 2001. Four seeds were planted per station about 5 cm deep to maximize germination.

Crop Management and Records of Observations

All plots were thinned to one plant per planting station three weeks after planting the two sites. Weeding was done using hand hoes, as weed pressure dictated. A single spraying of Dimethoate was carried out at both sites on 12 March to destroy leaf eaters.

Observations were done every day and records were taken for date to 50% flower, date to 75% maturity, plant height, final plant stand, harvest date, woody biomass yield and grain yield.

The crop at Matopos was affected by frost and both the indeterminate and determinate crops wilted. At the Lucydale site the crops received a further 20 mm of rainfall in June and all the varieties started flowering again. The indeterminate varieties could not reach maturity due to destruction by animals at the podding stage.

A one way Analysis of Variance (for randomized blocks) was performed on woody biomass and grain yield using Genstat for Windows (5th Edition).

Results and Discussion

Rainfall Data

Total rainfall for the season, October 2001 to June 2002 (Table 1), was close to the long-term average with 536.5 mm at the Matopos site and 427 mm at Lucydale. However, it was poorly distributed, and the determinate varieties received effectively 124 mm at Matopos and 133 mm at Lucydale. Given the moist condition of the seedbeds at planting at both sites, germination was good.

Responses of Determinate Pigeon Pea Varieties

Short duration determinate pigeonpea varieties flowered approximately two weeks earlier at the Matopos heavy clay site, when compared to the sandy Lucydale site, despite that planting was only one day apart (Table 2). Despite the earliness of flowering at Matopos, a similar length of time was required for the pigeonpea varieties to reach physiological maturity; typically 116 days from planting. However, the early flowering at Matopos

Table 1. Total rainfall (mm) at ICRISAT Research fields from October 2001 to April 2002.

Month	Oct01	Nov01	Dec01	Jan02	Feb02	Mar02	Apr02	Season Total	Longterm mean
Matopos	64	108	134	44	12	2	134	536.5	590
Lucydale	41	132	112	41	16	3	46	427	

Table 2. Characteristics of short duration determinate pigeon pea varieties grown during the 2001/2002 season at Matopos and Lucydale.

	Days to 50% flowering		Days to 75% maturity		Grain yield kg ha^{-1}		Biomass kg ha^{-1}	
Site/variety	Matopos	Lucydale	Matopos	Lucydale	Matopos	Lucydale	Matopos	Lucydale
Var 1 ICEAP 00360	61	77	118	118	739.3	504.0	7383.9	6329.9
Var 2 ICEAP 00394	61	71	118	118	746.7	343.3	6538.9	8521.7
Var 3 ICEAP 00535	61	73	115	114	902.0	614.0	5201.0	4468.9
Var 4 ICEAP 00536	61	77	115	115	848.7	634.7	5224.4	4555.6
Var 5 ICEAP 00753	61	77	116	118	705.3	360.7	6642.9	5785.8
Var 6 ICEAP 00781	61	75	117	118	1058.0	370.7	5815.6	5129.0
Var 7 ICPL 86012	61	73	115	114	744.0	458.0	4365.7	4177.3
Var 8 ICPL 87091	61	77	115	118	773.3	398.0	6114.3	4909.1
Var 9 ICPL 87105	61	71	115	114	840.7	592.7	4109.6	4668.1
Var 10 ICEAP 93027	61	77	118	115	749.3	546.7	6699.4	5046.7
Site mean	61	75	116	116	810.7	482.3	5810	5359
SED	0	3	0.901	0.870	172.3	93.9	426.4	899.1

had a major influence on yields. The pigeonpea yields at Matopos averaged 810.7 kg ha^{-1} compared with 482.3 kg ha^{-1} for Lucydale. There was no statistical difference between varieties at both sites.

Variety ICEAP 00394 yielded significantly (P>0.001) more woody biomass than other varieties at Lucydale, and performed similarly to the other varieties at Matopos. However, it had the lowest grain legume yield of any variety on the sands at Lucydale and gave one of the lowest yields at Matopos. Varieties ICEAP 00535 and ICEAP 00536 performed above average at Matopos and significantly (P<0.001) better than the other varieties on the sands, although they yielded lower biomass than the site averages. Variety ICEAP 00781 yielded the highest grain at Matopos and the worst at Lucydale.

Growth Characteristics of Indeterminate Varieties

Animals destroyed the Lucydale indeterminate block and as a result grain yield data could not be recorded.

Table 3. Growth Characteristics of Indeterminate short duration pigeon pea varieties

	Date to 50% Flower	Grain yield kg ha^{-1}	Biomass kg ha^{-1}	
Site/variety	Matopos	Matopos	Matopos	Lucydale
Var 1 ICEAP 00424	92.0	599	6414.0	6987.6
Var 2 ICPL 87091	71.3	829	7149.6	6175.6
Var 3 ICEAP 00719	79.7	604	6300.6	7669.6
Var 4 ICEAP 00725	97.3	628	6244.3	5396.6
Var 5 ICEAP 00723	92.0	524	5419.6	7349.2
Var 6 ICEAP 00720	92.0	577	6509.3	6671.6
Var 7 ICEAP 00727	95.3	594	4944.8	5691.7
Var 8 ICEAP 00721	90.0	682	6538.5	5748.6
Var 9 KAT 60/8	90.0	569	7727.0	5750.8
Var 10 ICEAP 00718	88.0	641	6172.8	5264.6
Var 11 ICEAP 00722	90.0	624	7557.4	7704.6
Var 12 ICEAP 00728	102.7	463	8007.9	7176.2
Site mean	90	611	6582	6466
sed	7.50	75.9	955.3	973.9

For the indeterminate varieties, early maturity was associated with highest grain yield. Variety ICPL87091 (829 kg/ha), ICEAP 00721 (682 kg/ha) and ICEAP 00718 (641 kg/ha) were the highest yielding indeterminate varieties, but these gave lower yields than the best performing determinate varieties. The average for the indeterminate varieties at Matopos was 611 kg/ha compared to 811 kg/ha for the determinate varieties (Table 3). The yields at Matopos were probably increased by a better nutrient supply and more moisture storage by the clay soil.

The highest yielding variety at the Matopos site was Variety ICPL 87091, which yielded 829 kg ha^{-1}. This was significantly (P<0.001) more than 10 varieties and still 140 kg more than the next best variety, ICEAP 00721. Lowest grain yields were obtained from those varieties that were slowest to flower.

No statistical differences between varieties were observed for woody biomass yields with the indeterminate varieties. However, the highest yielding variety at the Matopos site was ICEAP 00728 (8008 kg/ha) while at Lucydale ICEAP 00722 was the highest yielder, with 7705 kg/ha. This variety was the third best at Matopos, yielding 7557 kg/ha.

Potential Varieties

The 2201/2002 rainy season was an extreme season that tested the robustness of the pigeonpea germplasm under low moisture but without nutrient stress. Therefore varieties that performed well under these conditions are likely to be the best bets for risk aversion. However, it will be very important to see how the varieties would perform under smallholder farmer soil fertility conditions, which are often nutrient limited.

Based on these first results, ICEAP 535 and ICEAP 536 can be recommended for further trials in the semi-arid region of Matabeleland for grain yield because their yields were consistent on both soil types. The highest yielding variety on clay, ICEAP 00781, performed poorly on the sands so it is not a good variety for testing under farmer conditions where sandy soils are common.

The indeterminate varieties that can be tried are ICPL 87091, ICEAP 00721 and ICEAP 00718. The indeterminate varieties however need to be planted early if they are to reach full maturity under the low rainfall conditions in Matabeleland.

Woody biomass (with leaves dropped) yield can be used as a rough indicator of the fodder yield potential of the pigeonpea varieties. Promising determinates are ICEAP00394 and ICEAP 00360. The indeterminate varieties that can be tried include ICEAP 00728 and ICEAP 00722. These recommendations are tentative because several abnormalities occurred during the 2001/2002 season at Matopos where the trials were carried out.

The 2001/2002 rainy season had poorly distributed rain. Therefore it is difficult to predict what would have happened under a normal season. Pigeonpea is known to be prone to *Fusarium* wilt but the disease was not observed during the season. Some ICRISAT lines are tolerant to the disease, like ICP 9145 and ICEAP 40 which is commercially grown in Malawi.

Recommendations

This trial was able to give information about the short duration pigeopnpea varieties that can be grown in Matabeleland. There is need to determine how the crops perform in a more normal season in which rainfall is evenly distributed. There is also need to further expand the studies to include soil fertility benefits, fodder yield and other benefits such as the use as firewood. There is also need to explore the market for the crop in Matabeleland. Tsholotsho farmers were shown the crop and they expressed an interest to grow it, but only if a market for the crop could be found. The drive to promote pigeonpea should also include showing the farmers how to utilize it as a food crop.

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RISK DIVERSIFICATION OPPORTUNITIES THROUGH LEGUMES IN SMALLHOLDER FARMING SYSTEMS IN THE SEMI-ARID AREAS OF ZIMBABWE

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Abstract

This paper uses a simulation modeling approach to evaluate the long-term diversification gains and risks associated with adoption of a range of fertility options, including legumes, manure, and small doses of inorganic fertilizer in semi-arid areas. These options were tested by the Department of Agricultural Research and Extension (AREX), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the Tropical Soil Biology and Fertility Programme (TSBF), the International Maize and Wheat Improvement Center (CIMMYT) and the Smallholder Dry Areas Resource Management Project (SDARMP) in farmer participatory research trials during the 1999/2000 and 2000/2001 cropping seasons in pilot areas in three semi-arid regions in Zimbabwe. The study tests the hypothesis that legume-based soil fertility technologies will benefit farmers if diversification into legumes complements farmers' current investments compared to alternative investments and the demand on resources is within the boundaries of the resource-endowments of the farmers.

Results indicate that maize-cowpea and maize-groundnut rotations and maize-pigeon pea intercrops and rotations are good investment opportunties for diversification from the traditional maize and sorghum soil-mining practices currently being pursued by the majority of farm households.

Key words: Legumes, intercropping, rotation, risk simulation, diversification, return on investment

Introduction

During the past decade, there has been growing interest in the use of legume-based technologies as nutrient sources in smallholder farming systems in Sub-Saharan Africa because of constraints on expanded use of inorganic fertilizers. Historically, legumes were grown as intercrops with cereals, especially during pre-colonial times. In Zimbabwe, agricultural extension has discouraged intercropping in the past 50 years and encouraged farmers to grow pure crops targeted at commercial markets. Despite this advice, farmers have continued to grow legumes intercropped with cereals albeit in small areas. To re-introduce legumes into the system at large enough scale to enable farmers to capture potential benefits of biological N_2-fixation (BNF), the legume technologies need to give a competitive rate of return on investment compared to alternative investment options available to households, meet farmers' requirements for risk, and fit within the boundaries of resource endowments of smallholders.

This paper uses a simulation modeling approach to evaluate the long-term diversification gains and risks associated with adoption of a range of soil fertility options, including legumes, animal manure, small doses of inorganic fertilizer and water management. These were tested by the Department of Agricultural Research and Extension (AREX), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the Tropical Soil Biology and Fertility Programme (TSBF), the International Maize and Wheat Improvement Center (CIMMYT) and the Smallholder Dry Areas Resource Management Project (SDARMP) in farmer participatory research during the 1999/2000 and 2000/2001 cropping seasons in pilot areas in the semi-arid regions in Zimbabwe.

Objectives

The general objective of the study was to assess the potential for adoption of legume-based soil fertility improvement technologies. The specific objectives are to:

- o Estimate expected profitability and riskiness of alternative legume technologies
- o Determine the benefits offered by legume-based soil fertility management technologies through diversification to households with different resource endowments and risk preferences.

Research Approach: Theory and Methods

The conceptual framework used for guiding the study is derived from portfolio choice theory. Portfolio theory provides analytical tools and methods for analyzing farmers' decision-making under risk and how best to invest a given bundle of resources among several alternatives while minimizing the risk of their portfolios.

Conceptual Framework and Hypotheses

For farmers to invest resources in new technologies such as organic and inorganic fertilizers, the rates of return on these investments need to be competitive with returns on available alternative investment opportunities. Within a single crop enterprise such as maize production, the return on investment in new fertilizer technologies is compared with the return on capital using traditional soil-mining methods. Between different crop enterprises, returns on investment in new management technologies are compared against other investments including livestock, off-farm activities, temporary and permant labor migration. Because of the uncertainty of payoffs to alternative investments, new investments must fit farmers' objectives and requirements for risk in addition to profitability. Because high returns are associated with high risks, farmers face trade-offs between allocating resources to activities with high profits and more desirable but riskier and therefore less attractive outcomes compared to activities with low profits and yet less riskier, which makes them more appealing.

Moss, Weldon, and Featherstone (1991) have developed an approach for evaluating risk-return tradeoffs and diversification opportunities of alternative farm investments that is based on the portfolio theory of financial markets and the capital asset pricing model (CAPM). These analysts argue that for a new or candidate enterprise to improve the risk–return tradeoff provided by any existing group or portfolio of enterprises, the following condition must hold

$$\frac{\bar{r}_i}{\sigma_i} \succ \frac{\bar{r}_p}{\sigma_i}\rho_{ip}$$

Where

$\bar{r}_i$ = the mean return of the potential new investment alternative,

σ_i = the standard deviation of the new alternative,

$\bar{r}_p$ = the mean return of the current whole farm plan,

σ_p = the standard deviation of the current whole farm plan, and

ρ_{ip} = the correlation between the current whole farm plan's return and the new enterprise's return.

If the mean return divided by the standard deviation of new investment alternative is greater than the mean of the whole farm plan's return divided by the standard deviation times the correlation between investments the new investment will complement the current operation from a risk-return perspective. Based on this risk-return condition necessary for a new enterprise to improve the risk-return trade-off provided by the current farm's portfolio, one can calculate a risk diversification index (RDI) as follows:

$$RDI = \frac{\bar{r}_i}{\sigma_i} - \frac{\bar{r}_p}{\sigma_i}\rho_{ip}$$

If the RDI is greater than zero, the candidate technology is a good investment opportunity for diversification. But if RDI is less than zero the candidate technology offers no gains through diversification to the farm household.

Applying this conceptual framework generates the following two hypotheses about relationships between the risk-return characteristics of new technologies, farmers' risk management strategies, and potential for adoption that are tested in the study:

1. Legume-based soil fertility management technologies are attractive if they lie on the risk-efficient frontier and offer farmers expected returns that are high enough to compensate them for additional risks; and
2. Diversification into legume-based soil fertility management technologies will benefit farmers if the new technologies complement the current farm portfolio and better offset the total risk of the whole farm compared to allocating resources to alternative farm and non-farm investment opportunities available to farmers.

Methods

The study uses enterprise and whole-farm budgeting, and simulation modeling with APSIM and @RISK to evaluate the hypotheses. Enterprise budgets are constructed for alternative investment technologies. Different enterprises are defined by different outputs such as maize, sorghum, chickens, goats and cattle; sole stands and crop mixtures; and different crop production technologies, including low and high rates of application of kraal manure, pit-treated manure, inorganic Nitrogen fertilizer and organic and inorganic fertilizer combinations. Enterprise budgets are used to compare the profitability of maize and sorghum crop production using traditional methods and improved soil fertility management technologies with different activities available to farmers and the profitability of different enterprises for households with different resource endowments. The budgets are constructed using yield and input-output coefficients data from farm surveys, Farmer Participatory Research experiments, and yields predicted by the Agricultural Production Systems Simulator (APSIM) model. The input-output coefficients are combined with prices from the Ministry of Agriculture, Zimbabwe Farmers' Union and Commercial Farmers' Union to calculate gross margins per hectare for crops and per breeding animal unit for livestock. Input prices are reported at the supply point. Input prices paid by farmers are estimated by adding input prices reported by suppliers and the cost of transport. Output prices are reported at the marketing point. Farm gate prices are estimated conservatively by deducting cost of transportation from prices at marketing points. The opportunity cost of family labor is estimated by multiplying the minimum wage rate of engaging in urban employment multiplied by the probability of finding a job.

Because APSIM crop yield predictions are only available for 10 years from 1990 to 2000 and for a few improved technology options this analysis focuses on sole maize and sorghum grown without fertilizer and with small quantities of Nitrogen fertilizer; kraal and pit manure; manure and Nitrogen fertilizer combinations; sole cowpeas and groundnuts; maize and sorghum-cowpea and groundnut intercrops and rotations, maize-cowpea and maize-groundnut rotations. The budgets include only the physical grain output of crop enterprises for primary and secondary crops valued at farm gate prices. Farmers frequently produce crops in mixtures of more than two crops and the budget needs to include the whole mixture. The values of byproducts such as stalks, which have value as livestock feed, in construction and composts are not included. Livestock budgets include the market value of the animal, depreciation on the value of breeding animals, milk, eggs, and draught power. Values of animal manure and traditional religious ceremonies are not included. The enterprise budgets are used to construct whole farm budgets for current farm plans for different household categories by aggregating the returns per unit over the number of units produced by the households. Because there are expenses and revenues that cannot be allocated to particular enterprises, and cases where we do not have a linear budget, this may underestimate returns to some activities. The budgets are used to estimate the expected annual returns, the degree of risk, and correlation coefficients for different crop and livestock combinations.

Table 1. Expected annual returns (Zimbabwe $/ha) and risk of alternative maize and sorghum soil fertility management technologies for male-headed households, Gwanda, Tsholotsho and Zimuto, 1990/91-2000/01

	Gwanda		Tsholotsho		Zimuto	
Activity	Return	Risk	Return	Risk	Return	Risk
POSC savings account	289	328	289	328	289	328
Sorghum+kraal manure	-15272	3948	-13793	5310		
Sorghum+0kraal manure+0N	-2440	4350	-156	6347		
Maize+0kraal manure+0N	3286	4526	5046	5759	4249	7688
Sorghum+9N	-849	5856	1911	7642		
Maize+groundnut intercrop	1738	6302	1260	8213	-2285	5969
Sorghum+groundnut intercrop	-3486	6403	-4383	8872		
Sorghum+pit manure	-1888	6752	542	8752		
Sorghum-groundnut rotation	554	7033	2914	8054		
Sorghum+cowpea rotation	-319	7422	8769	11024		
Maize+9N	4286	7450	7188	7160	6860	7913
Maize groundnut rotation	3888	7535	6800	8902	5764	7862
Maize+cowpea rotation	3412	7545	12743	10542	8591	10656
Sorghum+18N	-2330	7703	788	9718		
Sorghum+kraal+18N	-154	7759	3314	10160		
Maize+kraal manure+9N	2629	8296	6547	7984	6127	8498
Maize+pit manure	2414	8723	6417	7768	6281	9132
Maize+cowpea intercrop	-1179	9006	6875	10783	168	9807
Maize+kraal manure	3717	9220	5557	9774	4303	9785
Sorghum+cowpea intercrop	-5177	9306	3498	13359		
Sorghum+kraal manure+9N	-450	9765	2711	11107		
Maize+18N	1614	9804	5588	8436	6081	10255
Maize+kraal manure+18N	3894	10286	8293	8874	8951	10480

Results and Discussion

Tables 1, 2, and 3 present the annual returns and risks per hectare above fixed costs for 11 years from 1990/91 to 2000/01 on alternative maize and sorghum soil fertility production technologies by farm household typology. The tables also include the annual return and risk of investing funds in a risk-free asset, the POSB savings account. For male-headed households with resident husband and higher labor and draft animal resource-endowments, the most profitable production technologies are, in decreasing order of importance, maize plus 9 kilograms of nitrogen per hectare, maize plus kraal manure plus 18 kilograms of nitrogen per hectare, maize-

Table 2. Expected annual returns (Zimbabwe $/ha) and risk of alternative maize and sorghum soil fertility management technologies for *de facto* female-headed households, Gwanda, Tsholotsho and Zimuto, 1990/91-2000/01

	Gwanda		Tsholotsho		Zimuto	
Activity	Return	Risk	Return	Risk	Return	Risk
POSB savings account	289	328	289	328	289	328
Sorghum+kraal manure	-12801	3654	-10128	4911		
Sorghum+0kraal manure+0N	62	4366	3177	6334		
Maize+0kraal manure+0N	3378	4422	5042	5965	3200	7619
Sorghum+9N	2203	6042	4874	7642		
Maize+groundnut intercrop	2007	6352	1417	8479	-11012	7138
Sorghum+pit manure	344	6435	4908	8839		
Sorghum+groundnut intercrop	-1151	6542	-843	8883		
Maize+9N	5591	6699	6657	7505	-1802	22751
Sorghum+groundnut rotation	1886	7039	5374	8204		
Sorghum+cowpea rotation	1509	7264	11369	11236		
Maize cowpea rotation	4456	7470	13524	10753	6449	10686
Maize+groundnut rotation	4422	7564	7563	9056	427	8424
Maize+kraal+9N	4505	7767	5937	7952	-1924	22736
Sorghum+18N	697	7863	3548	9749		
Sorghum+kraal manure+18N	2873	7911	6205	10293		
Maize+pit manure	3884	8166	5791	8155	4974	9054
Maize+cowpea intercrop	-482	9005	7217	11232	-896	9912
Sorghum+cowpea intercrop	-1860	9220	8243	13643		
Maize+18N	3491	9286	4625	8780	-10118	40691
Maize+kraal manure	4031	9334	4946	9764	3170	9678
Maize+kraal+18N	5770	9611	7682	8839	-6049	39594
Sorghum+kraal manure+9N	2577	9980	3890	8759		

groundnut rotation, and maize cowpea rotations. The ranking is similar in the lower rainfall sites (Gwanda and Zimuto) but in wetter sites (Tsholotsho) groundnut and cowpea rotation give the highest expect annual returns. For *de facto* female-headed households with intermediate resource endowments but better access to off-farm cash, maize plus kraal plus 18 kilograms of nitrogen, maize plus 9 kilograms of nitrogen, and maize plus kraal plus 9 kilograms of nitrogen give the best returns followed by maize cowpea and maize-groundnut rotation in the drier sites. But the maize-cowpea rotation, sorghum-cowpea rotation, and sorghum-cowpea intercrop gives the best returns in the wetter sites. For the *de jure* households who are most resource-constrained, the most profitable technologies are the same as for the *de facto* households for drier and wetter sites although the legume rotations and intercrops are more profitable for *de jure* households compared to *de facto* households across all sites. For all household categories, higher expected returns are associated with higher risks and lower expected returns with lower risks irrespective of site. This shows that the Capital Asset Pricing Model approximates the risk-return characteristics estimated for the soil fertility management investment options for the farm households.

Figures 1, 2, and 3 show trade-offs between expected returns and risks of the alternative soil fertility production technologies. The dominating technologies are reflected by the set of points on the frontier. Technology investments that lie inside the frontier can be eliminated from further analysis as inferior because households can choose from among better options on the frontier that give higher expected returns for the same level of risk. The efficiency frontier for male-headed households in Gwanda includes, in increasing order of risks and returns, POSB savings account, sorghum plus kraal manure, traditional maize production technology without manure and nitrogen fertilizer, traditional sorghum, maize plus 9 kilograms of nitrogen per hectare, maize plus pit manure, maize plus kraal manure plus 9 kilograms of nitrogen, maize plus 18 kilograms of nitrogen, and maize plus kraal manure plus 18 kilograms of nitrogen. The frontier for male-headed households in Tsholotsho is dominated by POSB savings account, traditional maize, maize plus 9 kilograms of nitrogen, maize-cowpea rotation, maize plus kraal manure and maize plus kraal manure plus 18 kilograms of nitrogen. Zimuto male-headed households have a smaller available set of risk-efficient technologies: POSB savings account, traditional maize, maize-groundnut rotation, maize plus 9 kilograms, and maize plus kraal manure plus 18 kilograms of nitrogen. In contrast, the frontier for *de facto* female-headed households in Gwanda includes POSB savings accounts, traditional maize technology, maize plus 9 kilograms of nitrogen, and maize plus kraal manure plus 9 kilograms of nitrogen. For Tsholotsho *de facto* female-headed households, the frontier consists of POSB savings account, traditional maize, maize plus pit manure, maize plus kraal manure plus 18 kilograms nitrogen, maize-groundnut, sorghum-cowpea, and maize-cowpea rotations. The risk-return frontier available for *de facto* households in Zimuto comprises POSB savings accounts, traditional maize, maize plus pit manure and maize-cowpea rotation. The frontiers for *de jure* female-headed households are similar to those for *de facto* female-headed households across the three sites although cowpea dominates the efficient sets for *de jure* compared to *de facto* households. We conclude that legumes lie on the frontier and dominating set for especially *de facto* and *de jure* households in Tsholotsho and Gwanda and therefore are attractive to farmers. The mix of legume-based technologies in the portfolio will depend on the tolerance for risk of different households. Because legume technologies are associated with high risks and high returns, especially maize-groundnut rotations, they are likely to be attractive to mostly households with a high tolerance for risk.

Because different technology investments are differently correlated with the current farm plan and farm households can choose to invest resources among several investments in order to reduce risk without reducing expected returns, we need to consider the effects of including a production technology on the whole farm portfolio when deciding whether or not to include it in the current farm plan. Tables 4, 5, and 6 report the risk diversification indices for the whole farm for different household typologies. The analysis is extended to include the benefits of diversifying to medium and long duration pigeon peas and temporary migration to urban labor markets. The risk indices for maize-cowpea and maize-groundnut rotations and maize-pigeon pea intercrops and rotations are positive for different kinds of households across sites indicating that these legume-based soil fertility production technologies offer significant gains through diversification. Therefore they are likely to be adopted by farmers.

Table 3. Expected annual returns (Zimbabwe $/ha) and risk of alternative maize and sorghum soil fertility management technologies for *de jure* female-headed households, Gwanda, Tsholotsho and Zimuto, 1990/91-2000/01

	Gwanda		Tsholotsho		Zimuto	
Activity	Return	Risk	Return	Risk	Return	Risk
POSB savings account	289	328	289	328	289	328
Sorghum + kraal manure	-13023	3668	-7821	4410		
Sorghum + 0kraal manure + 0N	1704	8129	5419	6018		
Maize + 0kraal manure + 0N	3692	4422	5375	5986	5560	7518
Sorghum + 9N	1981	5994	7181	7347		
Maize + groundnut intercrop	1976	6364	4721	8216	-15949	6092
Sorghum + pit manure	122	6398	6405	8531		
Sorghum + groundnut intercrop	-1795	6476	3966	8355		
Maize + 9N	5954	6714	7759	7529	-1997	22645
Sorghum + groundnut rotation	1696	7024	7986	7992		
Sorghum + cowpea rotation	2296	7278	12735	11081		
Maize cowpea rotation	5534	7482	14288	10698	6349	10647
Maize + groundnut rotation	4524	7571	9573	8990	-1777	7727
Maize + kraal + 9N	4869	7796	7044	7976	-2111	22647
Sorghum + 18N	475	7814	5855	9464		
Sorghum + kraal manure + 18N	2650	7861	8512	9992		
Maize + pit manure	4247	8185	6893	8175	4779	8970
Maize + cowpea intercrop	800	9076	8291	11151	-1108	9812
Sorghum + cowpea intercrop	-545	9171	10167	13431		
Maize + 18N	3855	9310	5727	8796	2983	9632
Maize + kraal manure	4394	9397	6053	9785	-6237	39510
Maize + kraal + 18N	6134	9632	8789	8865	-10313	40600
Sorghum + kraal manure + 9N	2355	9926	6197	8470		

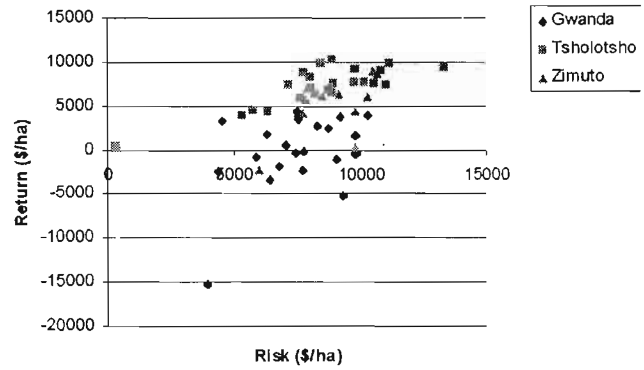

Figure 1. Risk-return tradeoffs of alternative maize and sorghum soil fertility management technologies for male-headed households, Gwanda, Tsholotsho and Zimuto, 1990/91-2000/01

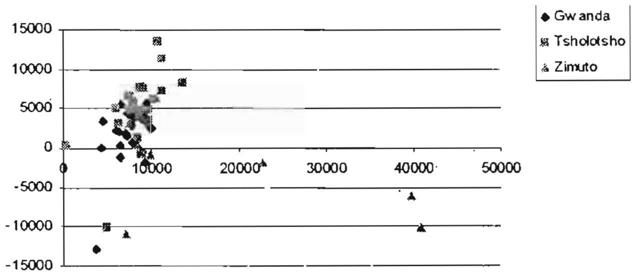

Figure 2. Risk-return tradeoffs of alternative maize and sorghum soil fertility management technologies for *de facto* female-headed households, Gwanda, Tsholotsho and Zimuto, 1990/91-2000/01

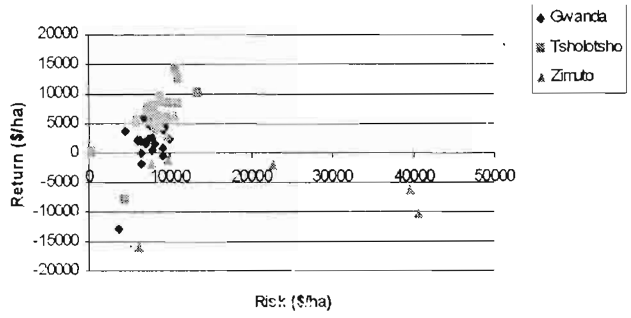

Figure 3. Risk-return tradeoffs of alternative maize and sorghum soil fertility management technologies for *de jure* female-headed households, Gwanda, Tsholotsho and Zimuto, 1990/91-2000/01

Table 4. Risk diversification indices of alternative maize and sorghum soil fertility management technologies for male-headed households, Gwanda, Tsholotsho and Zimuto, 1990/91-2000/01

Activity	Gwanda	Tsholotsho	Zimuto
Sorghum+kraal manure	-4.00	-2.30	
Sorghum+groundnut intercrop	-0.92	-1.10	
Sorghum+cowpea intercrop	-0.91	-0.40	
Sorghum+18N	-0.69	-0.55	
Sorgum+pit manure	-0.67	-0.52	
Sorghum+9N	-0.53	-0.31	
Sorghum+kraal manure+18N	-0.41	-0.31	
Sorghum+cowpea rotation	-0.37	0.09	
Sorghum+kraal+9N	-0.36	-0.26	
Sorghum+groundnut rotation	-0.25	-0.21	
Maize+cowpea intercrop	-0.14	-0.23	0.14
Maize+18N	-0.13	0.02	0.13
Maize+groundnut intercrop	-0.09	-0.33	0.09
Maize+pit manure	0.02	0.28	-0.02
Maize+kraal+9N	0.04	0.29	-0.04
maize+kraal+18N	0.09	0.34	-0.09
Maize+cowpea rotation	0.09	0.55	-0.09
Maize+kraal manure	0.16	0.27	-0.16
Maize+groundnut rotation	0.24	0.26	-0.24
Maize+9N	0.31	0.53	-0.31
Maize+long pigeonpea intercrop	0.56	0.19	0.14
maize+medium pigeonpea intercrop	0.61	0.53	0.13
POSB savings account	0.65	0.74	0.80
Maize+long pigeonpea rotation	0.89	0.74	-0.02
Maize+medium pigeonpea rotation	1.13	0.95	-0.04
Urban labor market	7.96	7.57	7.80

The risk analysis presented in this paper is a first cut to evaluate technologies that merit further study. In addition to meeting requirements for risk and return, new technologies must fit with the resource boundaries of farmers and management capabilities. Mathematical optimization provides tools for a more detailed analysis of the benefits and adoption potential of the technologies under the severe resource and institutional constraints faced by households in semi-arid areas.

Conclusion and Recommendations

The paper evaluates the attractiveness of alternative soil fertility management technologies for adoption by farm households with varying resources, and risk preferences. Results indicate that maize-cowpea and maize-groundnut rotations and maize-pigeon pea intercrops and rotations are good investment opportunties for diversification with traditional maize and sorghum soil-mining practices currently being pursued by the majority of farm households. Consequently, these legume-based soil fertility production technologies are likely to be adopted by farmers. Significant gains can also result from diversification into non-farm assets such as POSB savings accounts and urban employment. However, more detailed analysis using mathematical programming is needed to evaluate the feasibility and sensitivity of options to changes in environmental factors.

Table 5. Risk diversification indices of alternative maize and sorghum soil fertility management technologies for *de facto* female-headed households, Gwanda, Tsholotsho and Zimuto, 1990/91-2000/01

Activity	Gwanda	Tsholotsho	Zimuto
Sorghum+kraal manure	-3.64	-1.52	
Sorghum+groundnut intercrop	-0.84	-1.20	
Sorghum+cowpea intercrop	-0.81	-0.62	
Sorgum+pit manure	-0.60	-0.48	
Sorghum+18N	-0.58	-0.82	
Maize+cowpea intercrop	-0.44	-0.76	-0.38
Sorghum+cowpea rotation	-0.35	-0.16	
Maize+groundnut intercrop	-0.33	-0.72	-2.51
Sorghum+groundnut rotation	-0.32	-0.25	
Sorghum+9N	-0.31	-0.39	
Sorghum+kraal manure+18N	-0.30	-0.55	
Sorghum+kraal+9N	-0.28	-0.72	
Maize+18N	-0.26	-0.60	-0.18
Maize+pit manure	-0.09	-0.25	-0.10
Maize+kraal+9N	-0.05	-0.19	-0.03
maize+kraal+18N	-0.03	-0.18	0.05
Maize+cowpea rotation	-0.03	-0.03	-0.28
Maize+kraal manure	0.01	-0.24	-0.12
Maize+groundnut rotation	0.08	-0.13	-1.14
Maize+9N	0.24	0.05	0.16
Maize+long pigeonpea intercrop	0.49	0.52	-0.01
POSB savings account	0.50	0.30	-0.22
maize+medium pigeonpea intercrop	0.53	0.20	0.68
Maize+long pigeonpea rotation	0.80	0.45	1.18
Maize+medium pigeonpea rotation	0.99	0.76	1.34
Urban labor market	8.13	7.42	8.14

Reference

Moss B.C., Weldon N.R. and Feartherstone A.M., 1991. A simple approach to evalauting risk diversification opportunties. *Journal of American Society of Farm Managers and Rural Appraisors* 55:20-24.

Table 6. Risk diversification indices of alternative maize and sorghum soil fertility management technologies for *de jure* female-headed households, Gwanda, Tsholotsho and Zimuto, 1990/91-2000/01

Activity	Gwanda	Tsholotsho	Zimuto
Sorghum+kraal manure	-3.55	-1.81	
Sorghum+groundnut intercrop	-0.79	-0.82	
Maize+cowpea intercrop	-0.58	-0.70	-0.61
Sorghum+cowpea intercrop	-0.54	-0.35	
Sorghum+18N	-0.49	-0.59	
Sorgum+pit manure	-0.44	-0.55	
Sorghum+kraal+9N	-0.33	0.01	
Maize+groundnut intercrop	-0.23	-0.78	-3.11
Sorghum+9N	-0.22	-0.22	
Sorghum+kraal manure+18N	-0.20	-0.38	
Sorghum+groundnut rotation	-0.17	-0.21	
Maize+18N	-0.11	-0.68	0.54
Sorghum+cowpea rotation	-0.07	0.06	
Maize+kraal manure	-0.05	-0.60	0.44
Maize+pit manure	0.07	-0.44	0.51
Maize+kraal+9N	0.09	-0.39	0.65
maize+kraal+18N	0.12	-0.31	0.78
Maize+groundnut rotation	0.25	0.02	-0.81
Maize+cowpea rotation	0.30	0.34	-0.13
Maize+9N	0.43	-0.20	0.88
POSB savings account	0.44	0.72	0.27
Maize+long pigeonpea intercrop	0.51	0.24	0.51
maize+medium pigeonpea intercrop	0.56	0.52	0.70
Maize+long pigeonpea rotation	0.83	0.83	1.04
Maize+medium pigeonpea rotation	1.08	0.89	1.09
Urban labor market	4.02	8.17	6.98

EVALUATING MUCUNA GREEN MANURE TECHNOLOGIES IN SOUTHERN AFRICA THROUGH CROP SIMULATION MODELLING

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Abstract

*After an examination of opportunities for maintaining and improving soil fertility under smallholder systems, a case study using crop growth simulation in conjunction with historical weather data is presented. The potential for an improved resource management system that incorporates mucuna (*Mucuna pruriens*) to improve yields of the following maize crop in the drier areas of Zimbabwe is assessed with a crop growth simulation model. In this paper, APSIM was configured to simulate maize yields from crops receiving various amounts of N, or from an unfertilised maize crop following a mucuna crop. To take account of different levels of risk aversion, the technologies are examined in probabilistic terms based on the cumulative distribution functions of yield from 46 years of simulations.*

The analysis highlights large potential benefits from the use of mucuna as a green manure crop. The reason frequently proposed to explain low uptake rates of green manure technologies by smallholder farmers is the loss in maize yield during the year when the green manure crop is in the field. In environments where continuous maize cropping yields between 150 and 500 kg grain/ha, rotation with mucuna was predicted to give maize yield increments of over 1000 kg/ha when the mucuna is harvested at maturity and between 3000-5000 kg/ha when incorporated at flowering. Measured maize grain yield increases after mucuna in Malawi are of the order of 100-200%. These results are proving useful for Soil Fert Net members who have carried out a lot of research on velvet bean and other green manures for the region in recent years.

Key words: APSIM model, green manure, mucuna, computer simulation, semi-arid zones

Introduction

Maize is the primary food crop in Zimbabwe and occupies about one-half of the total agricultural cropland. In the smallholder sector, maize yields are low and variable primarily due to low inherent and declining soil fertility (Grant, 1981) coupled with low and erratic rainfall. About 70% of Zimbabwe is covered with coarse sandy soil derived mostly from granite. These soils are low in N, P and S and low in nutrient reserves and exchange capacity due to low organic matter and clay content. The risks associated with arable crop production in these areas limits the potential use of high input strategies by smallholder farmers. Average maize yields of between 1.0 to 1.5 t/ha are common under smallholder conditions as opposed to yields of around 5.0 t/ha in the large-scale commercial farming sector. Mataruka and Whingwiri (1988) identified soil moisture stress, poor soil and fertiliser management, low plant populations, late planting, poor weeding and labour bottlenecks as some of the major factors limiting maize productivity under smallholder conditions.

Researchers in Zimbabwe and Malawi under the Rockefeller-funded Soil Fertility Network have come up with a selection of soil fertility technologies that offer the 'best bets' for maintaining and improving the soil fertility of smallholder maize systems in a profitable and adoptable way. The range of technologies being tried out include:

- Flexible mineral N management based on rainfall for maize
- Soybean for communal areas
- Liming of granitic sands
- Rotations with grain legumes and maize
- Sole crop and intercropped legume green manures.

Background research papers on these technologies are presented in Waddington, Murwira, Kumwenda, Hikwa and Tagwira (1998).

Green manure technologies are not new in Zimbabwe, as some work was reported as far back as the 1920s to 1940s (Metelerkamp, 1988), although use of green manures has been mostly on large-scale commercial farms with some informal reports of use under smallholder conditions (Hikwa, et al. 1998). Rattray and Ellis (1952) noted that maize yield responses were larger when maize followed mucuna than after any of the other green manures used extensively through the 1950s. Recently there has been renewed interest in green manure technologies as the price of mineral fertiliser has increased.

The Risk Management Project (RMP) is a project under the CIMMYT Natural Resources Management Group with a broad objective of improving farm incomes and food self-reliance for poor smallholder farmers in Zimbabwe and Malawi by addressing problems of low soil fertility, climatic variability, low and unstable agro ecosystem productivity through the use of simulation modelling and farmer participatory research. Risk Management Project staff have been working in very close collaboration with a group of 14 farmers in the Zimuto smallholder area of Masvingo since 1999. The work has focussed on farmer-led on-farm experimentation with several legume-based soil fertility technologies coming out of the Soil Fertility Network trials. The approach used aims to enable farmers, together with researchers, to analyse and understand farmer strategies and practices of soil fertility management and to identify technologies that both meet farmers' needs and are sustainable. Preliminary results from the fieldwork and from focussed group discussions with the farmers indicate the robustness of mucuna under smallholder conditions and great interest in the mucuna technology amongst the farmers.

However, selection of an appropriate technology and management options is complicated by climatic variability. This means that management options must be assessed on a probabilistic basis. Moreover, the development of appropriate technologies, and the testing of the components, is complicated by season-to-season variability. Experiments to test different technologies must be run over many seasons to obtain reliable results. This is expensive and, in many cases, impractical. Simulation models, which integrate the major physical and biological processes, provide a solution to this problem.

Simulation Study

Simulations were carried out using the APSIM (Agricultural Production Systems SIMulator) model in conjunction with a 47-year long-term weather dataset for Masvingo, which is around 30 km south of the study area and about 50 mm/year drier. The APSIM software system allows a wide range of configurations of crops, sequences, mixtures and management practices to be simulated. It provides a flexible structure for the simulation of climatic and soil management effects on growth of crops in farming systems and changes in the resource base. A detailed description of APSIM, including its capabilities, design features, structure, user interface and the derivation of its main biological and environmental modules is provided by McCown, Hammer, Hargreaves, Holzworth and Freebairn (1995).

The simulation set-up consisted of growing either:

1. A maize crop, receiving various levels of N, year after year. The N levels ranged from 0 kg N/ha to 100 kg N/ha.
2. A crop of mucuna from the opening rains of the season. The crop of mucuna was managed in two ways:
    a) either the crop was grown to maturity and harvested on the 1st of July with 60% of the residues incorporated on the 1st of November just before maize planting (Management 1).
    b) or, the mucuna is harvested at the beginning of grain fill with 90% of the mucuna material incorporated at that time (Management 2).
3. The mucuna crop was grown in rotation with an unfertilised maize crop (cv. SC501). Two cropping systems were simulated for both residue management systems with either one maize crop after every mucuna crop (*mucuna-maize rotation*) or two maize crops after every mucuna crop (*mucuna-maize-maize rotation*).

Results and Discussions

Simulation runs on maize response to different amounts of mineral fertiliser and on maize following a mucuna crop were done using the long-term climatic data from Masvingo. On moderate fertility soils typical of most of the topland fields found in Zimuto, maize grain yields in the absence of mineral fertilisers were simulated to be, on average, 494 kg/ha. The yields from such unfertilised crops range from total crop failure to about 1600 kg/ha. These values are similar to values quoted elsewhere from on-farm and on-station results (Shamudzarira and Robertson, 2002) and are similar to measured yields for unfertilised maize in the area. Figure 1 shows the simulated responses to a range of different amounts of mineral fertiliser additions over seven seasons on a typically low fertility soil. There is enormous variation in maize response to any given rate of fertiliser applied, with the range being greater at higher rates of N applied. Smallholder farmers in this area normally cite the "risk" associated with the wide variations in yield with N application (Figure 1) as one of the reasons they use small amounts of mineral fertilisers. The simulations also show that in 20% of the seasons there is no benefit in use of mineral fertilisers in these environments.

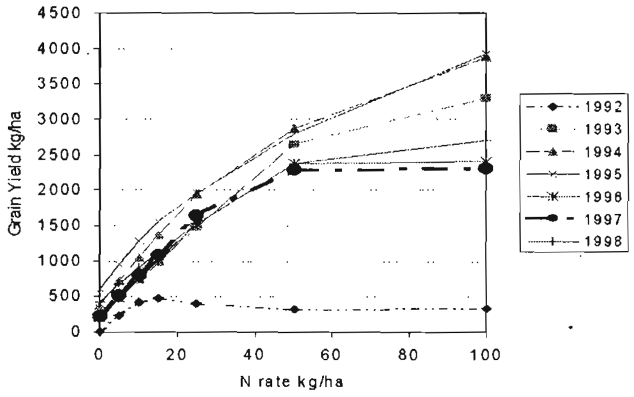

Figure 1. Maize grain yield responses on a low fertility soil to varying amounts of applied N (kg/ha) simulated using long-term weather data from Masvingo

Agronomic nitrogen use efficiencies (NUEs) were calculated from the simulated maize yields as extra kg grain produced divided by extra kg of N applied. Averaged over all years, agronomic NUEs declined from around 45-56 kg grain per kg of applied N at low application rates to about 33-38 at high N rates. In Figure 2, the agronomic NUE for a crop receiving 10 kg N/ha is plotted against the yield for an unfertilised maize crop. The data suggests that responses to low rates of N (commonly used by smallholder farmers) are generally larger on low than with high fertility soils.

Simulations were also conducted for the same climatic record for maize yields following a mucuna crop on a moderate fertility sandy soil. The mucuna was managed in two ways: - either harvested at maturity (1 July) and then incorporated just before maize planting (Management 1), or harvested and incorporated at flowering (Management 2). For each management system, two cycles of simulations were done, one in which a single crop of maize was grown following mucuna and the other in which two maize crops were grown in succession after a mucuna crop.

Despite having fewer seasons in which maize is grown in the mucuna-maize and mucuna-maize-maize rotations when compared to continuous sole maize, maize grain yields averaged over the 47-year record are predicted to be 3-5 times higher in rotations that include mucuna (Figure 3). With continuous sole maize cropping, just over 20 tonnes of maize grain is realised over 47 years compared to totals of between 80 and 120 tonnes in rotations that include mucuna (Figure 4).

At a 50% probability level, unfertilised maize grain yields are 3.5-4.0 t/ha for the mucuna-maize rotations and 3.5-4.5 t/ha for the mucuna-maize-maize rotations (Figure 5). These yields are far greater than the 200-300 kg/ha obtained for continuous sole maize cropping at the same probability level.

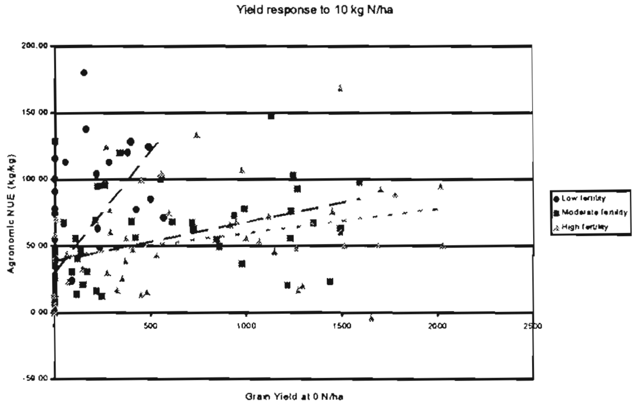

Figure 2. Simulated maize yield response to a 10 kg N/ha application for a crop grown on soils of different fertility status

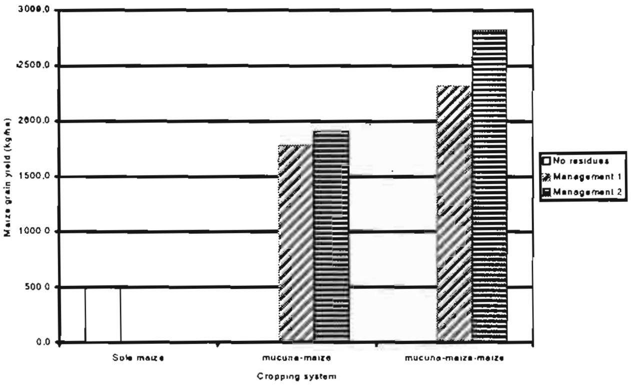

Figure 3. Mean maize grain yields for the 47-year record for different cropping systems

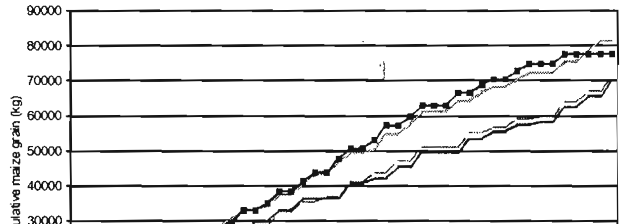

Figure 4. Cumulative maize grain production over 47 years for the different production systems

The loss in maize production from the piece of land where mucuna is grown in the first season, coupled with labour constraints, has been given by many workers as one of the limitations in the uptake of green manure technologies by farmers (Kumwenda, Waddington, Snapp, Jones and Blackie, 1997). However, in Northern Malawi on fairly good sandy soils, a one season sole crop green manure can increase maize yields from 200–300 kg/ha to up to 4 000 kg/ha. The data presented here also suggests at the 50% probability level, a yield surplus from an unfertilised maize crop of over 2000-3000 kg in maize output in mucuna-maize rotations and 5000-8000 kg in mucuna-maize-maize rotations as opposed to continuous sole maize cropping in situations where no mineral fertilisers are used (Figure 6). Muza and Mapfumo (1998) reported a trebling of maize yields in Chihota after incorporation of mucuna compared to an unfertilised maize crop that yielded 466 kg/ha.

Maize grain yields from continuous sole cropping without fertilisers show a slight decline with increase in amount of seasonal rainfall (Figure 7). In the rotation systems including mucuna however, there is a strong positive relationship between grain yield and seasonal rainfall. In environments where seasonal rainfall is below 350 mm, average maize grain yields are higher with the mucuna-maize-maize rotation than with the mucuna-maize rotation. Where seasonal rainfall is greater than 350 mm, mean yields are higher with mucuna-maize rotations than for two maize crops after every mucuna crop.

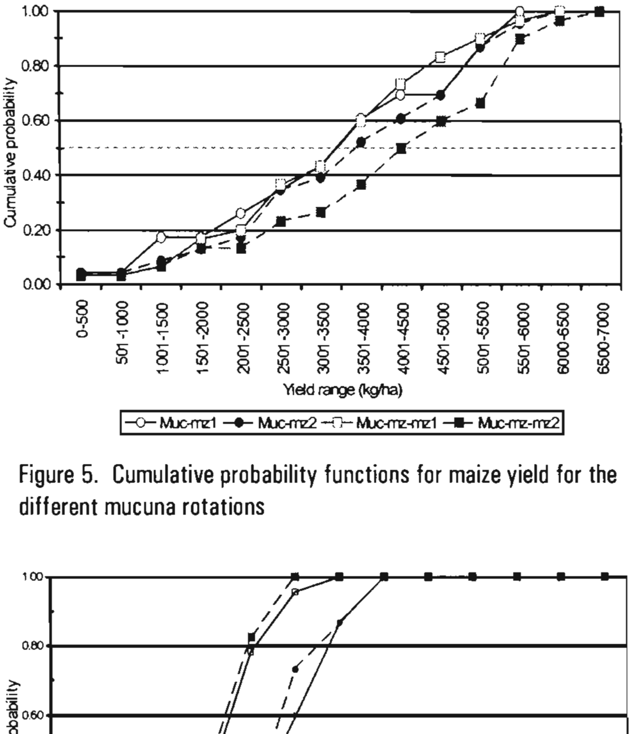

Figure 5. Cumulative probability functions for maize yield for the different mucuna rotations

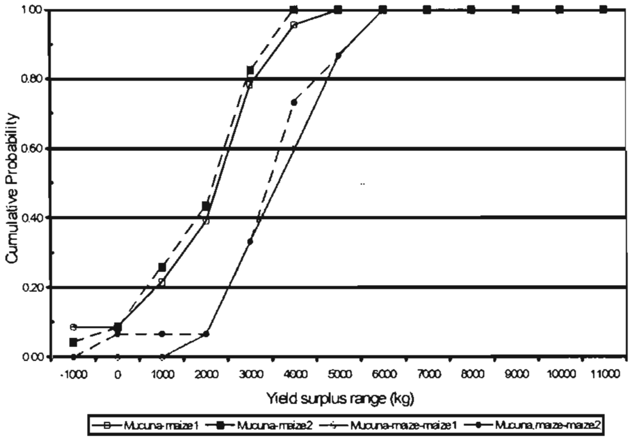

Figure 6. Cumulative probability functions for maize yield surplus from the different mucuna rotations compared to production from continuous maize cropping

In both cropping systems, maize yields are greater with an increase in the biomass incorporated. Maize yield responses are greater when the mucuna is incorporated at flowering than when it is incorporated at maturity. In the simulations, a mucuna green manure crop incorporated at harvest produced a mean maize yield response equivalent to a fertiliser rate of around 20 and 30 kg N/ha, for the mucuna-maize and mucuna-maize-maize rotations respectively, applied on a moderate fertility soil (Figure 8). Most of the farmers we are working with in Zimuto however, cite labour bottlenecks, draft power shortages and the need for mucuna seed, as some of the issues that work against incorporation of mucuna at the flowering stage.

The simulations also suggest biomass yields of over 6 t/ha in 50% of the seasons. However, these simulations assume no limitations on crop growth from any other nutrients apart from N. Most fields in the communal areas that have been cropped without regular applications of manure or mineral fertilisers show multiple nutrient deficiencies of N, P and S and sometimes Mg, K and Zn (Grant, 1967). Low inherent soil fertility under smallholder systems can adversely affect legume establishment. In some cases, it may be necessary to apply mineral fertilis-

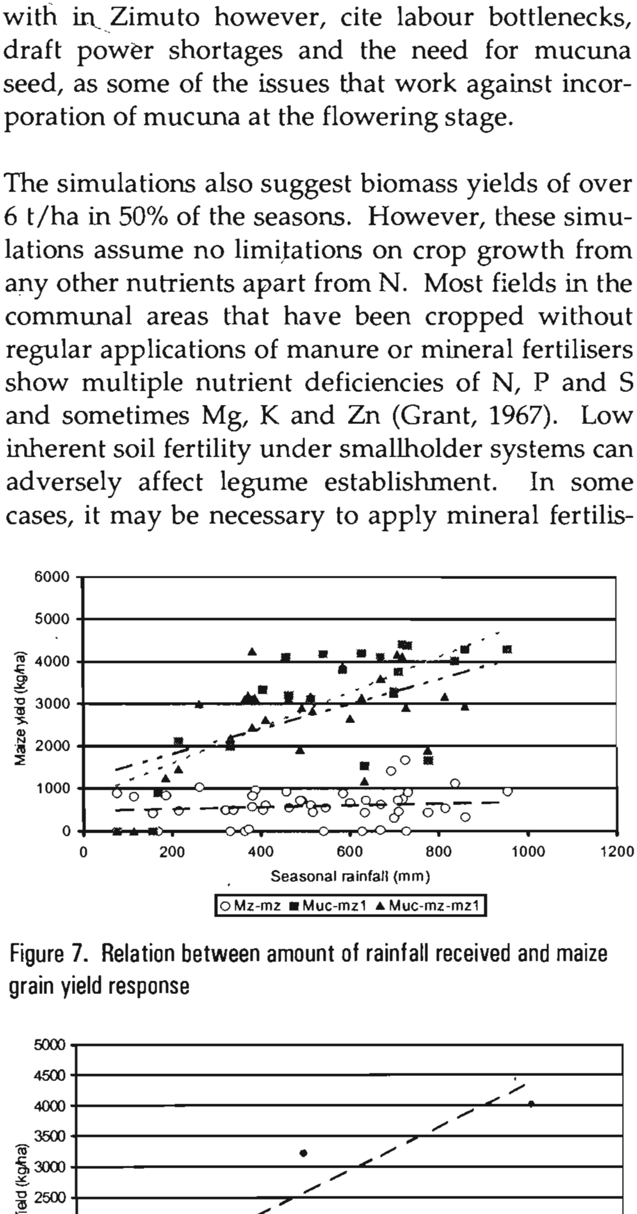

Figure 7. Relation between amount of rainfall received and maize grain yield response

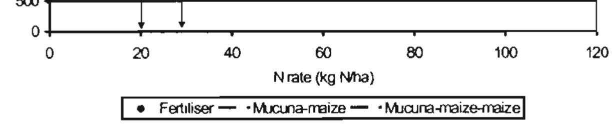

Figure 8. Mean maize yield response to different rates of applied N. Superimposed on the N response curve is the mean response to mucuna incorporated at maturity

ers, particularly P, to the legume to have reasonable biomass production for incorporation (Hikwa et al., 1998).

Conclusions

Crop growth simulation coupled to long-term weather data can assist in technology selection by generating probabilistic estimates of crop yield. The potential benefit of green manure technologies through field experimentation has been underestimated due to the short-term perspective of most field trials.

The foregoing analysis has highlighted large potential benefits from use of mucuna as a green manure crop. In environments where continuous maize cropping yields between 150 and 500 kg/ha, rotation with mucuna gives maize yield increments of over 1000 kg/ha when the mucuna is harvested at maturity and between 3000-5000 kg/ha when incorporated at flowering. The reason frequently proposed to explain low uptake rates of green manure technologies by smallholder farmers is the loss in maize yield during the year when the green manure crop is in the field.

Future studies need to confirm that the model has not overestimated the response to mucuna or that this response is not limited by factors not considered in the model (e.g. weeds, pests and diseases, other nutrients). Several workers have reported difficulty in establishing legumes under smallholder conditions citing soil infertility as the main factor. The residual effects from mineral fertiliser management on cereals on legume productivity have not received much attention and warrant investigation.

Socio-economic research needs to assess farmer attitudes toward risk and examine other constraints to mucuna use (e.g. access to capital, access to maize grain storage facilities, farmers' understanding of the full benefits of legumes in these systems, alternative uses of mucuna).

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Questions and Answers

Screening of Annual Legumes for Adaptation and Use

To Paul Mapfumo, et al.

Q: If the indigenous legumes dominate natural fallows, why is maize productivity so low after 1-2 years of natural fallows?
A: The current weed management approach in most farming areas is aimed at depleting the weed (including these legumes) seed bank through clean weeding. Therefore the current populations are probably too low to make an impact in the short term.

Q: If these 'indifallows' are left for two or more years, will they contribute more to productivity?
A: The duration of the fallow does play a big role in indigenous legume species diversity and abundance. In Chikwaka, legume biomass from one-year fallows was far less than that from two-year fallows for both species richness and abundance.

To Bongani Ncube, et al.

Q: Would it be useful to separate the woody tissue from leaves and their separate response to soil fertility? Will the woody tissue immobilize N?
A: Our research shows that it is beneficial to incorporate both leaves and stems soon after harvesting the grain. Stems decompose substantially within the year of incorporation (based on a five-year rainfall period). There seems to be better synchrony for maize under this system.

Q: Pigeon pea has been researched as long ago as the early 80's in Zimbabwe. Did you have an unsprayed crop and was spraying economic?
A: This was a nursery trial aimed at evaluating varieties, so we did not put up any control plots. Our aim was to assess what would grow in the semi-arid region of Matabeleland.

C: There is a lot of information about pigeonpea adaptability in Zimbabwe from Matopos, Makaholi, Panmure and Mlezu. See Agronomy Institute Annual Reports from 1987, 1988 and 1989.
A: It is very difficult to get access to this type of grey literature from the 1980's. None of the current literature we have reviewed makes reference to this early work.

Q: Did the research look at "weed suppression" on the experiments? In Mozambique it was found that just two weedings were needed when pigeonpea was intercropped with maize.
A: Our aim was to keep the crop as clean as possible, so weeding was done every time weed regeneration occurred.

To Richard Foti, et al.

Q:
1. The 18 kg N ha^{-1} for maize seems low for this heavy feeder crop. Is this practice not leading to nutrient mining?
2. Does the evaluation of the returns to a crop include the quantification of some of the more indirect crop values such as barter and exchange for labour?

A:
1. Farmers are already mining soils by not using any inorganic fertilizers at all and are therefore foregoing extra income that they could generate from using low rates of fertilizers, earn more income, buy more fertilizers and move upwards. Insisting that farmers use rates of fertilizer that they cannot afford and that fail to generate a competitive rate of return on their investment is retrogressive.
2. Yes the analysis uses the opportunity cost of these resources and products. This will vary for and are different for different people and areas, but we cannot do the analysis for each and every farmer. So we need to compromise and do the analysis for one set of prices. We then do sensitivity analysis to alternative prices.

C: In response to the first question, low rates of N fertilizer is not the problem contributing to soil mining. It is lack of investment in soil fertility in general by smallholder farmers, be it inorganics, legumes or manure. In dry regions, that is the cause of low productivity and low soil fertility. Low rates of N better suit the investment profile of semi arid farmers and therefore are more likely to be adopted than the higher "optimal" rates that are still recommended.

C: Work from southern Zimbabwe by ICRISAT + SDARMP have shown that 18 kg N ha^{-1} gives the most economic response. Above 18 kg N ha^{-1} often gives no more yield.

Q: Results from the @Risk analysis appear very close to what farmers in semi arid areas are actually doing anyway, except for cattle manure in the drier

areas, which many cattle owners do not use. Please comment.
A: Farmers believe that use of manure burns their crop in drier weather. This is because in the past AGRITEX has recommended high rates of application and farmers who have tried these have had bad experiences with the recommendations. Revising the recommendations downwards and experimenting with low quantities of manure is resulting in farmers revising their assessment of the risk associated with manure use and adopting manure. There is also the problem of a shortage of labour, especially because of high migration to South Africa and HIV-Aids which increases the opportunity cost of labour (probably to a higher level than used in our analysis) and so is making use of manure less profitable than the analysis suggests.

General Discussion

C: We do not have to keep doing screening. How are we sure that we target the correct accessions within the existing gene banks?

Q: Is there any research done by scientists here that has got results on the contribution of the depth of pigeonpea roots for bringing up nutrients and to organic matter content?

C: The screening of alternative legumes should be a continuous process against the biodiversity of pests and changing environments.

C: When to stop screening? The search for new materials amongst the available genetic resources should continue in accordance with projected demands – for better traits, crop diversification, etc, so you do not stop!

GREEN MANURE AND FOOD LEGUMES RESEARCH TO INCREASE SOIL FERTILITY AND MAIZE YIELDS IN MALAWI: A REVIEW

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Summary

This review was conducted in 2002 to document research on the soil fertility effects of green manures and food legumes on the dominant maize-based farming systems in Malawi. The findings indicated that green manures and grain legume crops have great potential to increase maize production and improve soil fertility. A great deal of work has been done. This can be grouped under the following subheadings: the potential of green manures to improve soil fertility and the yield of maize; combined inputs from organic and inorganic (mineral) sources; effect of time of residue incorporation on maize grain yield; effect of cropping system (intercropping or rotation) on maize yield; effect of method of residue application; and the role of applying inorganic fertilizers on the performance of green manures and grain legumes in Malawi maize-based systems. Most of the work that we have found and reviewed lacks socio-economic studies and this needs far more attention in the future.

Key words: Green manures, grain legumes, maize, Malawi

Introduction

This paper reviews some of the soil fertility research activities conducted in Malawi on green manures and annual food legumes. The objective was to document what has been done in Malawi on these legumes for increasing soil fertility in maize-based cropping systems. Information was collected from the libraries and annual reports of the Department of Agricultural Research on work carried out by scientists at research stations and on farm.

General Characteristics of Malawi

Malawi lies in the tropics of south central Africa. It has a total land area of 118 000 square km with an arable area of 53 071 square km. The total human population is estimated at just over 10 million (National Statistical Office, 1999). The country has three administrative regions; the Northern, Central and Southern Regions. The Southern Region is highly populated with 46% of the total population (4,632,000) followed by Central Region with 4,145,000 people and then Northern Region (1,264,000 million). The Northern Region retains a lot of uncultivated land with natural vegetation. Average land holding size per household in Malawi has declined to less than one hectare, but this may be even smaller for the Southern Region. The elevation of agricultural areas falls in the range of 600-2000 m above sea level (Benson, 1997). Malawi has a unimodal rainfall pattern that usually starts in October and ends in May, leaving a 6-8 month dry season. The country is divided into eight Agricultural Development Divisions (ADDs) based on different agroecological zones. Table 1 summarizes the major soil types and annual rainfall in the different ADDs (Malawi Government, Department of Surveys, 1983).

Importance of Maize

Maize is the staple food crop for Malawians. It contributes 80% of the daily food calories. About 76% of the total arable land is planted to maize (Malawi Government, 1999). However, farmers produce low grain yields averaging less than 1 t ha^{-1} compared with the yield potential of above 5.5 t ha^{-1}. These low yields lead to food insufficiency problems in most households. Low soil fertility is one of the major constraints to the production of higher yield. Nitrogen is the most limiting nutrient because it is required in larger amounts than the other nutrient elements and is often lost from current farming systems. The problem of low soil fertility has resulted from monocropping, low and inappropriate use of

Table 1. Annual rainfall and soil types in different Agricultural Development Divisions (ADDs) of Malawi

ADD	Annual Rainfall (mm)	Soil Type
Karonga	1200-1800	Mostly Lithosols. Some alluvial soils
Mzuzu	800-2000	Lithosols and Humic Ferallitic soils
Kasungu	600-1200	Weathered Ferallitic soils
Salima	800-1200	Alluvial soils often calcimorphic and Lithosols
Liwonde	800-1200	Lithosols, low natural fertility, Vertisols and some Mopanosols
Blantyre	1000-2000	Lithosols and Ferruginous soils
Lilongwe	800-1200	Ferruginous and Lithosols
SVADD	600-1000	Alluvial soils, Lithosols mostly and some gleys

SVADD: Shire Valley Agriculture Development Division
Source: *Soil Types:* Malawi Government, Department of Surveys, (1983)
Rainfall: Land Resources Appraisal (1991)

organic and inorganic (mineral) fertilizers, and crop removal without the return of nutrients.

Soil Fertility Status of Malawi Soils

Soil fertility is defined as the ability of the soil to supply the nutrients needed by plants (Ahn, 1993). According to Young and Brown (1962; 1965), nitrogen is the most limiting nutrient element in Malawian soils. Sulphur deficiencies are prevalent in some areas. In most upland areas, the soils are highly leached and as such, they are dominated by iron and aluminium oxides that fix phosphorus into forms that are unavailable for plant uptake. Phosphorus studies by Mughogho (1975) on some soils in Malawi indicated that soils in Mulanje, in the southern region of Malawi, fix a lot of phosphorus. This is one of the high rainfall areas that receives 1200-1800 mm of rain annually.

Soil Fertility Research Reviews in Malawi

Mughogho (1989) conducted a review of soil fertility research in Malawi. The overall objective of that work was to document existing information on soil fertility research from Malawi and other appropriate sources, to be used as a planning tool and database for proposed soil fertility studies. Findings from that study indicated that in addition to low soil nitrogen, most soils have large quantities of sesquioxides that fix phosphorus into unavailable forms, and sulphur is deficient in some areas. Mughogho (1989) further recommended the need for a detailed study on the characterization of soils in Malawi to build upon the work by Brown and Young (1962; 1965). The potential of sources of phosphate rock, to be used on acid soils needs to be explored.

A review report by Gilbert and Kumwenda (2001) highlighted some of the best-bet legumes for smallholder maize-based systems. For instance, *Mucuna pruriens* was described as a promising green manure. Successful grain legume-maize rotations and intercrops of pigeonpea or *Tephrosia* with maize were observed.

The following sections look in more detail at green manures, crop rotations (especially with grain legumes) and agroforestry interventions to raise soil fertility and maize productivity in Malawi.

Green Manures

Follet et al. (1981) defined a green manure crop as one that is grown and incorporated into the soil to add organic matter and N and subsequently improve crop yields. In Malawi, most farmers have used weeds as green manure materials. These are incorporated at the time of ridging, weeding or banding. The benefits from green manures include reduction of nutrient loss through leaching, the accumulation and maintenance of soil N, and improvement of soil structure. Other species like *Mucuna pruriens* help to reduce weeds (CIMMYT, 1998), thereby minimizing competition for soil nutrients and water. The success of a green manure for soil fertility improvement depends on its quality (C:N ratio), quantity of the material, and management (especially the timing and means of biomass incorporation). Proper timing allows nutrient release in synchrony with crop uptake. High biomass production can be attained if all essential soil nutrient elements are available. For instance, Giller and Wilson (1991) noted that phosphate fertilizer applications are necessary to support the luxurious growth of the green manure and hence its potential as an organic source of fertilizer. There are some leguminous species with higher quality biomass, and good ability to fix nitrogen biologically in Malawi. Some of these species include *Tephrosia vogelii*, Sunnhemp (*Crotalaria juncea*), *Tithonia diversifolia* and velvet bean (*Mucuna pruriens*). Benefits from the use of *Mucuna pruriens*, *Tephrosia vogelii*, sunnhemp, and bulrush millet have been reported (Lungu, 1973; Sakala et al., 2001; and Mwalwanda, 2002). However, Lungu pointed out that the one year lost to a sole crop green manure or improved fallow is a cost to a farmer and therefore this may reduce farmer interest and adoption.

The feasibility of improving soil fertility and maize yield through intercropping or rotation of maize with legumes was investigated at Chitedze Research Station in central Malawi (Kumwenda et al. 2001) from the 1995/96 to 1998/99 crop seasons. The treatments were as indicated in Table 2.

The results in Figure 1 illustrate that intercrops of maize with pigeonpea and sunnhemp gave higher yields than the maize/*Mucuna* system. Maize/

Table 2. Treatments from maize x green manure intercrop and rotation experiments in Malawi from the 1994/95 to 1998/99 crop seasons

	1994/95	1995/96	1996/97	1997/98	1998/99
Intercrop	Maize/PP	Same	Same	Same	Same
	Maize/ Mucuna	Same	Same	Same	Same
	Maize/ sunnhemp	Same	Same	Same	Same
Sole	Pigeon pea	Sole maize	Sole maize	Sole maize	Sole maize
	Sunnhemp	Sole maize	Sole maize	Sole maize	Sole maize
	Mucuna	Sole maize	Sole maize	Sole maize	Sole maize
	Maize	Sole maize	Sole maize	Sole maize	Sole maize

PP - Pigeonpea
Same - same treatment as in 1994/95 crop season was grown

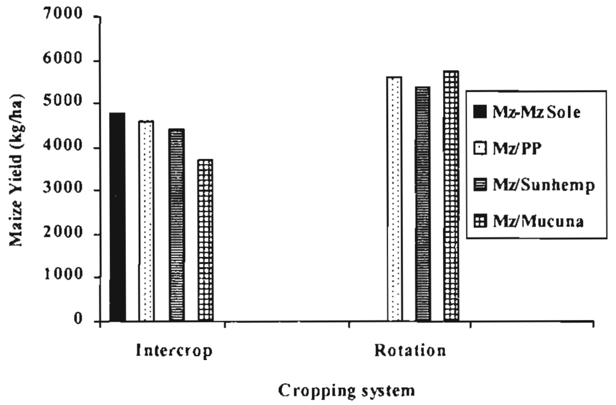

Figure 1. Maize grain yield (kg ha^{-1}) from different cropping systems, across four crop seasons in Malawi, 1995/96-1998/99. Source: Kumwenda et al., 2001

Mucuna intercropping yielded the least due to competition for growth resources. Rotation trials gave higher maize yields than the intercropping system due to larger biomass production from the legumes. However, an economic analysis indicated that continuous maize had higher net benefits than the legume-maize rotation. Similar studies on pigeonpea by Sakala (1998) have indicated that a farmer is better off opting for maize/pigeon intercropping than for a pigeonpea-maize rotation or the maize-maize cropping system.

Other studies have looked at the time of incorporation of the green manures as a factor that influences their potential as soil fertility enhancers. Kumwenda et al. (2001) carried out experiments where biomass was incorporated at either the time of maximum flowering, at pod initiation (early incorporation) or at harvest (late incorporation). Three species, *M. pruriens, C. juncea* and *T. vogelii* were used, along with maize. Higher maize grain yields were obtained from early-incorporated residues than with late incorporation (Table 3). This was attributed to high C:N ratios and high lignin contents in the late incorporated residues. However, work by Sakala et al. (2001) revealed that with late incorporation, lower yields are obtained in the first year only but in the subsequent years farmers realize higher yields, which was attributed to the build-up of nutrients. It was therefore recommended that farmers who are constrained for labour would still chose late incorporation and realize a longer stream of higher maize yields.

Table 3. Maize grain yield (kg ha^{-1}) as influenced by legume crop residues and time of incorporation at five sites in Malawi, 1996/97 crop season

Legume crop/Maize	Time of incorporation	Mean yield (kg ha^{-1})
M. pruriens	Early	3392
	Late	2223
C. juncea	Early	3218
	Late	2692
T. vogelii	Early	2845
	Late	1483
Maize-maize		397

Source: Kumwenda et al., 2001

A three-year study was carried out in Southern Malawi by Kamanga et al. (1999) to examine the feasibility of inter-planting nitrogen fixing perennial legumes into maize fields as a way to periodically add green manures to maize. The treatments were *Sesbania sesban, Tephrosia vogelii,* Pigeonpea *(Cajanus cajan)* and maize. The legumes were relay intercropped with maize at first weeding. It was shown that the application of 48 kg N ha^{-1} combined with residue incorporation increased maize yields by 62-71%. Higher maize yields were obtained from the inter-planting of *S. sesban* (2.9 t ha^{-1}) and *T. vogelii* (2.6 t ha^{-1}) than from pigeonpea (2.1 t ha^{-1}) and maize stover (2.0 t ha^{-1}).

Crop Rotation

Crop rotation refers to the repetitive cultivation of an ordered succession of crops on the same land (Mloza-Banda, 1994). The aim is to maintain and improve soil fertility, including both its physical and chemical characteristics. It also ensures that the carry over of pests and diseases from one season to another is minimized.

The benefits from crop rotations involving grain legumes (groundnut, bambara nut and soyabean) over a continuous maize-maize cropping system have been reported in several studies in Malawi (Brown, 1958; Lungu, 1973 and MacColl, 1989; Kumwenda, 1996; and Mhango, 2002). This has been attributed to improved soil fertility through biological nitrogen fixation (BNF) and crop residue incorporation. However, grain legume-maize rotations are not efficient because of the inadequate biomass they produce and the small amounts of N retained in crop residues to meet the N requirements of the subsequent maize crop. Giller and Wilson (1991) pointed out that most of the N fixed by grain legumes is exported away from the field due to high nitrogen grain harvest indices. Other studies have looked into the inclusion of pastures in crop rotations to enhance maize production. MacColl (1990) reported on long term trials whose aim was to determine the contribution to maize yield from a previous pasture legume crop. The treatments were two rates of N (0 and 80 kg N ha^{-1}) from CAN fertilizer; maize, pure silver leaf, pure stylo, silver leaf/rhodes grass, and stylo/rhodes grass. Pastures were grown from 1981 to 1984, and then the plots

Table 4. Yield of maize (t ha^{-1}) following different cropping sequences and grown at two levels of nitrogen fertilizer, across 4 years (1984/85–87/88 crop seasons)

Cropping sequence	N levels (kg N ha^{-1})	
	Zero	80
Maize	2.55	5.38
Silver leaf	3.85	5.90
Stylo	3.58	5.58
Silverleaf + Rhodes grass	3.05	5.55
Stylo + Rhodes grass	2.83	5.33

Source: MacColl, 1990

were planted to maize for three years (1985-88). Yields were higher when maize followed pasture legumes with successful establishment, with silver leaf out-yielding the other species (Table 4). The application of inorganic N increased maize yield, stressing the need for the combined use of organic and inorganic (mineral) fertilizers.

Use of combined inputs from organic and inorganic (mineral) sources appears to be the best approach to address soil fertility problems. Organic fertilizers improve the soil physical, chemical and biological properties. They also help to build up soil organic matter because nutrients are released slowly after mineralization. However, the amount and quality of the organic fertilizers is insufficient to provide adequate amounts of nutrients for crops, hence the need to supplement with inorganic sources. Mwato et al. (1999) conducted a 2-year study on combined inputs of crop residues for smallholder maize production in Malawi. The overall objective was to examine the effect of applying inorganic fertilizers and crop residues to the soil on the subsequent maize yield. Crop residues from maize and different varieties of soyabean were incorporated into the soil. Inorganic N was applied to maize at several rates. Maize grain yields were increased from 0.5 t to 1.3 t ha^{-1} after the addition of soyabean residues plus inorganic fertilizer.

Agroforestry

Agroforestry refers to those land use systems in which woody perennials are grown in association with herbaceous plants (crops, pastures) and/or livestock in a spatial arrangement, a rotation, or both, and in which there are both ecological and economic interactions between the tree and non tree components of the system (Young, 1989). Alley cropping and improved fallows are among the agroforestry systems practiced by some farmers in Malawi. Choice of a technology depends on the problem to be addressed, and the availability of resources such as land, rainfall and labour. Research work in Malawi has revealed the potential of raising soil nitrogen and maize yields with agroforestry technologies (Kwapata, 1994; Malawi Agroforestry Team, 1994; Makumba, 1998; and Phiri, 1999). Maize yields after *L. leucocephala, S. spectabilis* and *S. sesban* were 4.8, 4.5 and 4.4 t ha^{-1} respectively, compared with 3.2 t ha^{-1} produced from sole-crop maize plots (Chirwa and Maghembe, 1994). However, there are limitations with agroforestry systems. These include:

- The benefits from agroforestry technologies are long term
- A high labour requirement with some technologies, e.g. alley cropping
- High seed requirement, implying a cost to the farmers
- Problems with seedling establishment
- Insect pest attack on some tree species that have a high biomass potential, such as *L. leucocephala,* that is susceptible to psyllids (*Heteropsylla cubana*)
- Some tree species perform poorly on acid soils because of low available phosphorus.

A lot of research has been conducted with agroforestry to identify suitable candidate species for a particular technology, for biomass production, timing and application methods for biomass, and the effect of the technology on maize yield. *Faidherbia albida* is one of the tree species used in agroforestry. It is found growing naturally in farmers' fields in some parts of Malawi. The yield benefits to maize grown under *F. albida* trees has been reported by many investigators, including the Malawi Agroforestry Team (1994). Inorganic fertilizer supplements significantly further increase maize grain yield under the trees. Some of the candidate tree species for agroforetsry are *Cassia siammea, Gliricidia sepium, Leucaena leucocephala, Senna spectabilis* and *Sesbania sesban*. Chiyenda and Materechera (1987) conducted experiments from the 1983/84 to 1985/86 crop seasons with *L. leucocephala, C. siamea* and *C. cajan*. The overall goal was to determine the effect of incorporating prunings from these species on soil fertility and to assess the response of maize grown in alleys. The treatments were three rates of N (main plot); the three tree species with maize, and maize alone (sub plot); and three alley widths with three ridges of maize (as sub sub-plots). Phosphate, at 22 kg P ha^{-1}, was applied to all plots at planting. According to the results, better yields of maize were obtained from plots incorporated with the tree prunings, although, they were significantly lower than treatments that received 100 kg N fertilizer ha^{-1} (Table 5). The plant materials could not provide the amount of N that would be provided by moderate rates of inorganic fertilizers.

Kwapata (1994) worked on *L. leucocephala* in an alley

Table 5. Maize grain yield (kg ha^{-1}) as affected by incorporation of tree prunings and nitrogen fertilizer levels in Malawi

Crop Season	Crop System	N rate (kg ha^{-1})			Mean yield (kg ha^{-1})
		0	50	100	
1984/85	*Z. mais*	704	1954	3564	2074
	L. leucocephala	617	2454	2794	1957
	S. siamea	467	1856	3287	1870
	C. cajan	468	1523	3054	1682
1985/96	*Z. mais*	151	2317	3233	1901
	L. leucocephala	107	1665	2935	1411
	C. siamea	57	1049	1638	915
	C. cajan	255	1918	2870	1681

Source: Chiyenda and Materechera, 1987

system to determine the optimal rates and method of application of the leaf biomass. Residue incorporation gave larger maize yields than did surface mulching and this was attributed to a faster mineralization rate. Ten t ha^{-1} of fresh *L. leucocephala* was as effective as inorganic fertilizer N applied at 100 kg N ha^{-1}.

Conclusions

- Organic soil amendments from green manures and annual legumes have potential to enhance soil fertility and increase maize yields for Malawi smallholder farmers. They improve the soil physical, chemical and biological characteristics. They are relatively cheaper than inorganic (mineral) fertilizers but the nutrients provided are not adequate to meet crop demands and farmer needs. Therefore, the use of combined inputs from organic and inorganic fertilizers appears to be the best approach to address soil fertility problems.

- Crop residues have alternative competing uses such as to feed livestock, as in the case of legumes such as groundnut. This reduces their role in soil fertility.

- Intercropping of maize/pigeonpea has proved successful.

- For green manures as soil fertility enhancers in maize-based systems, *Mucuna pruriens, pigeonpea,* and *Tephrosia vogelii* are promising species. The key factors for success include the following:
  - o Quality of biomass
  - o Quantity of biomass
  - o Timing and means of incorporation of biomass.

- Most of the biological studies lack the socio-economic component of the technologies, and these need to be developed.

- Crop rotations involving grain legumes such as groundnut, and pasture legumes like stylo can boost maize yield. However, the opportunity cost for the farmer to forgo maize in the first year should be considered. This is a major restraint to adoption.

- Agroforestry technologies such as alley cropping and improved fallows have proved to be successful in maize based systems. Researchers should consider issues related to direct seeding, resistance from pests and tolerance to low soil available phosphorus. Extension workers should carry out awareness campaigns on the long-term benefits from agroforestry systems.

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GREEN MANURING IN ZIMBABWE FROM 1900 TO 2002

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Introduction

The ploughing under of crops for green manuring became popular with farmers in Zimbabwe, then Rhodesia, during the 1900s. Green manuring was mainly practiced before planting a maize crop or potatoes, to help supply N to that subsequent crop. Mineral fertilizers were not yet widely used and the ratio of maize to legume green manure area reached 4:1 (Tattersfield, 1982). Several research questions were raised about green manuring and a series of trials were conducted, mainly at Harare Research Station, to address the questions that farmers had from their early experiences in the 1900s. This paper reviews some of those research areas and findings on green manuring in the early 1900-1930s and traces the resurgence of recent work during the 1990s to 2000s in Zimbabwe.

Green Manuring from 1900 to the 1950s

Screening of suitable green manure crops

A need to identify suitable green manure species was addressed through the screening of non-leguminous and leguminous crops. A series of experiments was carried out for ten years, to screen crops such as niger oil, sunflower, geotani bean, kaffir, florida velvet bean, black velvet bean, sunnhemp and mixtures of these crops. Arnold (1909-1930) summarized the ten-year results in the Annual Reports of Salisbury (Harare) Agricultural Experiment Station and in a series of journal articles. Pure velvet bean, dolichos, sunnhemp and nigers oil, resulted in 8; 8.5; 17 and 15 t of above-ground biomass respectively at Harare. Sunnhemp was found to have the highest N mobilization in the above-ground biomass, whilst niger bean mobilized the highest amounts of P and K. Arnold noted that although sunnhemp produced the most green manure biomass, the subsequent maize crop was less vigourous compared with that after velvet bean, which had lower above-ground biomass. This may have been due to a high % N in the sunnhemp which results in rapid mineralization of N, not in synchrony with the N requirements of a subsequent maize crop. The lower N % (slightly less than 2% N) with velvet bean, resulted in a slower rate of N release, more likely in synchrony with the needs of the subsequent maize crop. It was concluded that no single green manure species was suitable for all soil types. Niger oil and sunflower generally gave lower subsequent maize grain yields.

Legumes were found to be the best crops for green manuring because of their ability to fix atmospheric N for their own requirement and that of a subsequent crop. Sunnhemp, velvet bean and dolichos bean were identified as the best among a range of potential green manure legumes and there was no significant difference between these crops. Sunnhemp became popular with equally beneficial results chiefly because of its hardiness and suitability to a wide range of soils, its ability to smother weeds and ease of ploughing its residues under when used for green manuring. Sunflower, a non-leguminous crop, was found to be suitable for green manuring purposes as well because of its ability to produce high above-ground biomass (above 4 t/ha in most cases), although its effect on the subsequent maize was often lower than with the legumes (Arnold 1928).

Ploughing under green manure crops vs. harvesting green manure crops for hay

Another research question of concern was whether it was more economical to plough under a green manure crop at flowering or leave the crop to mature and harvest the haulms and seed for hay or silage. A series of trials was set up to answer this question. Livestock owners found it more profitable to use their leguminous crop for hay or silage. There was a need to apply farmyard manure to maintain soil fertility when legumes were harvested as hay. Ploughing under of the whole crop increased maize grain yield by 1370 kg/ha, compared to harvesting the green manure legume as hay. Removing above-ground biomass for other purposes like hay reduced the subsequent maize grain yield by 6% with sunnhemp, 16% with velvet bean, 11% with dolichos bean and 13 % with niger oil green manures. The difference between ploughing under and not ploughing under was smaller with sunnhemp than with the other crops. This was due to the great amount of roots with sunnhemp. It was concluded that there was considerable merit in removing above-ground biomass and using it for an alternative purpose such as livestock feed since the reduction in the subsequent maize crop yields when residues were removed was so small.

Ploughing under green manure crops vs. burning

Comparisons of ploughing-under mature sunnhemp or burning sunnhemp on the field or outside the field to avoid sterilization of the soil were reported by Arnold (1934, 1935, 1937 and 1939). Burning was to cater for farmers that had insufficient machinery to plough ina green manure crop. There were no differences on the subsequent maize grain yield between burning and ploughing under of sunnhemp green manures, although the burnt plot had healthier crops during the early stages of crop growth.

Application of mineral fertilizers to green manure crops vs. application of fertilizers directly to maize

Another research question was raised by the Maize Association on whether it was more profitable to apply fertilizer to a green manure crop that is to be followed by maize or to apply the fertilizer directly to the maize crop after ploughing under an unfertilized green manure. The hypothesis was that a larger quantity of vegetative matter would be available for ploughing under if the fertilizer is applied to the green manure crop. The humus and N available to the following maize crop might be increased more than if the fertilizer is withheld for direct application to the maize.

These trials were conducted on land of both moderate and low fertility status. Phosphorous (P) fertilizers were added to the green manure crop in the form of raw phosphate, bone meal and super phosphate (Arnold 1931 and 1933). Application of P to a green manure crop increased the above-ground biomass of green manures by an average of 3 t/ha. The response was larger on soils of low fertility. Twenty-three kg/ha of bone meal and super phosphate applied to sunnhemp or velvet bean increased maize grain yield from 1000 kg to 2500 kg/ha. It was found that maize on its own was unable to make the fullest use of the phosphate supplied. N-fixing bacteria increased with the application of P, hence sufficient N was fixed to almost double the subsequent maize grain yields. The application of fertilizers, mostly P, to green manure crops was found to be economically justifiable in very exhausted lands particularly if a slow acting fertilizer such as rock phosphate was used.

Residual effects of green manuring

Arnold (1927) reported that the beneficial effects conferred by the green manure crop are pronounced during the first season after its application particularly if the season received heavy rainfall. In the second season after green manuring, the benefits were small.

Effects of green manuring on microbial population of the soil

Shepherd (1952) reported that green manuring stimulated the growth of antibiotic producing organisms and this was suspected to reduce pathogenic organisms, thus resulting in higher maize yields. Actinomycetes and moulds were shown to increase whilst bacteria numbers declined, possibly due to antagonistic mechanisms.

Intercropping and relay cropping of green manure legumes with maize

Loss of a cropping season to a green manure crop became an issue. Farmers were failing to make use of the green manuring technology because of the need to set apart a field to grow the green manure crop. The labour requirement for land preparation and ploughing-under of green manuring crops became a constraint to most farmers. As a partial solution, velvet bean intercropped into maize at 14 days after maize establishment gained favour among farmers in the late 1920s.

Research trials with maize and velvet bean intercropping indicated that climatic conditions exerted a big influence on the success or failure of maize and velvet bean intercrop. With excess rainfall, velvet bean suffered when sown with maize. With below normal rains, a moderate crop of velvet bean was reaped, but maize yield was considerably reduced. On very fertile land at a high velvet bean plant density, vines were liable to become interlaced across the rows of maize to such an extent as to interfere with harvesting. On exhausted soils, fair yields of both crops were obtained. The legumes intercropped with maize had a larger beneficial effect on the soil and grazing after the reaping of the two crops than did maize alone (Arnold 1925-26).

Maize relaying with green manure crops to avoid committing the whole season to a green manure legume was also experimented with. A range of green manure crops was sown under a maize crop at the time of final weeding in January. The green manure crops were allowed to develop during autumn and winter so that they could be ploughed under before the time for ploughing the next maize. Only those crops resistant to drought and frost would be suitable for this approach. Khaki jack bean, white jack bean and dolichos bean were researched.

All the legumes did well except for dolichos bean, which did not thrive when shaded by maize. By June, the bean crop had covered the ground but further growth was retarded by frost. Ploughing under was in September with maize planted in December.

The presence of a bean crop at the maize grain filling stage slightly reduced maize grain yield. Dolichos bean reduced the yield of the relayed maize crop and the subsequent maize crop, whilst white jack bean, khaki jack bean and dhal significantly increased maize grain yields (Arnold 1926-27).

Incorporation of immature vs. mature green manure crops

Arnold (1926, 1927 and 1929) reported results from a series of experiments that determined the effects of leaving green manure crops to mature before incorporation compared with ploughing under the green manure crops at first flowering. The other primary objective of the trials was to determine whether the ploughing in of two consecutive green manure crops in the same season would have toxic effects on the land or whether the additional organic matter would be more beneficial than the ploughing under of one mature crop. Sunnhemp, velvet bean and dolichos bean were used in the experiment. Incorporation of mature crops was 5-6 weeks later than the incorporation of immature crops at flowering.

This work found out that the growing season was too short to permit two velvet bean crops to mature unless they were ploughed under before podding. The biomass of mature crops was double for velvet bean and dolichos bean and four times for sunnhemp, compared with two immature crops. Subsequent maize yields obtained after immature green manures were less than those from mature crops, mostly due to a higher biomass in the mature crops. One fully matured green manure crop was better than two immature crops. These were also compared with the effect of a reaped mature velvet bean on the subsequent maize.

These experiments also determined whether irrespective of mass of green manure per unit land area, immature crops ploughed under will benefit the land as much as if the crops are fully grown. Mature plants provide a higher percent of organic matter than immature plants. Fully developed crops had a more beneficial effect than a partially developed crop. Mature green manure crops of velvet bean and sunnhemp more than trebled maize yield in the first season after green manuring whilst immature crops doubled maize yields compared with continuous unfertilized maize. The second season maize after both mature and immature green manure crops did not benefit from green manuring.

Timson (1946) also concluded that ploughing under of a green manure crop before the end of the rainy season led to excessive leaching of the nitrogen. Ploughing under at the end of April compared to February and March resulted in higher grain yields of the subsequent maize crop.

Green manure crops in rotations

Rotation experiments were carried out and green manure legumes were recommended in the different rotation systems; in pure crop production systems as well as for crop and livestock farming systems. An example of a recommended rotation, designed to meet the needs of a grain farmer whose income was solely dependent on maize and groundnut, is given below.

Year 1 = Maize + fertilizer
Year 2 = Green manure legume
Year 3 = Maize
Year 4 = Groundnut

A supply of humus in the soil was maintained by ploughing under the velvet bean and dolichos bean green manures. The green manure crops followed immediately after the maize crop that received mineral fertilizer, hence the green manure benefited from the residue of the fertilizer left in the soil. In this way, an adequate supply of humus was retained in the soil for the maize that followed the green manure crop.

For dairy farmers, succulent legume crops were also included in the rotation to provide ample feed for livestock, for example.
Year 1 = Maize plus farmyard manure
Year 2 = Oats, velvet bean or dolichos bean mixtures for hay
Year 3 = Maize plus mineral fertilizers
Year 4 = Sweet potatoes (succulent crop for winter food for stockfeed)

The rotational experiments highlighted the drawbacks of continuous (year-after-year) maize cropping on the same land. Over 13 years, maize yields were trebled in planned rotations compared with unplanned rotations similar to those found in smallholder communal areas, where continuous maize cropping is very common. Leaving the fields fallow was also found to be less productive when compared to inclusion of green manures for fodder purposes or exclusively as green manures. It was concluded that when farm stocks and crops are judiciously combined, the permanent fertility of the soil is increased and larger crops are secured. This was calculated to be profitable and a form of insurance against unfavorable seasons.

It was proved that a mixed farming system, which includes the raising of livestock and the growing of different kinds of crops, is more stable than one that relies on continuous production of the same crop.

The practice of ploughing under of green manure crops to maintain the humus content of the soil became routine for many farmers in Zimbabwe in the late 1920s but the opportunity cost of committing land to a pure green manure crop limits adoption of the technology.

For the relaying of green manure crops in January or February under a maize canopy, it was concluded that the practice could not be relied upon to give profitable results because success is largely dependent on the amount of rainfall that falls during February and March. In a below normal season, maize yields are significantly reduced through competition with the green manure crops, or the green manures fail to grow.

Fertilization of green manure crop
In the late 1920s with the introduction of chemical fertilizers, the questions of whether it was more profitable to apply phosphate fertilizers to green manures or directly to a maize crop arose. A series of experiments were run comparing application of rock phosphate, bone and super phosphates to green manures or to maize. It was concluded that if the fertility of the land has been maintained at a moderately high level it was less economic to apply the fertilizer to a green manure crop and better to apply the fertilizer directly to the subsequent maize crop. On fields where previous cropping had reduced the soil fertility status to a very low level, the application of fertilizers to the green manure crop was found to be economically justifiable, particularly if a slow acting fertilizer such as raw phosphate rock was used. On depleted soil, the application of rock phosphate to a green manure crop increased the subsequent maize grain yield more than four times (Arnold 1931 and 1933).

Saunders (1959) critically reviewed the available evidence on the value of green manuring in Zimbabwe up to the late 1950s. Work on continuous maize vs. maize in rotations with green manures in alternate years or with other crops or green manure crops removed for hay was reviewed. When alternate green manure were used with maize, slightly higher C and N levels in the soil were maintained compared with continuous maize cropping in the same fields. Use of green manure crops as hay was also better that continuous maize, although the soil C:N ratio was not affected. The main benefit of legume green manuring in Zimbabwe at that time was to augment available soil N, but it had also beneficial effects on the uptake of N, P, K and Ca. Average green manure crops were shown to contain 56-112 kg N ha^{-1} while a very good crop could contain as much as 170 kg N ha^{-1}. It was difficult to raise maize yields in non-green manure rotations to the same levels as those achieved after green manuring, but the loss of a season to a green manure crop resulted in a reduction in annual green manuring in Zimbabwe in the 1950s.

Green manuring in the 1950s to 1980s

Under Zimbabwean conditions where the cooler winter months coincide with the dry season, green manuring involves the elimination of a productive cropping season. Whether the loss of a season is compensated for by increased and sustained soil fertility benefits and cereal yields became a major issue for both farmers and researchers. With the widespread introduction of chemical mineral fertilizers in the 1950s and 1960s, use of green manuring continued to decline and it had almost disappeared from the 1960s to the 1980s.

The major nutrient contributed by green manures was nitrogen but the introduction of cheap N fertilizers towards the end of the 1950s made the high opportunity cost of committing land, inputs and labour to green manuring unattractive to commercial farmers (Saunder, 1959) and this replaced the legume green manure practice (Tattersfield, 1982). Most smallholder farmers had no experience of growing green manures, but they did readily adopt inorganic fertilizers in the 1970s and 1980s when access was greatly improved through government schemes (Hikwa and Waddington, 1998).

Green Manuring in the 1990s to 2002

Large rises in the prices of mineral fertilizer for smallholder farmers and renewed concern over the sustainability of current cropping systems dominated by continuous maize, led to renewed interest by Zimbabwean researchers in green manuring during the 1990s (Hikwa and Mukurumbira 1997). A feature of much of the new work was a focus on the needs of smallholder soil types and management systems. Most smallholders farm sandy alfisols, characterized by coarse textured sandy surface horizons derived from granite. The soil structure is weak and highly susceptible to crusting and compaction. Continuous mining of the soil through cropping with little fertilizer or organic matter input has further depleted the soil nutrients (Hikwa and Waddington 1998).

Jeranyama et al (1998 and 2000) reported on relay-intercropped cowpea (a food crop) and sunnhemp green manure legume with maize in experiments on a sandy loam soil at Domboshava, Natural Region 2. Legumes were planted 4 weeks after planting the maize. Herbage biomass (averaged over two seasons) was 2.3 t/ha for cowpea and 3.1 t/ha for sunnhemp. Total N accumulation in the legume biomass was 111 kg N/ha for sunnhemp and 59 kg N/ha for cowpea. Relay-intercropped maize fertilized with 60 kg N/ha had a grain yield equal to or better than those of a sole maize crop at the same fertilizer rate. However, at the other N rates, maize yields were reduced indicating competition between the maize and the legume. In the subsequent year, maize following relay intercropped legume with maize produced 20% more grain yield than the sole maize control. The grain N content of a subsequent maize crop was improved by 82% relative to the sole maize control. The legume contributed up to 36 kg N/ha to the subsequent maize crop. Other work on relaying maize and green manure legumes (Muza, 1998) reported that introducing the green manuring legumes at 4 to 6 weeks after maize crop emergence was the best time, but that velvet bean tended to intertwine with maize.

Chibudu (1998) reported on five years (1992-1996) of green manuring work with sandy low soil fertility status soils in Mangwende in Natural Region 2. Farmers, researchers and extension officers formulated and set up trials to screen legumes that could improve soil fertility, reduce *Striga* infestation and improve maize yields. The legumes used were velvet bean, sunnhemp, cowpea and dolichos in either a rotation or an intercrop with maize. The results showed that crops such as velvet bean, sunnhemp and cowpea could improve soil fertility, reduce striga infestation and subsequently increase maize yields. Farmers preferred to use velvet bean for improving soils in rotation but not intercropped with maize because it choked the maize plants making it difficult to harvest the maize crop. Cowpea was preferred by farmers for striga control and provision of grain for food.

Table 1. Maize grain yield (kg ha^{-1}) after green manuring with different legumes at Makoholi and Mlezu in 1990/91 (Agronomy Institute Annual Report)

Preceding green manure crop	Makoholi				Mlezu			
	(Inorganic N fertilizer (kg/ha))							
	0	40	80	120	0	40	80	120
Dolichos	0.24	0.80	0.75	0.72	2.40	2.85	2.98	3.09
Cowpea	0.19	0.55	0.84	0.93	2.83	3.35	3.40	3.65
Sunflower	0.31	0.53	0.51	0.49	1.95	2.44	3.04	3.12
Sunnhemp	0.44	0.57	0.54	1.38	3.15	2.64	2.88	3.20
Soyabean	0.23	0.57	0.78	0.95	1.61	2.73	2.10	2.51
Maize	0.26	0.34	0.74	0.46	2.35	2.51	3.00	2.99

Adapted from Agronomy Institute Annual Report, 1990-91

The Agronomy Institute of the Department of Research and Specialist Services (now part of AREX) evaluated five potential green manuring species. *Dolichos lablab*, sunnhemp, soyabean, cowpea and sunflower were tested for their green manuring potential and their effect on a following maize test crop, on two sandy soils at Makoholi Experiment Station in Natural Region 4 and at Mlezu Agricultural College in Natural Region 3 (Table 1). At Mlezu, biomass production was highest with dolichos (7.7 t/ha) and 7.0 t/ha with sunflower. Soyabean, sunnhemp and cowpea had 4.8, 2.7 and 1.6 t/ha of above-ground dry biomass, respectively. At Makoholi, the biomass was 1.9, 3.3, 1.3, 1.5 and 1.7 t/ha for dolichos, sunflower, soyabean, sunnhemp and cowpea, respectively.. Table 2 shows the biomass yield of velvet bean, sunnhemp and cowpea at three locations in Zimbabwe in 1995/96, reported by Muza, Gatsi, Pashapa and Bwakaya in 2000. The nitrogen, phosphorus and potassium contents of the green manures in those experiments are shown in Tables 3-5.

Table 6 shows biomass production by velvet bean, sunnhemp and fish bean (*Tephrosia vogelii*) in relation to phosphorus application in Soil Fertility Network trials in 1996/97. In the 1996/97 season, twelve farmers fields were selected, ten in Natural Region 2, one in Natural Region 3 and one in Natural Region 4. Either the selected fields were abandoned fields due to low soil fertility, or fields where

Table 2. Legume above-ground biomass (kg/ha) at different planting times (weeks after maize planting) and sites in 1995/96

Site	Legume	4 weeks	6 weeks	8 weeks
Chiwundura	Velvet bean	10 556	463	249
	Sunnhemp	2 256	162	76
	Cowpea	1 081	307	301
	Dolichos	860	83	98
	Tephrosia	23	131	488
	Pigeon pea	359	153	79
Chihota	Velvet bean	4 473	178	0
	Sunnhemp	2 469	1 097	294
	Cowpea	1 039	336	0
	Dolichos	218	0	318
	Tephrosia	669	0	0
	Pigeon pea	395	0	0
Mlezu	Velvet bean	3 148	1 788	445
	Sunnhemp	9 554	821	805
	Cowpea	4 699	2 223	1 030
	Dolichos	2 875	920	160
	Tephrosia	0	29	67
	Pigeon pea	538	301	159

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Table 3. Above-ground biomass (t/ha) and N, P and K contents (kg/ha) in biomass of green manures grown at Makoholi in 1989/90

	Dry biomass (t/ha)	N	P	K
Dolichos	1.9	46.7	6.1	39.2
Cowpea	1.7	41.9	5.2	34.9
Sunflower	3.3	41.2	8.2	94.1
Sunnhemp	1.5	40.7	5.1	25.5
Soyabean	1.3	26.7	4.7	18.4

Table 4. Average % Nitrogen and % Phosphorus in velvet bean, sunnhemp and cowpea above-ground biomass and roots at time of incorporating in April 1996

	Velvet bean		Sunnhemp		Cowpea	
	Above ground biomass	Roots	Above ground biomass	Roots	Above ground biomass	Roots
Nitrogen	1.9	1.38	3.00	0.84	2.16	1.52
Phosphorus	0.13	0.17	0.12	0.04	0.18	0.14

Muza et al 2000

maize grain yields in recent years were less than 500 kg/ha. Soil pH ranged from 4.1 to 4.8 and there was no correction for pH. Velvet bean, sunnhemp and fish bean were planted with 100 kg/ha P_2O_5 or without phosphorus.

Biomass production by the three legumes is shown in Table 6 and the grain yield of the maize test crop after green manuring for Chihota and Zvimba (where a maize crop was harvested) are in Table 7. Velvet bean performed the best, with six fields generating an above-ground biomass of over 4 t/ha when phosphorus was applied whilst four plots with no phosphorus also produced a biomass above 4 t/ha. Sunnhemp performance on the degraded soil was very variable. Dieback of the plants after crop emergence was common at most sites.

Velvet bean gave reasonable biomass on extremely nutrient depleted and somewhat acidic soils and has the potential to rehabilitate degraded fields when coupled with lime and phosphorus. Low pH and P levels in the soil inhibit legume growth; hence P and lime should be added.

There is still a need to screen more potential green manures, to expand the legume base.

Table 5. Total nitrogen and phosphorus (kg ha^{-1}) in above-ground biomass during the 1995/96 season

Site	Velvet bean		Sunnhemp		Cowpea	
	N	P_2O_5	N	P_2O_5	N	P_2O_5
Chiwundura	207	14	68	3	23	2
Chihota	87	6	74	3	22	2
Mlezu	62	4	287	12	102	8

Muza et al 2000

Table 6. Dry biomass production (kg/ha) by three green manure legumes, on exhausted sandy soils in northern Zimbabwe, 1996/97 season

Communal Area	Velvet bean		Sunnhemp		Fish bean	
	+ P	- P	+ P	- P	+ P	- P
Gokwe South (1)	2368	1916	1688	858	0	0
Gokwe South (2)	1826	1964	809	1000	0	0
Nyazura (1)	8020	7240	0	0	0	0
Nyazura (2)	6490	6610	0	0	0	0
Chiduku (1)	1757	1865	grazed	grazed	70	34
Chiduku (2)	4538	2703	116	13	64	66
Mangwende (1)	318	317	311	290	145	145
Mangwende (2)	5351	5250	5000	5040	3127	3125
Zvimba (1)	2410	1260	0	0	0	0
Zvimba (2)	850	1620	0	0	0	0
Chihota (1)	10665	5290	8460	2315	0	0
Chihota (2)	4275	3405	505	550	0	0

After Hikwa et al 1998

Green manuring extension work in Chihota

In the 1999/2000 season, four technologies were selected to help smallholder farmers in Chihota communal area to sustainability improve the crop productivity of their farms through improved soil fertility management practices. This pilot project was led by the extension service in Marondera District. Green manuring was one of the technologies selected and 411 farmers participated, in farmer groups, in demonstrations of green manuring on their farms. Generally, it was found that green manuring was a new technology to most of the farmers. Few had tried it or seen it. Forty percent of the experimenting farmers tried green manuring on their own fields whilst 83 farmers outside the groups also used it (Mwenye and Kuwaza, 2001). There is still a great need to expose far more farmers to green manuring through working with other extension districts in Zimbabwe.

Current Work and the Future

Green manuring work in Zimbabwe is still going on, with the Agronomy Research Institute looking at the possibilities of combining mulching using green manure legumes and minimum tillage. The University of Zimbabwe and the Agronomy Institute are also experimenting with different green manures to control *Striga*. Agronomy Institute, Crop Breeding Institute and ICRAF are researching the possibilities of intercropping *Sesbania sesban* with velvet bean and bushy and trailing cowpea. Researchers on livestock feeds at Research stations and the University of Zimbabwe are also looking at the suitability of velvet bean for use in stock feeds. The

Table 7. Maize grain yield (kg ha^{-1}) in 1997/98 following sunnhemp and velvet bean green manures grown during 1996/97 in Chihota and Zvimba Communal Areas, Zimbabwe

Treatment	Chihota-Chigora	Chihota-Chimhembeza	Zvimba-Chimedza	Mean
Maize + 0P + 60N	180	157	175	171
Maize + 0P + 0N	357	308	699	455
Maize + 100P + 60N	1665	223	123	670
Maize + 100P + 0N	325	165	272	254
Velvet bean (incorporated) + 100P + 45N	2863	556	1395	1605
Velvet bean (incorporated) + 100P + 0N	4240	308	1794	2114
Velvet bean (biomass removed) + 100P + 45N	3982	1688	273	1981
Velvet bean (biomass removed) + 100P + 0N	2532	587	207	1109
Velvet bean (incorporated) + 0P + 45N	1745	1266	1639	1550
Velvet bean (incorporated) + 0P + 0N	2407	710	1084	1400
Velvet bean (biomass removed) + 0P + 45N	143	1010	1355	836
Velvet bean (biomass removed) + 0P + 0N	731	664	1030	808
Sunnhemp (incorporated) + 100P + 45N	4726	1387	1503	2539
Sunnhemp (incorporated) + 100P + 0N	3628	410	1285	1774
Sunnhemp (biomass removed) + 100P + 45N	4715	3104	564	2794
Sunnhemp (biomass removed) + 100P + 0N	5984	1989	182	2718
Sunnhemp (incorporated) + 0P + 45N	2661	516	1021	1399
Sunnhemp (incorporated) + 0P + 0N	2082	1120	1214	1472
Sunnhemp (biomass removed) + 0P + 45N	144	951	1210	768
Sunnhemp (biomass removed) + 0P + 0N	890	1063	1047	1000

Adapted from Murata et al. 2000

Soil Conservation and Tillage Network based at the University of Zimbabwe is also working with some of the green manuring legumes in soil conservation and proposing their use as cover crops.

Seed availability is one of the major limiting factors to green manuring, hence there is a need to establish a sustainable source of green manure legume seed near the farming communities. In Chihota, a school has been asked to bulk velvet bean seed for local farmers.

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GRAIN LEGUMES AND GREEN MANURES IN EAST AFRICAN MAIZE SYSTEMS – AN OVERVIEW OF ECAMAW NETWORK RESEARCH

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Abstract

The Eastern and Central Africa Maize and Wheat (ECAMAW) Research Network, established in 1996, is one of 18 networks operating under the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). ECAMAW addresses constraints to maize and wheat production in the ten ASARECA member countries where maize is the number one priority crop and soil fertility is ranked as one of the principal constraints to improved maize productivity and production. Nitrogen (N) is the most limiting nutrient in the region yet smallholder farmers use very little fertilizer inputs due to high cost, poor infrastructure and risk due to climatic uncertainty. Legumes in systems with maize are a potential alternative source of N for the maize crop. During the past 5 years, the ECAMAW Network has funded 12 small grant projects dealing with green manure and grain legumes in systems with maize. Network collaborators have implemented some 24 on-station experiments and 195 on-farm trials to evaluate and identify suitable adapted grain legume and green manure species, and to quantify their impact on maize production in systems including intercrops, relay crops and rotations. Some 12 legume species were evaluated for nodulation, ground cover, resistance to pests and diseases, biomass production, seed production, etc. in the moist and dry mid-altitude, and lowland ecologies of Ethiopia, Kenya, Tanzania and Uganda. Mucuna pruriens, Canavalia ensiformis, Crotalaria ochroleuca *and* Dolicos lablab *were the most widely adapted and most effective N providers, although other species were locally more suited. Green manure legumes intercropped with maize had no significant beneficial effects on maize grain yields and, depending on their aggressiveness, sometimes significantly reduced maize yields. Green manure biomass production was reduced in intercrops and more so when relayed into maize. Depending on the degree of growth suppression and the duration of follow-on growth permitted after the maize harvest, green manures had either little or substantial effects on maize yields in the following season. The effects of green manures rotated with maize had more consistent and substantive effects on subsequent maize yields with increases as much as 385%, or 2.5-3.0 t/ha, on farmers' fields. Grain legumes, including soybean, cowpea, green gram and pigeonpea, had little beneficial or negative effect on maize productivity whether grown as intercrops or in rotations. Farmers' reactions to green manures was mixed, from reluctance to plant a crop which produced no food to appreciation of the weed suppressing effects and soil fertility gains they provided. A frequent question regarded the palatability of mucuna and canavalia seed. Despite considerable exposure to green manure legumes, farmers have been slow to adopt them into their farming systems. On the other hand, grain legumes, which produced a consumable or marketable product, were highly valued by farmers.*

Key words: ECAMAW Network, legume adaptation, intercropping, relay crops, rotations

Introduction

Maize is grown on more than 7.6 M hectares in Eastern and Central Africa with an average yield less than 1.3 t/ha (compared to a potential of 4.5–7 t/ha) (Pingali, 2001). Average per capita consumption of maize grain is 50 kg, but it ranges from 12-103 kg per person. Given the large area planted, and its importance as a food and cash crop, maize was identified as the number one priority for regional research by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). Low soil fertility, especially nitrogen (N), is one of the principal constraints to increased maize productivity in the region (ECAMAW, 1999). Fertilizer use is less than 10 kg/ha/yr (Bumb and

Baanante, 1996; Heisey and Mwangi, 1996) due to (i) high price and poor infrastructure, (ii) risk due to uncertainty in climate and the price of produce, and (iii) lack of access to credit for small holders.

The Eastern and Central Africa Maize and Wheat (ECAMAW) Research Network is a network of maize and wheat scientists from the National Agricultural Research Systems of the ten countries in Eastern and Central Africa operating under the Sub-Regional Organization, ASARECA. ECAMAW scientists address priority constraints of regional importance to improved maize and wheat production and productivity and operate through a system of small project grants overseen by a Steering Committee, a Network Coordinator and CIMMYT project scientists that fund the small grants program.

Due to the poor access farmers have to fertilizers, ECAMAW scientists have focussed on green manures and grain legumes as alternative sources of N for maize systems. The potential for legumes to supply N to cropping systems is well known, and the benefits and constraints were recently reviewed by Giller et al. (1997). Legumes in cropping systems can be broadly classified as those that produce a consumable seed (grain legumes) and those that are grown solely for agronomic purposes, such as a source of biologically fixed N (green manures), weed control, and ground cover. While grain legumes can fix substantial amount of N, with few exceptions (e.g., groundnut, cowpea, pigeonpea), most of the fixed N is harvested with the grain and little is left to the soil and subsequent cereal crops. Green manures provide considerable N to the soil when grown in rotations with crops but also remove land from production to gain that benefit. Both grain legumes and green manures grown as intercrops suffer from competition from the companion crop, reducing biomass accumulation, biological N fixation and the potential benefits to the systems.

During 1997-2002, the ECAMAW Network supported 12 small grant projects, each spanning periods of two or more years and often implemented across several sites, to evaluate grain legumes and green manures in maize systems. Most of these projects were executed on-farm with farmer participation at multiple sites. The objectives of this research were to:

- Identify suitable adapted green manure and grain legume species for the major ecologies of ECA;
- Evaluate appropriate management practices for them in intercrops, relay crops or rotations with maize;
- Quantify the impact of green manures and grain legumes on maize productivity;
- Determine the fertilizer-N equivalence of green manures in rotations; and
- Evaluate green manures and grain legumes in systems on-farm with farmers to ascertain farmers' perceptions and acceptance.

This paper summarizes the results of these regional network trials and describes on-going and future research and dissemination activities of ECAMAW network scientists with legumes in maize-based systems.

Methods

Evaluations of legumes for adaptation, biomass production and N-fixation

Regional trials were established at Namulonge (Uganda), Arusha (Tanzania), Tanga (Tanzania), Jimma (Ethiopia) and Kakamega (Kenya) to screen green manure and grain legume species for adaptation to the local environment. A core set of 12 species (Table 1) were generally evaluated at all sites; an additional 10 species (*Dolichos-Renga, Cajanus cajan, Pueraria phaseoloides, Voandzeia subterranea, Crotalaria brevidens, Desmodium intortum, Lablab purpureus, Macroptilium atropurpureum, Phaseolus vulgaris* (cv. Selian wonder) and green gram) were evaluated at single selected sites. Species were sown in small plots on station at the onset of the rains and were scored at appropriate periods for establishment, nodulation, percent ground cover, resistance to pests and diseases, seed and biomass production among other criteria. N supply capacity was estimated from the total biomass production and N content of the biomass.

Effects of green manures and grain legumes in maize-legume systems

Trials were conducted on station and on farm to evaluate promising legume species (based on regional screening trials) in systems with maize. Systems included the following:

- Rotations within a year (bimodal rainfall) or in alternate years (monomodal rainfall distribution);
- Relays, including the effect of relay date on green manure biomass production and sequenced maize production; and
- Intercrops of green manure or grain legume species with maize.

The effect of legume species and system on maize productivity (yield of maize grain per hectare) was measured. In some cases, the effect of maize on legume biomass production was also determined, including the N content of the aboveground biomass where possible. All results were subjected to analyses of variance and means were separated by the Duncan's Multiple Range Test where appropriate.

Results

Legume adaptation in ECA ecologies

Table 1 summarizes results of regional legume species evaluation trials across five sites for 12 species according to six criteria using a 5-point scale from very good through fair to very poor. Species considered include green manures and grain legumes. Visually, the most adapted green manure species appeared to be *Mucuna pruriens, Dolicos lablab, Crotalaria ochroleuca* and *Canavalia ensiformis* although there were regional variations in adaptation. Grain legume species tended to be less adapted than green manure species but this may be a reflection of the evaluation criteria that favoured attributes for soil fertility enhancement and sequenced maize production.

Table 1. Adaptation of green manure and grain legume species to the moist and dry mid-altitude and tropical lowland ecologies of Eastern Africa*

Legume species	Establishment	Nodulation	Ground cover	Diseases and pests	Seeding capacity	Biomass (t/ha)
Calopogonium mucunoides	2	5	2	1	2	3.0
Canavalia ensiformis	3	4	2	2	1	12.5
Crotalaria ochroleuca	4	1	2	3	3	8.1
Dolichos lablab	2	3	1	3	3	7.6
Mucuna pruriens (black)	2	4	1	1	1	10.6
Mucuna pruriens (white)	2	3	1	1	1	8.3
Sesbania sesban	3	3	3	3	2	12.3
Glycine max (Soybean–Nyala)	3	3	3	3	4	3.3
Glycine max (Soybean-SCs)	4	3	3	2	4	1.5
Vigna unguiculata (Cowpea)	2	1	3	4	4	2.9
Vicia dyascarpa (=lana vetch)	2	4	3	4	5	1.8
Vicia villosa (=purple vetch)	4	4	3	4	5	2.8

*Legend for evaluations	1	2	3	4.	5
	v. good	good	fair	poor	v. poor

The potential contribution of green manure and grain legume species to soil N status is shown in Table 2, based on the mean biomass production across one or more sites in the region and their measured or estimated N contents. Green manures were grown as sole crops and sampled at the end of the season at a growth stage considered appropriate for incorporation into the soil. With few exceptions, the mean levels of N provided by green manures were well in excess of a maize crop's requirements. Grain legumes such as cowpea and groundnut left suboptimal amounts of N for a subsequent maize crop.

Shading and competition for water and nutrients reduces the growth of green manures sown as intercrops with maize, and hence reduces the amount of N available for subsequent maize crops. Figure 1 compares biomass production of mucuna, canavalia and crotalaria grown as sole crops, or intercropped with maize 2-3 weeks after maize emergence, or relay planted into maize at 2 weeks after tasseling at Jimma, Ethiopia, and Namulonge, Uganda. Legume biomass was measured at the time of harvesting the maize and, consequently, does not include potential further biomass accumulation that may occur if they are allowed to continue growing on residual moisture subsequent to the maize harvest, the possibility of which depends on the presence or absence of free-ranging cattle that are often allowed to graze crop residues in these systems.

Table 2. Biomass production and estimated nitrogen content of green manure and grain legume residues at ECAMAW regional screening sites (1998-99)

Legume species	Common name	No. of sites	Biomass yield			Mean N content§
			min	max	mean	
			···· (t-DM/ha)		······	(kg-N/ha)
Calopogonium mucunoides	Calopo	3	1.4	4.2	3.0	61
Canavalia ensiformis	Jackbean	5	2.9	18.2	12.5	316
Crotalaria brevidens	Sunhemp	1	3.4	3.4	3.4	85*
Crotalaria ochroleuca		4	2.0	15.0	8.1	267
Lablab purpureus	Dolicos lablab	5	2.1	16.6	7.6	131
Macroptylium atropurpureum	Siratro	1	2.0	2.0	2.0	50*
Mucuna pruriens (black)	Velvet bean	5	2.5	20.7	10.6	289
Mucuna pruriens (white)	Velvet bean	2	4.5	12.0	8.3	208*
Pueraria phaseoloides	Tropical kudzu	1	2.1	2.1	2.1	33*
Sesbania sesban	Sesban	1	12.3	12.3	12.3	308*
Vicia dasycarpa	Lana vetch	2	0.5	3.0	1.8	45*
Vicia villosa	Purple vetch	2	0.6	5.0	2.8	70*
Cajanus cajan	Pigeon pea	1	17.1	17.1	17.1	428*
Glycine max (Nyala)	Soybean	3	0.5	4.7	3.3	83*
Glycine max (SCs-1)	Soybean	3	0.3	3.7	1.5	117
Phaseolus vulgaris	Field bean	1	0.1	0.1	0.1	3*
Vigna radiata	Green gram	1	2.0	2.0	2.0	50*
Vigna unguiculata	Cowpea	2	1.2	4.5	2.9	70
Voandzeia subterranea	Bambara groundnut	1	1.1	1.1	1.1	28*

§ mean N contents calculated from measured N concentrations of biomass except those marked with * which are estimated N contents based on an average concentration of 2.5% N in the biomass.

Effects of legumes in rotations on maize production

The effects of green manures grown in rotations

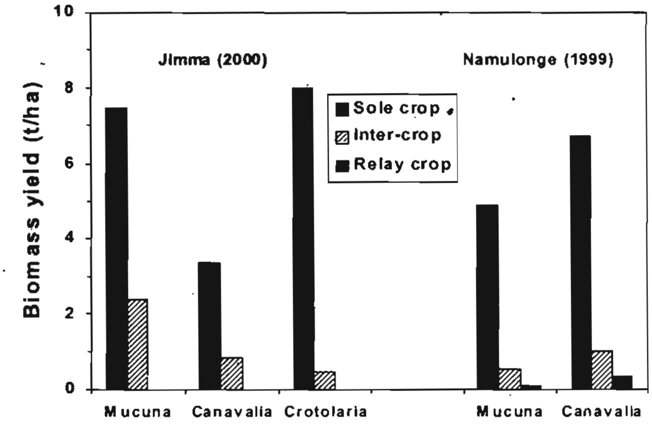

Figure 1. Effect of intercropping and relay cropping on biomass production of legumes in maize-legumes systems at Jimma, Ethiopia, and Namulonge, Uganda. (Inter-cropped legumes sown into maize 2-3 weeks after maize emergence; relayed legumes sown into maize 2 weeks after maize tasseling.)

with maize in research station trials at Bako and Jimma (Ethiopia), Mlingano (Tanzania), Kakamega (Kenya) and Namulonge (Uganda) are summarized in Table 3. These trials generally compared maize response to the legume sown in the preceding season with response to the recommended level of N fertilizer. Fertilizer N at locally recommended rates (see Table 3 footnote) generally increased yields by 46-108% across sites. With the exception of Mlingano, legume rotations consistently produced significantly higher maize yields than unfertilized maize in monocrop systems and usually as great or greater yields than fertilized maize in monoculture. Yield gains ranged from 1.5-3.5 t/ha or 27-134%. The poor response to the legume rotation at Mlingano may be due to soil hydraulic properties and high rainfall leading to leaching of N mineralized from the residues in the intervening dry season.

Table 3. Response of maize grain yield* (t/ha) to green manures sown in the preceding season (year) and incorporated prior to sowing maize in the current season – on-station trials

Maize-green manure rotation§	Ethiopia			Tanzania	Kenya	Uganda	
	Bako	Jimma		Mlingano	Kakamega	Namulonge	
	1998	2000	2001	2000	1998	2000	2001
Maize – Fert-N	3.12 a	5.00 a	1.95 a	2.05 a	5.43 a	3.11 a	3.93 a
Maize + Fert-N#	5.12 b	8.67 b	3.15 bc	4.27 b	–	4.54 bc	6.94 c
Mucuna	–	–	2.92 b	2.50 a	–	5.01 c	5.65 b
Canavalia	–	–	3.85 cd	2.70 a	6.87 b	4.00 b	6.47 bc
Crotalaria	–	8.48 b	4.56 d	–	7.29 b	–	–
Sesbania	–	8.18 b	–	–	–	–	–
Dolicos lablab	5.20 b	–	–	–	–	–	–

§ Green manures sown in preceding year and incorporated before sowing maize the following year, except Kakamega and Namulonge where rainfall is bimodal and green manures were sown in the previous short rainy season and incorporated prior to long rainy season.

* Grain yields in a column followed by the same letter are not significantly different.

Fertilizer N applied = 110 (Bako), 92 (Jimma, 2000), 69 (Jimma, 2001), 50 (Mlingano), 70 (Namulonge, 2000) and 120 (Namulonge, 2001) kg-N/ha.

During 1998-2001, on-farm trials to evaluate and promote green manures in rotation with maize were carried out in Ethiopia, Kenya, Tanzania and Uganda on more than 70 farms; 42 were successfully harvested (Table 4). Green manure species included mucuna, crotalaria, Dolicos lablab and canavalia. Response of maize to the preceding season's green manure crop was compared to monocropped maize with and without the recommended rate of fertilizer N for the area. Responses to fertilizer N were generally greater on farmers' fields than on-station, ranging from 1.4-3.3 t/ha (21-133% increase). Except at Shoboka, Ethiopia, green manure rotations consistently produced as much, and occasionally more, maize than the fertilized monocrops, increasing maize yields by 1.75-4.5 t/ha (34-384% increase).

Table 4. Response of maize grain yield* (t/ha) to green manures sown in the preceding season (year) and incorporated prior to sowing maize in the current season – on-farm trials

Maize-green manure rotation§	Ethiopia		Tanzania	Kenya			
	Shoboka	Walda	Mlingano	Kakamega	Kitale		
	1998	1998	2001	1998	1998	1999	2000
No. of farmers	1	1	14	4	10	7	6
Maize – Fert-N	2.38 a	3.12 a	1.48 a	0.70 a	6.7 a	4.1 a	4.4 ab
Maize + Fert-N#	5.55 b	6.48 b	2.78 bc	–	8.1 b	6.5 b	7.3 d
Mucuna	–	–	3.22 c	–	9.0 bc	6.0 b	3.7 a
Crotalaria	–	–	–	3.39 b	6.2 a	6.1 b	5.6 bc
Dolicos lablab	2.70 a	6.33 b	–	–	11.1 c	6.9 b	6.5 cd
Canavalia	–	–	2.31 b	–	–	–	–

§ Green manures managed as described in Table 3.

* Grain yields in a column followed by the same letter are not significantly different.

Fertilizer N applied = 50 (Mlingano), 60 (Kitale), and 110 (Bako) kg-N/ha.

Although green manure species can potentially provide an excess of N to a subsequent maize crop, not all of the N in the green manure residues may be available and considerable losses via various pathways (leaching, volatilization) may occur before the maize crop can access it. Thus, on-station experiments were conducted at Namulonge, Uganda, and Jimma, Ethiopia, to estimate the N fertilizer equivalence of mucuna, canavalia, sesbania and crotalaria grown in the preceding season.

Four rates of fertilizer N were applied to maize in plots previously under maize or the green manure. At Namulonge, mucuna and canavalia produced maize yields equivalent to about 120 kg-N/ha while, at Jimma, sesbania and crotalaria green manures were equivalent to >70 kg-N/ha of fertilizer (Figure 2).

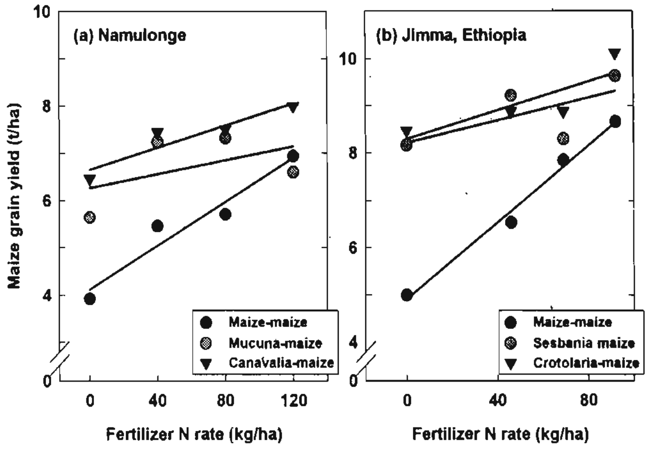

Figure 2. Maize response to fertilizer N rates following maize monocrops or green manure rotations in the preceding season, at (a) Namulonge, Uganda, and (b) Jimma, Ethiopia

Effects of intercropped legumes on maize production

Table 5 summarizes maize response to green manure intercrops at three on-station sites over several years. Although maize responded significantly to N fertilizer in 4 out of 6 site-years, the legume intercrop significantly increased the subsequent season's maize yield in only one instance (crotalaria at Jimma in 2000). Mucuna, canavalia and crotalaria intercropped or relayed with maize in regional on station trials at Jimma, Mlingano and Namulonge generally had no significant effect on maize yields in the subsequent season (Table 5). This was attributed to low legume biomass production (and hence N fixation) under the shady conditions of the maize canopy.

Table 5. Effect of green manure intercrops and relay crops on maize grain yields§ (t/ha) sown with the green manure or alone in the subsequent season – researcher managed trials on station

Maize-Green manure system	Jimma		Mlingano			Namulonge
	2000	2001	1999	2000	2001	2000LR
Sole Maize – fertilizer N	4.89 a	1.95 ab	1.28	2.05 a	3.76	3.11 ab
Sole Maize + fertilizer N§	6.02 ab	3.15 c	1.77	4.27 b	3.89	4.54 c
Mucuna intercrop*	5.22 ab	1.60 a	2.12	2.74 a	3.49	3.51 b
Mucuna relay crop#	4.86 a	2.36 b	2.30	2.28 a	2.84	3.14 ab
Canavalia intercrop*	5.96 ab	2.25 bc	1.77	2.40 a	2.53	3.94 bc
Canavalia relay crop#	5.62 ab	1.88 ab	2.26	2.71 a	2.28	2.57 a
Crotalaria intercrop*	6.52 b	2.15 ab	–	–	–	–
Crotalaria relay crop#	5.34 ab	1.96 ab	–	–	–	–

Yields within a column followed by the same letter (or no letter) are not significantly different

§ N rate (kg/ha) = 69 (Jimma), 50 (Mlingano), 70 (Namulonge);

* planted 2 weeks after maize

planted 2 weeks after tasselling

Mixed results of legume intercrops and relays were obtained in some 56 on-farm trials conducted in Northern and Eastern Tanzania during 2000 and 2001 (Table 6). In some cases, maize yields were increased by 60-120% (1-2 t/ha) while in others no significant effects were obtained. On the positive side, neither did intercropped legumes have any negative impact on maize yields in these trials, although experience in other trials has found considerable competition from legumes such as mucuna if not properly managed.

Table 6. Effect of green manure intercrops or relay crops on yield of maize grain§ (t/ha) sown with the green manure or alone in the subsequent season – on farm trials

Maize-Green manure system (intercrop or relay)	Tropical lowland ecology				Dry mid-altitude	
	Ngomeni	Tanganyika	Mlingano		Hai#	
	2000	2000	2000	2001	2000	2001
No. of farms	4	4	18	14	8	8
Sole Maize – 0 kg-N/ha	1.82 a	3.30	2.22	1.48 a	0.8	2.2 a
Sole Maize – 25 kg-N/ha	2.49 b	3.86	–	–	–	–
Sole Maize – 50 kg-N/ha	3.28 c	3.19	2.49	2.78 b	–	–
Maize/mucuna	2.88 bc	3.57	2.32	2.40 b	1.1	4.1 b
Maize/canavalia	2.92 bc	3.71	2.49	2.31 b	0.0	4.3 b
Maize/Dolicos lablab	–	–	–	–	1.1	4.6 b
Maize/calopogonium	2.52 b	3.84	–	–	–	–

green manures relayed into maize in 2000; maize sown alone in 2001

§ yields within a column followed by the same letter (or no letter) are not significantly different

Discussion and Conclusions

During the past five years, the ECAMAW research network has identified and characterized several green manure and grain legume species that have good biophysical adaptation to the moist mid-altitude and tropical lowland ecologies of Eastern and Central Africa. In monoculture situations, most of these legumes were able to biologically fix N much in excess of a maize crop's requirements. However, in intercropping situations, biomass production and biological nitrogen fixation was severely limited by competition for light and moisture with the maize crop. Furthermore, intercropping was found to be highly management sensitive, especially with respect to the competition that aggressive legumes such as mucuna can exert on the maize crop. As a result of these effects, intercropped green manures were found to have very mixed effects on a subsequent maize crop's yields. In contrast, green manures grown in rotation with maize had benefits that are more consistent. The results of these studies by the ECAMAW network are therefore in substantive agreement with similar results obtained elsewhere in the region (Giller et al., 1997).

Farmers' perceptions and constraints to adoption of green manure/grain legume systems were assessed in informal questionnaires during field days organized around on-farm trials. While farmers had much interest in new and alternative crops, they were concerned with the lack of a consumable or marketable product for many of the green manure species. For many, the spatial requirements for green manures grown in rotations may not be acceptable. In intercropping situations, competition effects, especially for creepers such as mucuna, were also very undesirable. Nevertheless, the benefits of both green manures and intercropped legumes in weed control and reduced dependence on fertilizer inputs were recognized by farmers.

Based on this experience, current and future ECAMAW activities with green manures and grain legumes in maize-based systems are focussing on the following:

- Combining legumes with new low-N maize varieties that have been developed by breeders working with CIMMYT in the region – these varieties will respond to lower levels of available soil N and should increase the potential benefits of legumes that, due to their nature or the system in which they are grown, provide less than the required N into the system.
- Introducing and evaluating multi-purpose legumes that fit into existing maize systems – in response to farmers' concerns regarding a marketable/consumable product and the lack of space in their systems for fallows.
- Assessing the economic viability of maize-legume systems in on-farm trials with farmers.

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THE ROLE OF COWPEA (*VIGNA UNGUICULATA*) AND OTHER GRAIN LEGUMES IN THE MANAGEMENT OF SOIL FERTILITY IN THE SMALLHOLDER FARMING SECTOR OF ZIMBABWE

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Abstract

Cowpea is a widely grown legume in both high and low rainfall smallholder farming areas of Zimbabwe. Its popularity with farmers can be attributed to the multiple uses the crop can be put to and adaptability to different environments. It is often used for making relish, it is an important source of protein for human beings, as livestock feed and for enhancing soil fertility through biological nitrogen fixation (BNF). This paper reports results of a study on the current cowpea production practices by farmers in Chihota, Shurugwi and Zimuto. The aims of the study were to assess the constraints, opportunities and the justification for wider use of cowpea for improving soil fertility in maize based farming systems as well as household livelihoods on smallholder farms.

The area put under legumes in Chiota, Shurugwi and Zimuto ranged from insignificant to small portions of the farm (0.2–2.5 ha in one season). Farmers were aware that there are soil fertility benefits associated with the legumes they grow, with 97% ploughing under the residues and 80% using the residues to make composts. More farmers grew cowpea intercropped (>94%) with cereals, mainly on the homestead fields, than in rotations (<6%). Cowpea ranked second to groundnut in providing biomass on farms for use in soil fertility improvement. No planned fertilization practices were applied on cowpea but in intercrops it benefits from fertilizers targeted for maize. Seed availability was a problem. Most farmers (88.5%) retained seed or got it locally from fellow farmers. Only 11.5% obtained seed from commercial seed outlets. Women were at the centre of cowpea production. Pests common under the current scale of production could be suppressed using simple methods like using ash or "Surf" washing powder in water. Utilization of cowpea products was as boiled beans, porridge and livestock feed.

We concluded that cowpea was perceived to have high potential to increase soil fertility on most farms in high and low rainfall zones of the smallholder farming sector. Most farmers grew cowpea intercropped with maize on small portions of their homestead fields. However, the biomass produced did not significantly improve the farm level nitrogen budgets. Cowpea had an important dietary role in the rural communities. Seed availability, limited product markets and lack of proper fertilization (especially P) were the major constraints to cowpea production. The utilization of more products (food and non-food) of the right varieties when properly targeted could greatly improve the role of cowpea in the farming systems. Pests were not a major constraint to the production of cowpea since farmers used simple measures like sprinkling Surf and ash solutions to contain the pests. The economic and financial benefits of cowpea production could also be realized through involving male farmers more in the production process and its promotion. Development of the product chain is required.

Key words: Cowpea, smallholder farming, stakeholder consultation, farmer survey

Introduction

Legumes play a significant role in the improvement of nitrogen budgets through biological nitrogen fixation (BNF) and cycling of other nutrients on the farm (Giller and Wilson, 1991; Giller, 2001). Cowpea (*Vigna unguiculata* (L). Waip.) can be considered a cheap legume to grow in that its fertility and rainfall demands are low. Hegewald (1990) found cowpea to produce acceptable yields on acidic oxisols. However, the economics and yield benefits of BNF in maize/cowpea rotation have not been fully explored (Shumba et al. 1990). Its role in increasing and maintaining soil fertility is not clearly defined. Often farmers do not have a planned P and N fertilization strategy for these rotations. The fertilization of cowpea grown in rotation with maize has not been studied thoroughly, especially the economics of fulfilling the P requirements of the legume. There is need to evaluate the different fertilization practices in relation to their agro-economic effectiveness for different farmer domains.

Soils in the smallholder farming sector of Zimbabwe are inherently poor in fertility. Deficiencies in both macro- and micronutrients have been reported in these sandy soils (Grant, 1981; Mashiringwani, 1983; Nyamapfene, 1991). Farmers use different strategies to either add and/or recycle nutrients on their farms. Use of cattle manure, composts, mineral fertilizers, crop or grass residues, grass fallows, grain legumes and green manures in cereal/legume rotations are loosely practiced by farmers as ways of managing soil fertility (Nhamo et al. 2002). Such practices on sandy soils are important in the management of the most limiting nutrients and soil organic matter and there is potential to improve their efficiencies. In all, the practices have been to add whatever is available to the soil or nothing at all. This results in addition of much less, just enough or more than required nutrients for the field crops. With these practices, the use of both organic and mineral fertilizers has no scientific basis. This has rendered optimum crop production and profit levels difficult to attain on sandy soils.

Besides the soil fertility contribution, cowpea provides the needed proteins in rural households through both the pea and the leaves that are used as relish. Traditionally, cowpea porridge was an important and nutritious dish making part of the diet for the farming communities. It is a multiple-purpose legume which can be used for human food and livestock feed (Johnson, 1970; Rao and Mathuva, 2000).

In the smallholder farming systems of Zimbabwe the cultivation of tradition legumes, including cowpea, is not emphasized. Current uses of cowpea for improving household food security and soil fertility vary from area to area. The reasons for this variability are not clear. The aims of this study were to determine the current cultivation practices, perceptions of farmers on the benefits and constraints of effectively utilizing cowpea in their farming system, and to evaluate the role cowpea could play in improving soil fertility and hence household food security.

Materials and Methods

A survey was conducted in three communal areas, Chihota (Mashonaland East Province), Zimuto (Masvingo Province) and Shurugwi (Midlands Province) representing natural regions II, III and IV of Zimbabwe respectively. Chihota receives annual rainfall of between 800 and 1000 mm whereas Shurugwi and Zimuto receive 600-800 mm and 450-600 mm respectively. The rainfall distribution within and across season is variable, and in all the areas mid-season droughts are a common feature.

Farmers in Chihota, Shurugwi and Zimuto rely on agriculture for food and to generate income to sustain their families. Most families have financial constraints and limited agricultural inputs are purchased for use in the production of both legumes and cereals.

Within each of the areas, a formal questionnaire was administered to collect information on cowpea practices. The questionnaire captured information on household characteristics, crop production practices, and cowpea placement in the farming systems, current constraints and opportunities for increased productivity. The semi-structured questionnaire was administered to a sample of sixty households in each of the three communal areas. Well-trained enumerators carried out data collection. The data collected was captured and analyzed using SPSS (Statistical Package for Social Sciences).

Results

Like most communal areas in Zimbabwe, maize dominates other crops and most of the land was put under this staple food crop in Chihota, Shurugwi and Zimuto. Tables 1 and 2 show the area under several non-legume and five legume crops grown in the study areas. Minor traditional crops like millets (rapoko) were also commonly cultivated on small areas in the study areas. A few farmers grew cash crops including cotton, tobacco and paprika.

Table 1. Non-legume cropping pattern of farmers from each of the sites

	Zimuto			Chihota			Shurugwi		
	% growers	Area (ha)	Yield (kg/ha)	% growers	Area (ha)	Yield (kg/ha)	% growers	Area (ha)	Yield (kg/ha)
Maize	100	2.66	327	100	2.32	442	100	3.55	323
Rice	67	1.35	382	21	0.62	226	48	0.53	479
Rapoko	64	0.57	512	30	0.58	253	21	0.51	749
Sunflower	10	4.69	133	8	0.81	632	5	0.85	210
Sorghum	0	.		6	0.89	693	8	0.60	245
Paprika	2	0.75	27	10	0.75	293	2	0.75	80
Millet	0	.		0	.		3	0.07	3077
Tobacco	2	0.50	1000	2	1.00	600	0	.	
Cotton	2	0.04	1163	0	.		0	.	
Total cultivated	93	4.35		100	3.43		102	5.00	
Total fallow	62	2.13		48	2.63		72	2.24	

Table 2. Area (ha) put under various legumes in the 2000/2001 season in Chihota, Shurugwi and Zimuto

	Zimuto		Chihota		Shurugwi	
	Sole	Intercrop	Sole	Intercrop	Sole	Intercrop
Cowpea	0.93	1.68	1.07	1.59	0.53	2.49
Bambara	0.64	0.43	0.67	0.50	1.49	0.60
Garden bean	1.37	0.90	0.85	0.49	0.27	0.38
Groundnut	1.57	0.60	1.31	0.83	0.77	0.67
Soyabean	0.20	-	1.37	-	0.75	-

In all three communal areas most of the cowpea was intercropped, whereas groundnut and bambara are consistently grown as sole crops. A few farmers grew soyabean and garden beans for household consumption (Table 2). Groundnut was the dominant legume grown by the farmers.

Though most farmers grew cowpea as intercrops, the yields reported for the sole cropped cowpea are higher than those grown in intercrops. The national average grain yield for cowpea of 300 kg ha^{-1} was close to the reported yields for sole cropping (Table 3). Higher yields were obtained from sole stands than from intercrops.

Cowpea, groundnut and bambara nut were the legumes commonly grown by most farmers in Chihota, Shurgwi and Zimuto. Groundnut and bambara nut were grown by the majority of farmers as sole crops, while cowpea was intercropped (Table 4).

Cowpea was mostly grown on the homestead fields with a reasonable proportion on the topland fields, while less than 5% of the farmers grow it in the vleis and gardens (Table 5).

Farmers acknowledged that legumes are important in soil fertility and for breaking disease/pest cycles on their fields. Groundnut was perceived by farmers to be better than cowpea for improving fertility. Farmers utilized cowpea residues for soil fertility through incorporation by ploughing under (97% of the farmers) and use in composts (80% of the farmers). Some of the residues were however fed to livestock.

To farmers the soil fertility benefits derived from rotations and intercrops are not significantly different (Table 6). Farmers perceive that both growing the cowpea in rotation with maize and as an intercrop with maize has positive soil fertility benefits.

There were no deliberate fertilization practices followed by farmers when growing cowpea. A significant amount of fertility inputs are applied to plots

Table 3. The mean grain yields (kg/ha) of different legumes obtained by farmers in the 2000/2001 season in the three areas

	Zimuto		Chihota		Shurugwi	
	Sole	Intercrop	Sole	Intercrop	Sole	Intercrop
Cowpea	269.5	61.0	278.5	66.4	339.1	62.5
Bambara	352.2	299.3	1021.0	40.0	330.3	26.0
Groundnut	551.2	147.9	437.6	90.0	262.0	97.8
Garden bean	540.0	39.2	790.7	103.7	80.9	35.0
Soyabean	.	.	389.4	.	.	.

Table 4. Numbers of farmers growing different legumes in Zimuto, Chihota and Shurugwi

	Zimuto			Chihota			Shurugwi		
	Sole	Intercrop	Total	Sole	Intercrop	Total	Sole	Intercrop	Total
	n	n	n (%)	n	n	n (%)	n	n	n (%)
Cowpea	10	51	61 (100)	19	43	62 (98))	8	51	59 (94)
Bambara nut	48	6	54 (89)	43	2	45 (71)	49	5	54 (86)
Soyabean	1	0	1 (2)	4	0	4 (6)	1	0	1 (2)
Garden bean	6	3	9 (15)	24	4	28 (44)	4	2	6 (10)
Groundnut	47	7	54 (89)	51	3	54 (86)	53	3	56 (89)

(% of farmers growing the legumes in brackets)

Table 5. Types of fields (%) to which farmers in Chihota, Shurugwi and Zimuto grow cowpea

	Zimuto	Chihota	Shurugwi	Total
Homestead field	53	57	52	54
Vlei margin	10	3	·	4
Garden	·	2	·	1
Topland	37	38	48	41
Total	100	100	100	100

Table 6. The perceptions of farmers on which cowpea growing pattern results in improved soil fertility

		Shurugwi		Zimuto		Chihota	
		n	%	n	%	n	%
Rotation	Yes	55	97	52	91	47	86
	No	2	3	5	9	8	14
Intercrop	Yes	53	88	53	88	40	67
	No	7	12	7	12	20	33

where cowpeas are grown. The common practice observed though was that of intercropping maize and cowpea. In the intercrop, manure and fertilizers applied were targeted to the maize crops and not to the cowpea (Table 7; Figure 1). A few farmers apply legume innoculant on the cowpea.

The fertilizer types used on the maize-cowpea intercrops are the recommended ones for sole crops of maize. Both the basal and the top-dressing fertilizers were applied in limited amount, far lower than the standard recommendations. The rates applied were low and similar to those reported by Nhamo et al. (2002) of less than 50 kg ha^{-1} of compound D and 25 kg ha^{-1} of ammonium nitrate fertilizer. The use of lime was recorded only in Chihota, where some trials on lime use had been conducted by researchers.

Seed availability was a problem in all the three areas, with most families planting their own retained part of their harvest for seed. About 88.5% of the households used retained seed, were given seed by other farmers or bought it from other farmers in the area (Table 8). Farmers also reported the absence of an organized market with attractive prices, lack of marketing information and low selling prices in the local market.

The majority of farmers grew the spreading cowpea varieties (49%), only 5% used the bush type and the remainder used both types. Most of the local varieties had their names derived mainly from the appearance of the plant or the colour of the bean. Names such as *rutandavare, chigogova, chitumbe, chitonono, dzemavara, chena, jerimeni, dahwa,* and *chipichipi* were common in the areas studied. Others had names linked to the source like *zvimugabe* and *mharapara*. Names like *chinyabundi, kaboko, chizharawanya* and *chingwa* were also recorded.

Table 7. The soil fertilization practices followed on cowpea crops (% farmers)

	Shurugwi		Zimuto		Chihota		Total	
	Yes	No	Yes	No	Yes	No	Yes	No
Inorganic fertilizer	30	70	39	61	70	30	47	53
Cattle manure	61	39	90	10	62	38	71	29
Legume innoculant	·	100	8	92	5	95	4	96

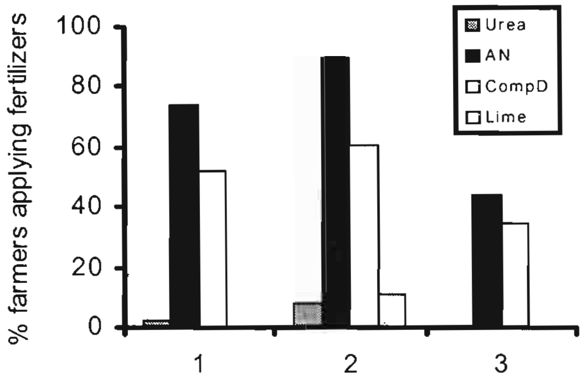

Figure 1. The percentage use of different fertilizers on the maize cowpea intercrops where; 1 represents Zimuto, 2 represents Chiota and 3 represents Shurugwi

Table 8. Sources of cowpea seed for the 2000/2001 growing season (% farmers)

	Zimuto	Chihota	Shurugwi	Total
Own saved	72.9	68.3	66.1	69.1
Bought from other farmers	5.1	3.3	3.2	3.9
Given by other farmers	15.3	15.0	16.1	15.5
Bought commercially	6.8	13.3	4.8	8.3
Project		·	9.7	3.2
Total	100	100	100	100

The major pest reported by farmers was the aphid. A significant number of farmers did nothing about the common aphid problems they encounter and they observed that once they receive some rains the aphids disappear from their crops (Tables 9 and 10). To solve this and other problems, some farmers used simple methods like sprinkling "Surf" washing powder or ash solutions.

Cowpea grown on small portions of the farm is mainly meant for domestic consumption and very little is sold. About 65% of the cowpea bean produced in the three areas is eaten at home and the greater part of the remainder is barter traded with other crops. The utilization of cowpea through boiled beans both as a side dish and as relish was most common (Table 11). The use of fresh leaves as vegetables was also found to be common.

Table 9. Common pests on cowpeas as mentioned by farmers

	Zimuto	Chihota	Shurugwi
Aphids	75.9	58.5	77.9
Beetles	-	17	10.2
Worms	8.6	9.4	8.5
None	3.4	1.7	1.7
Termites and ants	3.4	7.5	-
Stemborers	1.7	1.9	-
Weevils	3.4	1.9	-
Others	3.4	3.8	1.7

Table 10. Solutions to some of the pest problems suggested by farmers

	Zimuto	Chihota	Shurugwi
Chemicals	3.3	13.8	4.9
Traditional herbs	16.4	15.5	8.2
Cultural practices	11.5	6.9	6.6
Do nothing	68.8	63.8	80.3

Women made important decisions on the production of legumes and minor crops, including cowpea. Among the reasons why women farmers took this role were; traditionally it's a woman crop, women were responsible for providing food and relish in the household, men perceived that cowpea was not an important crop, women realized the importance of the crop and that women sometimes made decisions on farm operations in the absence of men.

Discussion

Area under legumes and cowpea

Compared to cereals, the area planted with legumes in the three communal areas ranges from insignificant to small portions of the farm (Tables 1 and 2). Most of the cultivated land is put under maize because it's the staple crop, followed by cash crops like tobacco, paprika and cotton. however, most farmers (99%) devote part of the farm to cultivation of at least one legume crop among which are groundnut, bambara or cowpea. The small area planted determines the modest contribution made by legumes to the N budget on the farms. In most communal areas, biomass production is key to the utilization of these high quality materials. The successful use of these legumes in improving soil fertility depends on the quantities of organic materials available for use on the farm. Work done by Nhamo et al. (2002) has shown the importance of the amounts of organic materials available on the farm in the adoption of some of these organic based soil fertility technologies. Biomass production following the planting of cowpea on these small areas at low plant populations is insufficient to make a big impact on the fertility status of soils.

Table 11. Scoring on the utilization of cowpea by farmers for domestic consumption

	Zimuto	Chihota	Shurugwi
Porridge (Rupiza)	3	3	4
Relish (Leaves)	2	2	3
Relish (Grain)	4	4	2
Boiled beans (Mutakura)	1	1	1

Farmers in the study areas grew several crops including small grains to spread the risk of crop failure. Under unpredictable climatic conditions, smallholder farmers use such strategies to ensure household food security. Millets however are also important in beer brewing for the traditional rituals.

Soil fertility benefits of cowpea

Farmers perceived that there were soil fertility benefits and improved yields of maize grown after cowpea (Table 6). The soil attributes linked to these improvements varied from the observable soil colour to the soil water holding capacity. Cowpea ranked second after groundnut in residue production and hence soil improvement potential (Table 4). Most farmers intercropped cowpea and maize or other cereals. Intercropping maize and cowpea has been reported to increase yields in some cases (Olasantan, 1988; Jeranyama et al. 2000) and even better yields have been reported in rotations where there are no moisture competition effects (Kouyate et al. 2000; Rao and Mathuva, 2000). However, few studies have been conducted comparing the two farming systems directly. Work done by Hardter et al. (1991) has shown that while mixed maize-cowpea cropping had lower yields than rotations, continuous monocropping had the lowest productivity. The reasons why farmers intercrop are varied. With regards to soil fertility, these can be explained scientifically by the residual effects on cereals following legumes in rotation and by the below ground nutrient transfers that occur in the rhizosphere in intercrops (Bandyopadhyay and De, 1986).

Incorporating legume residues to the soil improves its fertility. Work done on legumes has demonstrated the usefulness of legumes grown in rotation with cereals in general (Giller and Wilson, 1991, Giller 2001). For cereal/legume rotations to be successful, a reasonable amount of legume non-grain residue/biomass has to be produced and its management has to be effective. Residues generated by legumes are in two forms; the roots (below ground) and the stems and the leaves (aboveground) (Giller and Wilson, 1991). The agronomic contributions of the above and below ground portions of the cowpea have not been studied. Because of the possible conflicting uses that legume leaves have on the farm, it is important to quantify the economic benefits separately and together.

Similar to other field crops, grain legumes require soil nutrients for them to grow as well as fix N from the atmosphere. The growth is a response to the soil type, fertilization and soil water availability. On sandy soils that are commonly found in the communal areas, the nutrition of N fixers that contribute to the successful symbiosis has not been emphasized. Higher cowpea yields from homestead fields (Table 5) are a result of better soil fertility management. Studies have shown that they respond well to P application (Giller, 2001). However, the P, K, micronutrients and lime requirements for cowpea in a maize/cowpea rotation have not been worked out. Fertilization of the legume in a legume/cereal rotation is important if productivity is to improve from the current low levels. At present, there is scant information on the effective and efficient way of using organic and inorganic fertilizers on legume-cereal rotations (Giller, 2001). The current practice of adding mineral N reduces the N-fixing capacity of the legumes in these farming systems (Table 7). For the different agro-ecological zones, rates of P application need to be worked out. The economics of the first application as well as the residual P effects on both the cereal and the legume in rotations, as well as in intercrops for the different soil types, are required. This information will be important and useful in targeting legumes properly on the farm. Work on row spacing of maize and cowpea show improved yields with wider spacing but the wider spacing leads to low plant populations. This leads to low biomass production and hence less effective utilization of the BNF from legumes.

Soil nutrients interact with the available moisture.. As reported by Muza and Mapfumo (1999), soil nutrient and water interactions have a large effect on the overall biomass production of legumes. Cowpea has the advantage of a deep rooting system that makes it adaptable to different agro-ecological zones. However different varieties have different attributes so proper targeting is important for effective use of cowpea in farming systems. Grown in rotations with maize, cowpea has been reported to reduce weed pressure in the residual season (Kamau et al. 1999). Similar findings have been reported in intercrops, except that the weed suppression in intercrops is in the first season.

Cowpea utilization

Most cowpea grown is utilized as boiled beans for either direct consumption or as relish. It remains a cheap source of protein especially during the dry winter season. In Shurugwi a study done at a school positively correlated the consumption of cowpea to the high turn out and class performance of primary school pupils (SDARMP, 1997). Other less commonly used dishes include porridge, scones/bread, and there is potential for more. For the benefit of the communities these other benefits in addition to soil fertility technologies have proven to be important in technology acceptability. In the case of cowpea, the health effects of the dishes have to be considered to see how these could be made part of the diet of HIV/AIDS affected persons. Cowpeas provide both calories and protein (Venter et al. 1997). For food security, indigenous and traditional crops need to be improved since their important contribution has largely been ignored in recent years.

Constraints in cowpea production

Fertilization. Constraints on using legumes effectively in soil fertility management in the smallholder farms are varied. Low perception about minor crops, little biomass from a small area planted, seed availability problems, lack of exposure to information on their production and little information on the potential benefits of using the legume crop in maize-based farming systems are some of the reasons why legumes are little used in fertility management (Rusike et al. 2000). Cowpea grown in intercrops benefits from the fertilizer applied on the maize. The nitrogen from basal and topdressing maize fertilizer reduces the amount of N fixation by the legumes. This reduces the benefits from the cowpea and the potential N addition to the nutrient budget through BNF. Farmers sometimes also complain about the higher labour demands with legume crops compared to the cereals (Jeranyama et al. 2000). Soil fertility management based on rotations can be used to come up with integrated soil fertility management strategies that have the potential to improve he livelihoods of people in the smallholder-farming sector of Zimbabwe. Use of combinations of organic and inorganic nutrient sources can produce better crop yields and improve the soil organic matter levels in the long term (Murwira et al. 2002 ; Nhamo et al. 2001).

Marketing. The cowpea market is underdeveloped. The whole product chain has not been developed and supported enough to benefit the farmers. Seed sources identified in the study are mainly local and little commercial seed finds its way to the farmers. Interested farmers are therefore faced with the uncertainty of growing unproved seed. A large proportion of the farmers keep some of their harvest for seed for the commonly grown legumes. Considering that some of the grain is consumed by the family, seed availability could be one of the root causes of the low areas for cowpea (Rusike et al. 2000). A few of the farmers interviewed acquire cowpea seed from approved seed dealers and the local market for retained seed is not organized. This leads to reduced areas under cowpea and other legumes. The high percentage of farmers who rely on retained seed posses a problem in seed availability and viability. The viability of seed depends on the storage conditions under which the bean is stored. These post harvest storage facilities have not been developed in the smallholder farming sector resulting in limited storage, fast loss of quality seed and small quantities that can be stored at any one time. The use of inferior cowpea varieties could also have caused reduced areas under their cultivation. Most farmers grew the spreading type of cowpea and had retained seed used over long periods. Over time, the vigor of the seed could have declined causing reduction in the potential yield. As observed by Franzel and Scherr (2002), some cropping systems function below their potential productivity because of using poorly adapted species, varieties and management practices.

The current poor market structures for cowpea do not warrant investment in proper fertilization, use of pesticides and other planned agronomic practices on the crops. The economics of cowpea beyond barter trade need to be explored to include organized national markets as well as export markets. Such a development would enhance the direct and indirect financial benefits of cowpea to farmers. Promoting other products from cowpea of dietary, direct and indirect monetary importance creates a market for the legume.

Pests and diseases. In this study, pest and diseases on cowpea were not regarded by farmers as a major constraint to production. The suggested solutions to pests showed that those that have grown cowpea know about them in general and that the occurrences have not been large enough to reduce the yields by economic margins. Several options followed by farmers need to be refined and avoid the wait-for-rains strategy which could reduce yields to below economic levels. The use of Surf and ash solutions has been documented through the experiences shared by farmers in Shurugwi. Use of uncertified seed produced without inspection could be one way in which there has been a build up of diseases over the years (Madamba, 2002). The implications of pest build up with increased area under cowpea also need to be looked at. Practicing rotation can always break the disease cycles.

Gender in cowpea production. Whilst it is widely agreed that women are overall responsible for growing cowpea and other legumes for the family, they are faced with serious knowledge limitations on sustainable agronomic practices with these crops. Women make decisions on the area to which the legumes are cultivated since they are the ones who keep and know the quantities of seed available for these crops. Very few received training or advice on cowpea production from extension agents. Most legumes are labeled as women crops in all the communal areas visited though labour to work on fields with legumes is provided by the whole family. The implications of this are that cowpea production becomes low priority, is perceived as a non-cash generating activity and hence no fertilizers or fertility practices are targeted towards its production. However, the farmers who use legumes for consumption and local trade ranked them as highly important in improving the livelihoods and food security of the household at particular times of the year. For the effective and wide production of these legumes, the myths and beliefs around their production present a challenge. Since gender is central to their production, there is need for a participatory 'degenderization' of the commonly grown legumes. Research and development of such crops have lagged behind too much compared to what are referred to as men crops or cash crops like maize, tobacco and cotton.

Conclusion

The potential of cowpea to improve soil fertility and household food security and income was high. Most farmers intercropped cowpea with maize. The area put under legumes in the three areas ranged from insignificant to small portions of the farm. Farmers acknowledged the role of cowpea in soil fertility used in both rotations and intercrops. However, no planned fertilization practices on cowpea were followed by farmers.

The cowpea product chain was undeveloped in Chihota, Shurugwi and Zimuto. The current utilization of cowpea was mainly through four simple dishes in the form of porridge, relish (bean and leaves) and boiled bean (mutakura). Farmers incorporated some of the residues while some were fed to livestock. There is therefore need for diversification through the utilization of more products. Traditional crops have been recommended as part of the diet for people suffering from HIV/AIDS, and cowpea could find a place in some of these diets. Seed availability was a major problem to farmers with the majority using retained seed. Varieties suited for the different agro-ecological zones need to be studied to improve grain and non-grain biomass production of cowpea. The area under cultivation needs to be properly fertilized for both rotations and intercrops. Seed availability and markets of the cowpea need to be organized, both the local and external channels.

Women played an important role in the production of cowpea and there is need for sensitization of all stakeholders to remove the gender bias of the crop so that its economic, financial, nutritive and other benefits could be explored to the maximum. Farmers need to be empowered with knowledge to enable them to appreciate the real economic and financial value of cowpea in the household, on agricultural markets and in the farming system.

Pests are not a major constraint under the current cowpea production and farming systems. Increasing area under cowpea cultivation could lead to demand of a more systematic way of dealing with pests and diseases.

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BIOMASS PRODUCTION OF GREEN MANURES AND GRAIN LEGUMES IN SOILS OF DIFFERENT CHARACTERISTICS IN ZAMBIA AND ZIMBABWE

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Abstract

Several green manure and grain legumes have been identified as having potential for use in soil fertility improvement and for food in southern Africa. The ecological boundary conditions under which the different legumes perform have, however, not been ascertained. A study was carried out in the 2001/02 season to assess the influence of soil characteristics on legume establishment, growth and biomass production and grain yield in Zambia and Zimbabwe. On-farm experiments were established in different agro-ecological zones in Zambia and Zimbabwe to capture soils of different texture, pH, soil fertility status and CEC. Drought experienced during the season resulted in low yields for all the legumes. Of the five legumes planted, the green manures, Crotalaria grahamiana *and* C. juncea, *and* Mucuna pruriens, *gave higher biomass than the grain legumes, Cowpea* (Vigna unguiculata)*, and Soybean* (Glycine max)*.* Crotalaria juncea *produced biomass yields around 2300 kg ha^{-1} in Zimbabwe and* Crotalaria ochraleuca *accumulated up to 10000 kg ha^{-1}. Cowpea had biomass yields as low as 150 kg ha^{-1} while soyabean had close to 2000 kg ha^{-1} biomass yields in Zambia. There were no significant soil textural effects on legume biomass yields in the Zimbabwean sites. In Shurugwi, wetland soils had higher biomass yields than dryland soils mainly because of the drought that was experienced during the season. In Zambia,* Mucuna pruriens *had high biomass yields on the loamy sands while* Crotalaria ochraleuca *had the highest yields under the sandy clay loams. There were weak but positive correlations of legume biomass yield with clay content, organic C, soil pH and available P.*

Key words: green manure and grain legumes, biomass yields, soil characteristics

Introduction

Herbaceous legumes have been shown to have potential in soil fertility improvement in many parts of Africa. Legumes play a significant role in the improvement of nitrogen budgets through biological nitrogen fixation and cycling of other nutrients, reducing the amount of mineral nitrogen fertilizer required (Giller, 2002). Legumes can be grown either as sole crops in rotation with cereal crops or intercropped with cereal crops, depending on their compatibility.

Green manure legumes like *Mucuna pruriens, Crotalaria* species and *Tephrosia* species have been identified to have potential to produce high biomass and increase soil fertility in turn (Muza, 1997; Gilbert, 1997). Giller and Wilson (1991) reported that green manure legumes have potential to accumulate up to 250 kg N ha^{-1} year^{-1}. Grain legumes that include *Glycine max, Vigna unguiculata* and *Cajanus cajan* have been shown to have high potential to yield high amounts of grain and some residual leaf litter and root biomass that can contribute significantly to soil fertility improvement (Mapfumo et al. 2001; Nyakanda et al. 1997; Saka et al. 1998; Schulz et al. 2001). Growth performance of the different legumes varies from site to site, with some legumes being more tolerant of low soil fertility conditions than others. It is usually essential to add P fertilizer to enhance legume growth, especially in the communal area soils, which are infertile. Hikwa et al (1998) showed that biomass yields of *Mucuna pruriens* doubled with P fertilization while there were no P responses with *Crotalaria juncea*. Soil moisture affects legume performance with both waterlogging and drought conditions reducing crop growth of some legumes (Muza and Mapfumo, 1998). The biophysical boundary conditions under which different legumes perform need to be ascertained.

The objectives of this study were to establish the influence of soil biophysical conditions on legume biomass and grain yields in Malawi, Zambia and Zimbabwe, and to evaluate legume performance in different agro-ecological zones. Only data from Zambia and Zimbabwe are reported. It was hypothesized that legume biomass and grain yields would increase with increase in clay content, CEC, C content and P content.

Materials and Methods

On farm experiments were carried out on soils with different characteristics to cover soils of different texture, C content, P content, pH and CEC in Zambia and Zimbabwe. The legumes were planted in a randomized block design, together with fertilized and unfertilized maize as treatments.

Zambia

Four legumes, *Mucuna, Crotalaria juncea, Glycine max* and *Vigna unguiculata,* were planted on six farms in Zambia in Choma, Magoye, Kabwe, Muswishi, Kasama and Mungwi. Choma and Magoye are in medium rainfall areas with annual rainfall of 600-800 mm, while Kabwe and Muswishi were in high rainfall areas (800-1000 mm annual rainfall), and Kasama and Mungwi receive 1000-1200 mm rainfall annually. Kabwe and Misamfu were on sandy loamy soils, while Mungwi was on a loamy sand and Muswishi on a sandy clay loam (Table 1). All the sites had low contents of available P of less than 7 μg P g^{-1} soil with the exception of Kabwe which had 40 μg P g^{-1} soil available P. CEC was less than 10 $cmol_+kg^{-1}$ except for Muswishi, which was on a sandy clay loam and had a CEC of 39 $cmol_+kg^{-1}$ (Table 1).

Zimbabwe

The experiment was carried out at 24 sites in two districts, Murewa and Shurugwi. Murewa was a high rainfall area, receiving up to 1000 mm rainfall annually while Shurugwi was in a low rainfall area receiving around 650 mm annual rainfall. Six legumes were planted; *Mucuna, Crotalaria juncea, Crotalaria grahamiana, Glycine max, Cajanus cajan* and *Vigna unguiculata.*

The sites in Murewa covered red and black clays, loamy sands and sands (Table 2). The coarse textured soils had low C contents with most of the sites on coarse textures having less than 0.8% C, while sites on heavier soils had C contents of up to 3% C (Table 2). All the sites in Murewa had low contents of available P and low CEC with most of the sites having less than 3 μg P g^{-1} available P and less than 6 $cmol_+kg^{-1}$ CEC.

All the sites in Shurugwi were on coarse textured soils, all with less than 7% clay content (Table 3). pH at the sites in Murewa averaged around 5.5 (Table 2) and were lower than those in Shurugwi which had a mean of 7 (Table 3). The sites in Shurugwi were of low soil fertility status than those in Murewa and Zambia. Most of the sites in Shurugwi had less than 0.6% C, 3 μg P g^{-1} available P and less than 3 $cmol_+kg^{-1}$ CEC (Table 3).

Results and Discussion

Biomass yield of different legumes in Zambia and Zimbabwe

At all the sites, green manure legumes had larger biomass yields compared with the grain legumes,

Table 1. Initial soil characterization of Zambian sites

Site	pH (KCl)	% sand	% clay	% silt	Textural class	% C	% N	$\mu g\ g^{-1}$P	Mg me%	Ca me%	Na me%	K me%	CEC
Kabwe	6.3	77	9	14	Sandy loam	1.48	0.11	40	2.3	5		0.9	10.1
Misamfu	4.2	70	15	15	Sandy loam	0.86	0.06	7	0.8	1	0.08	0.36	5.8
Muswishi	5.5	58	22	21	Sandy clay loam	1.44		6.2	2.3	4.15	0.05	0.48	39.1
Mungwi	5.1	82.1	9.8	8.1	Loamy sand	0.7	0.03	5	0.7	2.1	0	0.1	5.8

Table 2. Initial soil characteristics of sites in Murewa, Zimbabwe

Farmer	pH (H_2O)	% sand	% silt	% clay	Textural class	% C	% N	$\mu g\ g^{-1}$P	Mg me%	Ca me%	Na me%	K me%	CEC
Nzvere	5.3	86	6	7	Loamy sand	0.44	0.08	2.12	0	0.1	0.03	0	0.13
A. Darare	5.4	32	15	52	Clay	1.98	0.17	2.27	0.89	1.35	0.05	0.04	2.33
Kwari	5.6	30	20	49	Clay loam	2.28	0.21	2.07	0.87	1.53	0.03	0.05	2.48
Mutsago	5.4	46	14	37	Sandy clay	1.26	0.11	2.02	0.87	1.35	0.05	0.05	2.32
Chokurongerwa	5.3	82	6	11	Loamy sand	0.46	0.08	2.02	0.01	0.09	0.03	0	0.13
Matambanadzo	5.4	82	6	11	Sand	0.77	0.11	2.96	0.11	0.37	0.08	0.03	0.59
Mandebvu	5.3	82	6	11	Sand	0.7	0.1	3.11	0.07	0.26	0.02	0.02	0.37
Kaitano	5.2	84	6	9	Loamy sand	0.45	0.07	2.57	0	0.05	0.02	0	0.07
Musegedi	5.4	86	6	7	Loamy sand	0.39	0.08	2.22	0.01	0.06	0.03	0	0.1
Mugwagwa	5.3	86	6	7	Loamy sand	0.64	0.14	1.63	0	0.06	0.02	0	0.08
Takarova	5.5	84	6	9	Loamy sand	0.49	0.07	2.81	0.04	0.22	0.04	0	0.3
Ndoro	5.6	42	16	41	Clay	3.06	0.27	1.63	2.45	2.92	0.04	0.03	5.44
B. Darare	5.5	32	18	49	Clay	2.96	0.26	3.56	2.78	3.61	0.05	0.04	6.48
Gwara	5.5	46	20	33	Sandy clay loam	2.81	0.38	1.78	1.59	2.29	0.06	0.02	3.96

Table 3. Initial soil characteristics of sites in Shurugwi, Zimbabwe

Farmer	pH (H_2O)	% sand	% silt	% clay	Textural class	% C	% N	$\mu g\ g^{-1}$P	Mg me%	Ca me%	Na me%	K me%	CEC
Gweru	6.87	83	11	6	Loamy sand	0.28	0.03	0.9	0.1	0.61	0.08	0	0.79
Munyika	6.86	85	9	6	Loamy sand	0.59	0.04	2.76	0.14	0.95	0.09	0	1.18
Marime	7.13	87	7	6	Sand	0.4	0.02	1.01	0.14	0.93	0.09	0.03	1.19
Manatsa	6.82	85	11	4	Loamy sand	0.49	0.03	3.27	0.13	1.21	0.07	0.03	1.44
Masendeke	7.33	87	9	4	Sand	0.35	0.02	1.07	0.07	0.52	0.07	0.01	0.67
Chimviri	7.38	95	3	2	Sand	0.37	0.04	1.18	0.02	0.49	0.07	0	0.58
Majoni	7.15	87	11	2	Sand	0.32	0.03	0.51	0.06	0.71	0.07	0	0.84
Makovere	6.67	90	8	2	Sand	0.46	0.01	2.93	0.02	0.42	0.07	0.04	0.55
Mugwagwa	7.45	89	7	4	Sand	0.24	0.01	2.54	0.07	1.11	0.09	0	1.27
Ngwalati	7.38	85	11	4	Loamy sand	0.23	0.01	0.56	0.15	2.47	0.08	0	2.7
Gwatsvaira	6.78	91	7	2	Sand	0.18	0.02	0.73	0.04	0.41	0.07	0.02	0.54

with *Crotalaria juncea* and *Crotalaria ochraleuca* giving the highest biomass yields in Zimbabwe and Zambia (Table 4). Mucuna had yields around 2000 kg ha^{-1} in Zimbabwe while it yielded more than 7000 kg ha^{-1} in Zambia (Table 4). The mean yields for *Crotalaria juncea* were 2300 kg ha^{-1} in Zimbabwe and 10000 kg ha^{-1} for *Crotalaria ochraleuca* in Zambia (Table 4). In western Kenya, Ojiem et al (1998) observed higher dry matter accumulations of up to 9 t ha^{-1} for the green manure legumes (*C. ochraleuca, C. grahamiana, C. incana* and *Mucuna*) while soyabean accumulated dry matter of about 2 t ha^{-1}. In Zambia, soyabean accumulated biomass yields close to 2000 kg ha^{-1} while less than 400 kg ha^{-1} biomass yields were obtained in Zimbabwe. Cowpea had up to 800 kg ha^{-1} biomass yields in Zimbabwe while in Zambia it was as low as 150 kg ha^{-1}.

Schulz et al (2001) reported that biomass yield and N contribution potential of the different legumes varies and may be ranked in terms of soil fertility improvement in the following order: green manure crops> forage crops> low harvest index grain legumes> high harvest index grain legumes. Higher biomass yields were observed in Zambia than in Zimbabwe, probably because the sites that were sampled in Zambia were not under moisture stress while the Zimbabwe sites were affected by drought.

Table 4. Biomass yield of legumes obtained in the 2001/02 season from different agro-ecological zones in Zambia and Zimbabwe (Murewa and Shurugwi)

Treatment	Biomass yield (kg ha^{-1})			
	Zambia (800-1000 mm rainfall)	Zambia (1000-1200 mm rainfall)	Zimbabwe (800-1000 mm rainfall)	Shurugwi (<650 mm rainfall)
Cowpea		146	835	651
Crotalaria grahamiana			1715	2056
Crotalaria juncea			2312	2316
Crotalaria ochralueca	12841	10000		
Mucuna	4981	10250	2331	1562
Soyabean	2482	1062		391
LSD (0.05)	1083.6	974.3	276.2	457.5

There were no differences in biomass obtained in Murewa and Shurugwi, probably because both areas were affected by drought (with annual rainfall of 542 mm and 595 mm respectively), reducing the potentials for legume growth (Table 4).

Effect of soil characteristics on legume biomass production

In Zambia, *Mucuna pruriens* had the highest biomass yields when sown under loamy sands while *Crotalaria ochraleuca* had the highest biomass yields on sandy clay loams (Figure 1). In Zimbabwe there were no significant differences in biomass yields of legumes grown under soils of different texture (Figure 1). In Zimbabwe, the effects of the different soil characteristics on legume biomass production were masked by the poor rains that were received during the growing season resulting in little growth for all the legumes. There were no differences in biomass yields of legumes grown in soils of different texture in Murewa. This is despite soils having different soil fertility status. In Shurugwi high biomass yields were observed in legumes planted on wetlands, mainly because there were no moisture limitations. The wetland sites were however on sandy soils, which were expected to yield lower than the fine textured soils. The C contents of the wetland sites were in the low range. Makovere and Chimviri had C contents of 0.46 and 0.37, respectively (Table 3). This suggests that there is an interaction between soil fertility and soil moisture.

There was a positive correlation between legume biomass yield and clay content for all the legumes although the correlations were weak for both Zambian and Zimbabwean sites (Figure 2). This shows that there might be a strong correlation between legume biomass yield and clay content, provided moisture is not limiting. There was no correlation between organic C content and legume biomass yield (Figure 2). Legume biomass yield increased with increase in pH, although the correlations for the different legumes were weak (Figure 2). There were

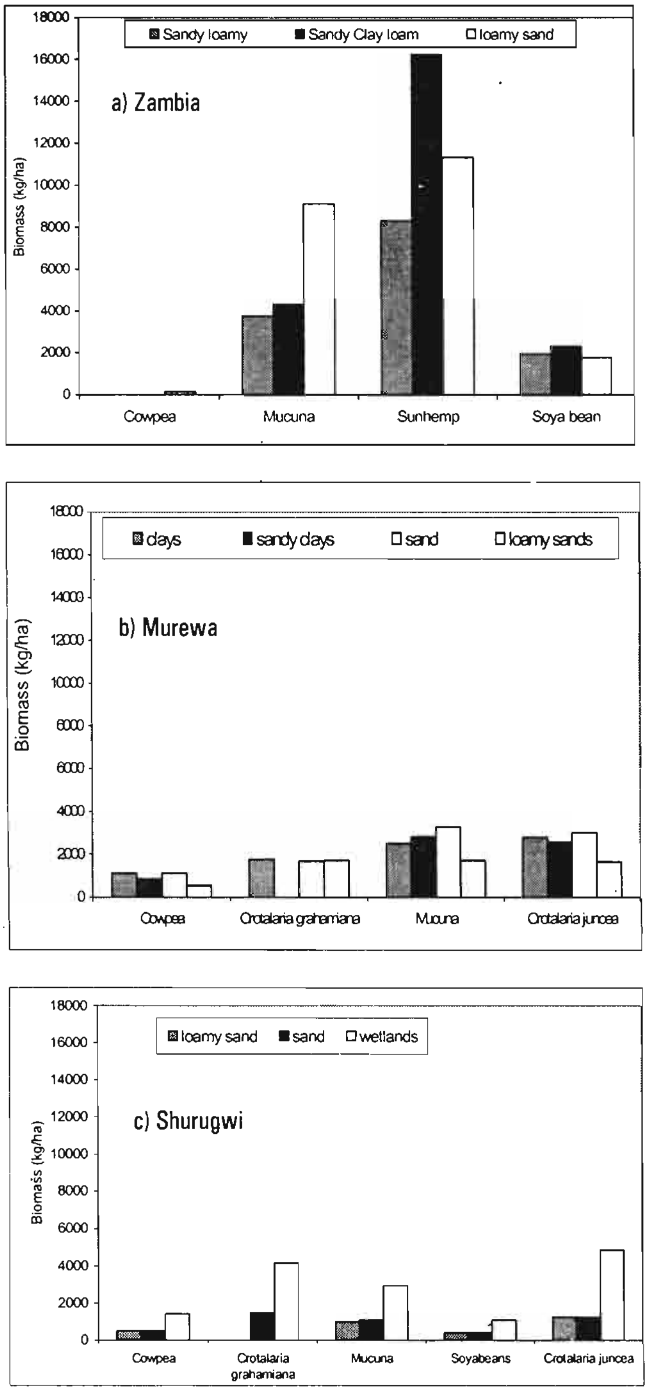

Figure 1. Biomass yields of different legumes in soils of different textural classes in, a) Zambia, b) Murewa, and c) Shurugwi

weak but positive correlations between legume biomass yields and available P for the different legumes except for *Mucuna pruriens,* which had a negative relationship (Figure 2). This was in contradiction with the observations of Hikwa et al (1998) where biomass yield of *Mucuna pruriens* increased with increase in available P.

Conclusions

It is difficult to give definite conclusions from this study because of the drought experienced that de-

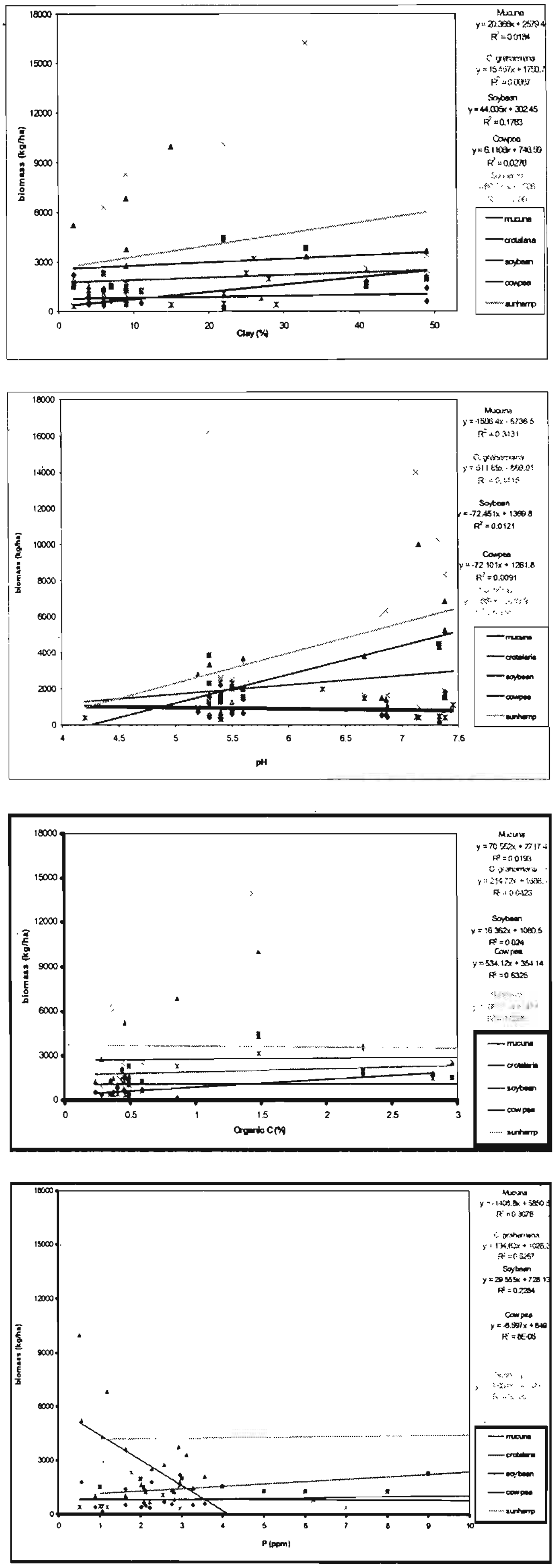

Figure 2. Correlations of legume biomass yield with a) clay content, b) pH, c) organic C content, and d) available P, in Zambia and Zimbabwe (Murewa and Shurugwi)

pressed growth of most crops. The observations made in the 2001/02 season however indicate that moisture is essential for legume growth. Legume biomass yields increase with increase in clay content, pH and soil fertility in general. There are interactions of the different soil characteristics such as soil moisture, clay content, soil pH, and soil fertility on legume biomass production. There is therefore, a need to explore the effects of the interactions of the different soil characteristics on legume establishment, growth and biomass yield. Green manure legumes outyield grain legumes and all legumes require some soil moisture to produce meaningful biomass yields that can impact on soil fertility improvement. More data analysis is required to discriminate the importance of the various parameters measured. A spatial analysis of the data could help in drawing up recommendation domains for the various legumes.

Acknowledgements
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EFFECT OF DIFFERENT GREEN MANURE LEGUMES AND THEIR TIME OF PLANTING ON MAIZE GROWTH AND WITCHWEED (*STRIGA ASIATICA*) CONTROL: A PRELIMINARY EVALUATION

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Abstract

A pot experiment was established at Henderson Research Station (30° 58′, 17° 35′) and a field experiment was conducted at Mlezu (29° 30′, 19° 8′), Zimbabwe during the 2001/2002 cropping season to evaluate the effect of green manure legumes, and their time of planting when intercropped with maize, on Striga asiatica *emergence and maize growth and yield. The green manure legumes tested were velvetbean (*Mucuna pruriens, *fish bean (*Tephrosia vogelii*), sunnhemp (*Crotalaria juncea*), and dolichos (*Lablab purpureus*). There was less Striga* asiatica *incidence when legumes were planted at the same time as maize, compared with staggering the planting dates. There were no significant differences among the green manure legumes in their ability to suppress Striga. Planting the maize and legumes at the same time increased interspecies competition and reduced maize leaf area and plant height significantly. Velvet bean reduced maize leaf area more than the other legumes. However, the competitive effect of the legumes did not reduce grain yield in the pot experiment.*

Key words: Striga asiatica, *Striga suppression, velvet bean, fish bean, sunnhemp, dolichos*

Introduction

Striga asiatica is one of the biological constraints to maize production in the smallholder farming areas of Zimbabwe. *Striga* species are difficult to control because they cause damage before the *Striga* plants emerge from the soil after most weeding operations have been completed (Musambasi, 1997). Research in Zimbabwe and elsewhere has shown that *S. asiatica* can be controlled by several methods. These include hand pulling before flowering, hoeing, ridging, trap and catch cropping, intercropping with legumes such as cowpea (*Vigna unguiculata* (L.) Walp], bambara nut (*Vigna subterranea*) and soyabean (*Glycine max*), crop rotations with non hosts and false hosts, resistant varieties, herbicides (such as 2,4-D, dicamba and trifluralin), use of multipurpose trees and timely planting (Chivinge et al, 2001; Kasembe, 1999; Musambasi, 1997). However, all of these have shortcomings as shown by very little or no adoption. Nitrogen (N) has been shown by many workers to reduce *Striga* infestation and improve maize grain yield. Smallholder farmers sometimes apply N on the soil around the maize plant at about four weeks after planting. However, sources of mineral N are very expensive for smallholders. Alternative methods that can add N to the soil and at the same time control *Striga* are therefore urgently needed. Green manure legumes such as velvetbean (*Mucuna pruriens*), fish bean (*Tephrosia vogelii*), sunnhemp (*Crotalaria juncea*), and dolichos (*Lablab purpureus*) are an important source of nutrients (particularly biologically fixed N) in Zimbabwe (Chibudu, 1998). Green manure legumes have been used by Zimbabwe smallholders for soil N amelioration in areas such as Chihota, Mangwende and Zvimba (Hikwa et al, 1998; Chibudu, 1998). However, the effects of these green manure legumes on *Striga asiatica* dynamics have not been studied in Zimbabwe. In Sudan, *L. purpureus* planted on the same day as sorghum (*Sorghum vulgare*) reduced the *Striga* plant population density by 48-93%, their dry weight by 83-97% and number of capsules by 52-100% (Babiker, 2000). This present study was conducted to investigate the effect of maize/green manure legume intercrops and their time of planting on *Striga asiatica* emergence and maize yield components in Zimbabwe.

Materials and Methods

A pot trial was established in January 2002 at Henderson Research Station, just north of Harare. Black polythene bags measuring 30 cm diameter and 40 cm height were used. The experiment was arranged as a completely randomized design and replicated four times. Three maize seeds of hybrid SC501 were planted in each pot and these were thinned to one plant after two weeks. Legumes (*Mucuna pruriens,* *Lablab purpureus, Crotalaria juncea, Tephrosia vogelii*) were planted at the same time as the maize in half the pots and then two weeks after planting maize in the others. Sole crops were also included as a control treatment. The legumes were thinned to one plant per pot at two weeks after planting. Compound D (8N: $14P_2O_5$: $7K_2O$) was applied to supply 0.6 g N/maize plant, 1.1 g P_2O_5/maize plant and 0.6 g K_2O/maize plant; an equivalent of 300 kg/ha of the fertilizer in the field. Ammonium nitrate (34.5 % N) was applied at 4 and 8 weeks to make up to 0.8 g/pot total N. Plants were given supplementary irrigation to field capacity as necessary. Maize plant heights were taken at 4 and 8 weeks, while leaf area, shoot dry weight and root dry weight were taken at 4, 6 and 8 weeks after planting. *Striga* counts per pot were recorded at 40 days after planting and weekly thereafter.

A similar trial was conducted at Mlezu Institute of Agriculture, also near to Harare, in a field that had been artificially infested with *S. asiatica* the previous year. Maize was planted to achieve a plant population density of 37 037 velvet bean and dolichos plants/ha, 74 064 sunnhemp plants/ha and 10 000 fish bean plants/ha. Compound D was applied as initial fertilizer at a rate of 300 kg/ha. No topdress N was applied because of prolonged dry spells. *S. asiatica* counts were taken from the four centre rows every two weeks after planting. Data analysis was done using GENSTAT 5 Release 3.22. Treatment differences were compared using the least significant difference (LSD P<0.05).

Results

Pot Experiment

Plant heights and leaf area. In the pot experiment, maize plants were taller in maize/sunnhemp, maize/fishbean intercrops and sole maize treatments after 55 days than in maize/dolichos and maize/velvetbean intercrops, when planted at the same time as maize (Table 1). There were no significant differences in maize plant height at 55 DAP but differences were significant at 25 DAP when legumes were intercropped two weeks after maize.

Legumes planted two weeks after maize achieved a higher maize leaf area than those simultaneously planted with maize. Maize interplanted with velvet bean at the same time had significantly lower leaf area than the other treatments and sole maize at 6 WAP (Figure 1).

There were no significant differences between leaf area of sole maize and that of maize intercropped with green manure legumes at 4 WAP (Table 2).

***Striga asiatica* counts and number of capsules per pot.** *Striga asiatica* counts were higher ($Lsd_{0.05}$=0.18) where legumes were planted two weeks after maize than where legumes were planted at the same time as maize at 45 DAP (Figure 2). There was no significant interaction between time of planting and the type of intercrop on *S. asiatica* counts and number of capsules. Sole maize did not differ significantly with the intercrops for *S. asiatica* emergence and the number of capsules.

***Striga asiatica* dry weights.** Green manure legumes intercropped with maize, as well as their time of planting, did not have a significant effect on *S. asiatica* dry weights. However, planting the green manure legumes two weeks later resulted in increased *S. asiatica* growth (Table 3.)

Table 1. The effect of time of planting green manure legumes in maize/legume intercrops on maize plant height (cm)

	---25DAP---		---55DAP---	
Intercrop	PLST	PTWL	PLST	PTWL
Maize/dolicos	58.4	60.7	110.6a	114.0
Maize/velvet bean	58.3	63.6	101.6a	122.8
Maize/sunnhemp	59.9	61.6	125.9b	115.0
Maize/fishbean	57.8	62.4	118.0b	118.4
Sole maize	59.5		117.7b	
LSD (P < 0.05): Intercrop x Time	NS		14.5	
CV%	6.5		8.1	
Time of planting	58.62	62.06		
LSD (Time) (P < 0.05)	3.0			

PLST - Legumes planted at the same time as maize

PTWL - Legumes planted two weeks after maize

DAP - Days after planting

Means in the same column followed by the same letter are not significantly different

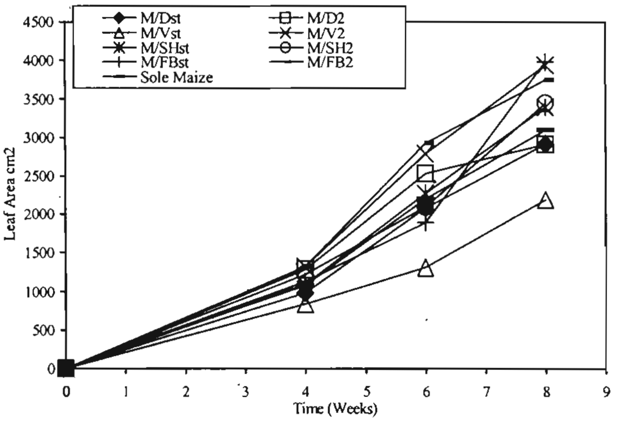

Figure 1. Effect of green manure and time of green manure planting on leaf area of maize in maize/legume intercrops

Key:

M/Dst - Maize and Dolichos planted at the same time, M/D2 - Maize and Dolichos planted after 2 weeks, M/Vst - Maize and velvet beans planted at the same time, M/V2 - Maize and Velvet beans planted after 2 weeks, M/FBst - Maize and Fish beans planted at the same time, M/FB2 - Maize and Fish bean planted after 2 weeks, M/SHst - Maize and Sunnhemp planted at the same time, M/SH2 - Maize and Sunnhemp planted after 2 weeks

Table 2. The effect of time of planting green manure legume and type of maize/legume intercrop on maize leaf area (cm²) 6 WAP.

Intercrop	Maize leaf area	
	Planted at same time	Planted 2 weeks after maize
Maize/dolichos	2077a	2529
Maize/velvet	1311b	2790
Maize/sunnhemp	2269a	2094
Maize/fishbean	1891a	2925
LSD (P < 0.05)	753	
SED	365	
Time of planting	1887	2584
LSD (P < 0.05)	377	
SED	183	
CV%	23	

Means followed by the same letter in a column are not significantly different (P < 0.05).

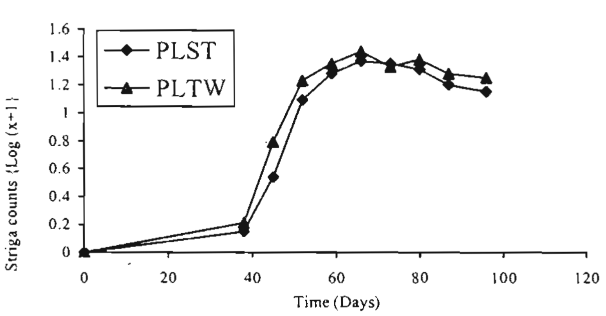

Figure 2. Effect of time of planting green manure legumes on *Striga*

Table 3. The effect of intercrop type and time of planting of green manure legumes on *Strigc asiatica* dry weight (g/pot)

Intercrop	*S. asiatica* dry weight (g/pot)	
	Planted simultaneously	Legumes planted 2 weeks later
Maize/dolichos	0.24	0.26
Maize/velvet bean	0.05	0.13
Maize/sunnhemp	0.26	0.49
Maize/fish bean	0.17	0.50
Significance (P < 0.05), (Intercrop*Time)	NS	
SED	0.20	

Grain yield. There were no interaction effects of type of intercrops and their time of planting on maize yield. Maize/dolichos and maize/velvet bean resulted in higher yields when legumes were planted two weeks later, although this was not significant. The opposite was true for maize/sunnhemp and maize/fish bean (Table 4).

Field Experiment at Mlezu

The rainfall distribution at Mlezu is in Figure 3. The experiment was established during the second week of December. This was followed by poor rainfall distribution in February where 60 mm of rainfall fell on one day during the month. The subsequent months also had a very low rainfall frequency. The experiment was severely affected.

Striga asiatica counts. Although not significantly different, legumes planted two weeks after maize (PLTW) allowed slightly higher *Striga asiatica* counts of 0.25 compared to 0.06 for simultaneous planting in the field at Mlezu (80 days after planting). Legume intercrops showed that they do not differ in the way they suppress *S. asiatica* emergence. Time of establishment of the legume is more important.

Discussion

The study demonstrated that differences in planting date for the component crops influenced competition between component crops in the green manure legume/maize intercrops (measured as leaf area and plant height). Planting legumes and maize at the same time increased inter species competition for growth limiting factors, resulting in reduced maize leaf area and maize plant heights. Where the planting of maize and legumes was staggered, interspecies competition was reduced and maize attained higher leaf areas and height than with simultaneous planting. Velvet bean reduced maize leaf area. This could be attributed to velvet bean's ro-

Table 4. The effect of intercropping and time of planting of green manure legumes on maize yield (g/pot)

Intercrop	Maize grain yield (g/pot)	
	PLST	PLTW
Maize/dolichos	2.1	2.7
Maize/velvet bean	1.4	11.9
Maize/sunnhemp	12.4	7.9
Maize/fish bean	5.2	4.9
Significance (P < 0.05), (Intercrop*Time)	NS	
SED	7.0	

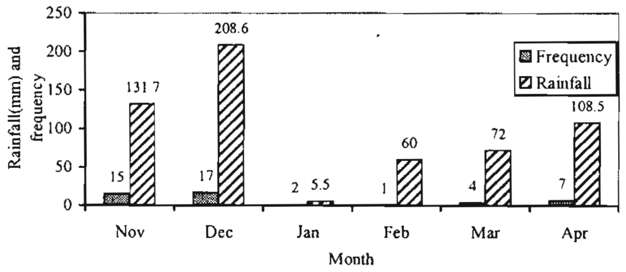

Figure 3. Monthly rainfall distribution and frequency at Mlezu (2001/2002)

bust growth habit that enhances its competitive ability for growth limiting factors. Gilbert (1998) reported that *Mucuna* can be excessively competitive with maize because it has an aggressive climbing growth habit. When maize is intercropped with velvet bean and established at the same time, interspecies competition increases, particularly at later stages of growth. For instance, there was no difference in maize leaf area between the sole maize and the intercropped maize at two and four weeks after planting. During this period, interspecies competition of the intercrop appears not affect maize leaf area. Probably plants were too young to interfere with each other but as they grow, competition begins that reduces leaf area at later stages of growth.

When legumes were planted two weeks later, *S. asiatica* counts were generally higher than when legumes were planted at the same time as maize. This trend was also observed in the field experiment. Legumes caused suicidal germination of *S. asiatica* when planted at the same time and this could have reduced the *S. asiatica* numbers. When maize and legumes were planted two weeks apart, more *S. asiatica* plants emerged as the parasite that germinated from the maize stimulant successfully attached to the maize roots. Carsky et al (1994) postulated three reasons for reduction of *Striga* when intercropped with cowpea. These include suicidal germination of *Striga*, release of nitrogen into the soil and shading which consequently lowers soil temperature. These reasons were also supported by Musambasi et al (2002) who suggested that legumes could provide shade which smother and kill *S. asiatica*. These reasons can therefore be used to extrapolate the results obtained. Planting legumes and maize at the same time, allowed legumes to quickly develop a crop canopy that produced a shading effect, lowering the soil temperatures that could have affected the emergence of *S. asiatica*. Babiker et al (1993) found that the density of *Striga hermontheca* was reduced in a sorghum-dolichos intercrop. Probably maize is a better germination stimulant than the legumes tested. The *S. asiatica* that germinates due to the legumes is of no significance as compared to *S. asiatica* that maize stimulates and supports. However, the time of planting the green manure makes the difference in terms of *S. asiatica* numbers. Similar trends were observed with *S. asiatica* dry weights.

There was no grain yield from the field experiment owing to the poor rainfall distribution. Yield from the pot experiment was not influenced by the green manure legumes or their time of planting. It would be interesting to find out how these factors influence yield in a normal season under field conditions. The competitive effects of the green manure legumes experienced during the fourth to the sixth week after planting were not enough to significantly reduce yield in the pot experiment.

Recommendations

Green manure legumes intercropped with maize should be planted two weeks later to reduce competition among component crops. For *S. asiatica*, the green manure legumes should be established at the same time with maize in a field heavily infested with *S. asiatica*. A legume that does not compete with maize for resources should be planted at the same time as maize. The experiment needs to be conducted again in another season to get conclusive results in the field.

Acknowledgements
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LEGUMINOUS AGROFORESTRY OPTIONS FOR REPLENISHING SOIL FERTILITY IN SOUTHERN AFRICA

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Abstract

Nitrogen is the major nutrient limiting maize production in Zambia and Southern Africa. Removal of subsidies on inorganic fertilizers made them very expensive and most farmers cannot afford them. Short duration planted fallows using a wide range of leguminous trees have been found to replenish soil fertility and increase subsequent maize yields. Species such as Sesbania sesban, Tephrosia vogelii *and* Cajanus cajan *have been found excellently suited for planted fallow technology. These improved fallow crop rotations are being adopted by small-scale farmers in Eastern Zambia. Since the seminal paper of Kwesiga and Coe (1994), research has been done to understand how the planted tree fallows replenish soil fertility and improve maize yields.*

A wide range of species has been screened as alternatives to sesbania fallows to overcome some of the limitations of sesbania. Species such as Gliricidia sepium, Leucaena leucocephala *have maintained maize yields of 3 t/ha over 8 years of cropping when sesbania fallows yields declined to 1.1 t/ha after 3 years of cropping. The selection criteria for good fallow species are high biomass production and litterfall. Maize yields after fallows were highly correlated to biomass and litterfall yields. High quality biomass, which is low in lignin, polyphenol and high in N, is needed for higher maize yields. Mixing of gliricidia and sesbania fallows resulted in higher maize yields compared to single species fallows (3.0 vs. 1.8 t/ha). Mechanisms on how mixed fallows work need further investigation.*

Preseason inorganic N (NO_3 +NH_4) was highly correlated with maize yield ($r^2 = 0.62$) and this could be used to select fallow species and management practices. Nutrient budgets of N, P and K showed over 8 years that a positive balance of N and P was maintained for coppicing fallows while a negative balance of K started showing from the fourth year onwards on fertilized maize, gliricidia, leucaena and sesbania fallows. This points to the need to use inorganic fertilizers such P and K to supplement N supply from leguminous fallows. Improved fallows increased infiltration, reduced runoff, increased water storage, and reduced soil loss. The order was sesbania = tephrosia > natural fallow = maize + fertilizer. The biophysical limits of most fallow species and other emerging issues such as pests and diseases, the need to inoculate with rhizobium, amount of N fixed by different species and provenances and soil acidification under improved fallows are under further research.

Biomass transfer technology using biomass from leguminous trees was evaluated on maize and vegetable production in the dambos (wetlands). Maize and vegetable yields were significantly increased by application of high quality biomass from gliricidia and leuceana. However, financial analysis showed that it is not viable to apply biomass on a low value crop like maize. Biomass transfer was economically viable on high value crops such a vegetables.

Key words: Eastern Zambia, improved fallows, soil fertility, nutrient budgets, nitrogen fixation and sustainability

Introduction

Soil infertility is now increasingly recognized as the fundamental biophysical root cause for declining food security is smallholder farmers of sub-Saharan Africa (Sanchez et al. 1997). Maize is a staple food crop in Southern Africa. Nitrogen is the major nutrient that limits maize productivity, with phosphorus and potassium in limited cases. Although inorganic fertilizers are used in the region, the amounts applied are normally insufficient to meet crop demands due to high costs and uncertain availability. Most countries in southern Africa have developed fertilizer recommendations for major crops, sometimes with regionally specific adaptations. However, the amount of fertilizer used in southern Africa is very small in comparison to other parts of the world, with the highest rates found in a country like Zimbabwe in the commercial sector. For most smallholders, fertilizer use is as low as 5 kg/ha/ year (Gerner and Harris, 1993). While the need for increased use of inorganic fertilizers in southern Africa is clear, there are problems with an approach based exclusively on inorganic fertilizers where water supply is limited and variable. In many areas outside the higher rainfall zones or away from irrigated areas, any sensible farmer will use expensive mineral fertilizer with caution and supplement with organic sources. In most areas, fertilizer is therefore used mainly on home fields, gardens or high value crops such as cotton and vegetables.

While the need for increased fertilizer use in Southern Africa is apparent to all, the challenge of achieving this is very great. A high external input strategy cannot rely on fertilizer-seeds-credit packages, without addressing other requirements for successful uptake of green revolution technologies, including water management, credit systems, infrastructure, fertilizer manufacture and supply and access to markets. Most African conditions are unlike the plains of Asia so that the approaches which produced such successes there are not easily transferable to the African continent. Given the acute poverty and limited access to mineral fertilizers an ecologically robust approach of improved fallows is discussed in this synthesis. This approach is a product of many years of agroforestry research and development by ICRAF and its partners in southern Africa.

Improved Fallows

Improved fallows and their topology

Improved fallows are the deliberate planting of fast-growing species, usually wood tree legumes, for rapid replenishment of soil fertility. Fallows are as old as agriculture in southern Africa. Grass fallows are a common feature of the farming systems in the sub humid and semiarid zones of the region. Improve fallows were not a major area of research during the green revolution due to the focus to eliminate soil constraints by use of mineral fertilizers. With the development of the second soil fertility paradigm based on sustainability considerations (Sanchez, 1994), the biological dimensions of soil fertility began to receive increasing attention and research on improved fallows has increased since the mid 1980s. Reported work includes Kwesiga and Coe (1994), Drechsel et al. (1996), Rao et al. (1998) and Snapp et al. (1998). Large-scale adoption of short-term improved fallows by farmers is now taking place in southern Africa and east Africa. The main species used are legumes of the genus *Sesbania, Tephrosia, Leucaena, Gliricidia, Crotalaria* and *Cajanus.*

Non-coppicing fallows

Since the seminal work of Kwesiga and Coe (1994) on *Sesbania* fallows, a lot has been learnt about the performance of improved fallows. There has been extensive testing of fallows on farm to determine the maize productivity and processes that influence fallow performance. The performance of *Sesbania* and *Tephrosia* in a wide range of biophysical conditions is shown on Table 1. Improved fallows of two-year duration with both species significantly increased maize yields well above unfertilized maize (which is a common farmer's practice). Fertilized maize performed better than improved fallows in most cases. It is very clear from these results that the residual effects of fallows on maize yield declined after the second year of cropping. In a third year of cropping, maize yields were similar to unfertilized maize. Farmers have asked researchers how can they extend the residual effects of fallows beyond two years of cropping. Suggestions have included applying low rates of inorganic fertilizer in the second or third year of cropping to increase residual effects. Alternatively, farmers can use species of trees which coppice after cutting and use coppice regrowth to increase residual effects.

Coppicing fallows

Most of the work on improved fallows has concentrated on *Sesbania sesban,* but this species has drawbacks. When cut at fallow termination, which is 2-years of growth, it will not resprout or coppice. Hence *Sesbania* fallows are called non-coppicing fallows. Non-coppicing species include *Tephrosia vogelli, Tephrosia candida, Cajanus cajan* and *Crotalaria spp.* In the case of *Sesbania* farmers must rely on a

Table 1. Maize grain yield after *Sesbania sesban* and *Tephrosia vogelii* fallows on farmers' fields in eastern Zambia during 1998-2000

Fallow species	Maize grain yield t ha^{-1}			
	Land use system (LUS)	Year 1	Year 2	Year 3
Farmers testing *Sesbania sesban* fallows	Sesbania fallow	3.6	2.0	1.6
	Fertilized maize	4.0	4.0	2.2
	Unfertilized maize	0.8	1.2	0.4
	LSD (0.05)	0.7	0.6	1.1
	Number of farmers	8	6	4
Farmers testing *Tephrosia vogelii* fallows	Tephrosia fallow	3.1	2.4	1.3
	Fertilized maize	4.2	3.0	2.8
	Unfertilized maize	0.8	0.1	0.5
	LSD (0.05)	0.5	0.6	0.9
	Number of farmers	17	9	5

fresh supply of seedlings or seed reserves to generate their fallows. Trials at Msekera Research Station, Zambia have shown that natural regeneration of *Sesbania* fallows through seed reserves is possible, but highly erratic. Farmers therefore prefer to reestablish fallows from bare-rooted seedlings.

The residual effects of *sesbania* fallows on subsequent maize yields have been shown to be high for two or three seasons, but they will start to decline rapidly in the third season (Table 1). This may be related to depletion of soil nutrients and deterioration in soil chemical and physical properties. It can be hypothesized that fallows with coppicing species will increase residual effects beyond 2 to 3 years, because of the additional organic inputs derived each year from coppice regrowth. Coppicing species include *Gliricidia sepium, Leucaena leucocephala, Calliandra calothyrsus, Senna siamea* and *Flemingia macrophylla*. An experiment was established in the early 1990's at Msekera Research Station to test this hypothesis. The species tested were *Senna siamea, Gliricidia sepium, Leucaena leucocephla* and *Flemingia macrophylla*, which were compared with grass fallows, and continuous maize with or without recommended fertilizer as additional controls. The experiment has been cropped for 8 seasons during which maize and coppice growth were monitored (Figure 1).

The species showed significant differences in coppicing ability and biomass production (Table 2). *Leucaena, gliricidia* and *Senna siamea* had the highest coppicing ability and biomass production while *calliandra* and *flemingia* performed less. *Sesbania,* as expected, did not coppice. The trends in maize yields over the 8 seasons are shown in Figure 1. Maize yields were high for the first 3 seasons and declined to the same level as control plots for *sesbania*. *Flemingia* and *calliandra* showed low maize yields over years. There were no significant differences in maize grain between *gliricidia* and *leucaena* fallows over the seasons.

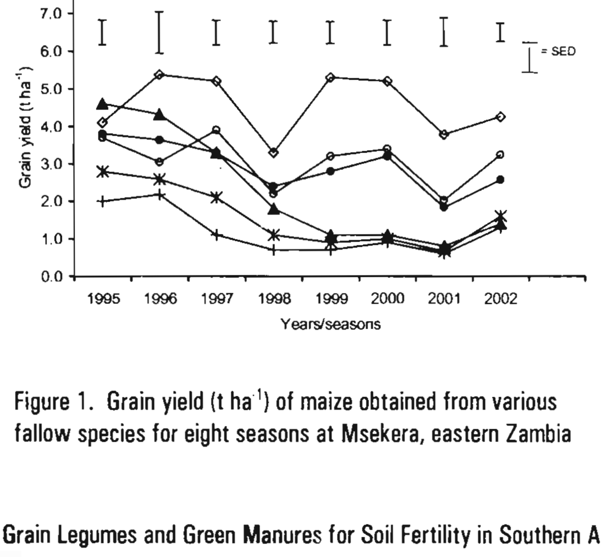


Figure 1. Grain yield (t ha^{-1}) of maize obtained from various fallow species for eight seasons at Msekera, eastern Zambia

The effects of different fallow species on maize yield can be explained partly by the different amounts of biomass added and the quality of the biomass and coppice regrowth during the dry season. Species such as *leucaena* and *gliricidia* have good coppicing ability and produce large amounts of high quality biomass, with high nitrogen content and low contents of lignin and polyphenols. Biomass with low lignin and polyphenols and high N release N rapidly, resulting in higher maize yields. Although *sesbania* produces high quality biomass, it's inability to coppice renders it unable to supply biomass during the cropping period leading to less prolonged residual effects. Species such *as flemingia, calliandra* and *Senna siamea* produce low-quality biomass, which is high in lignin, polyphenols and low in nitrogen. This will lead to N immobilization and reduced maize yields.

We hypothesized that the coppicing of *gliricidia* can utilize the residual soil water after maize harvest and recover soil nitrogen below the maize rooting depth during the long dry season from April to October. We monitored the soil water and nitrogen dynamics in all treatments for two seasons, 1997 to 1998, to test this hypothesis. This information will be used to simulate the long-term trend of maize yield, water and nitrogen dynamics using the WaNuLCAS model. Theoretical simulations indicated that *gliricidia* coppicing could utilize enough residual soil water in an average rainfall year of 980 mm/year to produce 2-4 t/ha of tree biomass and increased maize yield.

At the end of the dry season, soil moisture profiles confirmed that the coppicing *gliricidia* treatment utilized about 40 mm more water, primarily from below 75 cm soil depth, than in either the *sesbania* or continuous cropping treatments. This is probably an under estimation of the total deep uptake of residual water by the coppicing *gliricidia* since soil wa-

Table 2. Total seasonal coppice biomass (t ha^{-1}) recorded from various fallow species at Msekera, eastern Zambia during 1995-2002

	1996	1997	1998	1999	2000**	2001	2002
C. calothyrsus	0.3	0.4	0.2	0.4	0.6	0.4	0.6
S.siamea	2.8	2.1	1.6	1.7	1.8	1.2	2.2
F. mycrophylla	0.6	0.6	0.3	0.6	0.7	0.4	0.5
G. sepium*	1.7	1.5	1.3	1.1	3.1	1.4	1.2
L. leucocephalla*	3.5	2.6	1.7	2.8	3.4	2.2	1.9

*leucaena has more twig biomass added to the system than *Gliricidia* which also has low survival

** Biomass cut in 2 months interval (Nov, Jan & Mar) normal- Nov, Dec & Jan) ter content at 180 cm was still well below that of the other treatments. Deeper access tubes are required to determine the actual depth of water extraction by *gliricidia* roots. Based on the amount of biomass produced by *gliricidia,* we would expect the uptake of an additional 40 mm of water, i.e. rooting depth would have to go beyond another metre deeper.

This trend in the soil water profile between the three treatments was maintained even after five months with a total of 767 mm of rain, indicating the maize crop in the *gliricidia* treatment used more water than in the other two treatments. In addition, the high soil water content in both the *sesbania* and no fallow treatments indicate that nitrogen leaching can be a serious problem during this rainy period in both the *sesbania* and no fallow treatments. Indeed, measurements of inorganic nitrogen profiles for all three treatments confirmed substantial differences in N levels below 75 cm depth, with maximum concentrations in the no fallow treatment, followed by the *sesbania* and *gliricidia* treatment (Figure 2). These findings indicate that coppicing *gliricidia* provides a much more sustainable system than the *sesbania* fallow systems because of its ability to utilize residual soil water and to prevent N leaching in such environments.

We have concluded that *gliricidia* and *leucaena* have potential as coppicing fallows. Cumulative maize yield of these fallows is greater than from *sesbania* after 4 years of cropping. This is because of the constant nutrient replenishment obtained from harvesting coppice regrowth. We will continue the trial for another 5 seasons to test the sustainability of coppicing fallows in terms of nutrient budgets such as NPK. In addition, we have established on farm trials to evaluate responses widely and screen more coppicing species.

Mixed fallows

Improved fallow systems with shrub legume species like *sesbania* have become a key agroforestry technology for soil fertility management in southern Africa and western Kenya. Large increases in maize yields have been reported following short duration (9-24 months) fallows with single species. *Sesbania* has been the main focus for improved fallows for its ability to add huge amounts of high quality biomass and fuelwood provision. The dependence on a few successful fallow species has revealed some drawbacks. *Sesbania* is susceptible to root-nematode and Mesoplatys beetle. Introduction of new species has led to the outbreak of new pests and diseases as observed with *Crotalaria grahamiana* in western Kenya (Cadisch et al. 2001). Thus there is an urgent need to diversity the species and fallow types to farmers. Mixing species with compatible and complementary rooting or shoot growth patterns in fallows may lead to a more diverse system and maximize above and below ground growth resource utilization. Undersowing herbaceous legumes under open canopy species may use more photosynthesis radiation by the whole canopy and increase primary production.

Mixing shallow-rooted species with deep-rooted species can enhance the soil water and nutrient uptake zone within the soil profile. More importantly, it will enhance utilization of subsoil nutrients, e.g. nitrate lost through leaching. Mixing species in fallows may also reduce the risk of failure with fallow establishment, in case one species is susceptible to water stress, diseases and pests. Multiple products obtained from mixed fallows and increased biodiversity of the system are other positive characteristics that make the whole system more attractive. We tested a variety of mixed fallows of tree legumes or tree legumes with herbaceous legumes to test the above stated hypotheses.

Mixing coppicing fallow species such as *Gliricidia sepium* and a non-coppicing species (*Sesbania sesban*) significantly increased maize yields compared to single species fallows (Figure 3). However mixtures of noncoppicing species did not increase maize yield compared to sole species. The mixture of cop-

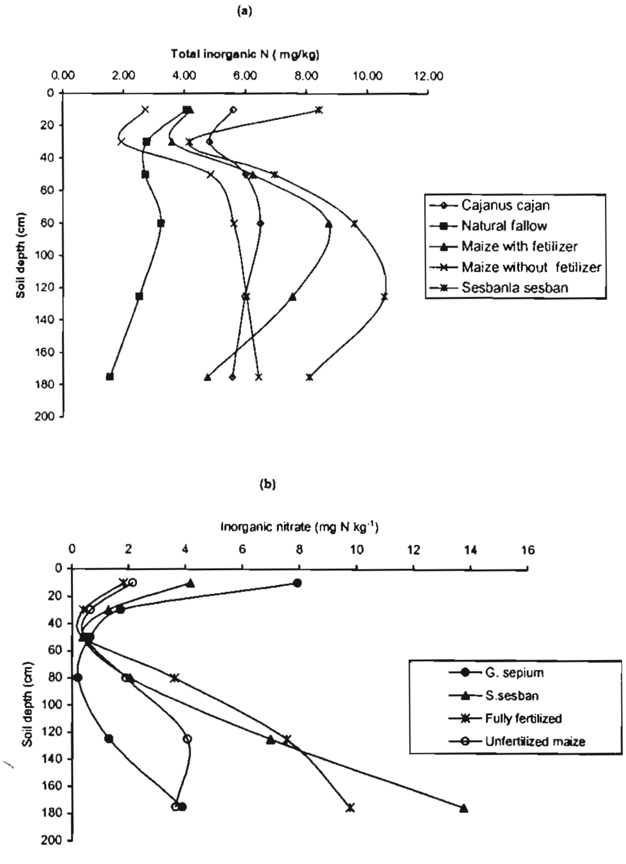


Figure 2. Total inorganic nitrogen (a) and inorganic nitrate (b) (mg / kg soil) as affected by two year fallow species and soil depth at Msekera, eastern Zambia in February 1998 and February 2001

picing and noncoppicing species reduces the level of subsoil nitrate and controlled *mesoplatys* beetles. However mixing *gliricidia* or *tephrosia* or *sesbania* with herbaceous legumes such as *mucuna* or *archer dolichos* reduced tree growth and hence maize yield. These mixtures also lead to the build up of *mesoplatys* beetle, which may have led to a larger attack of *sesbania* by the beetles (Sileshi and Mafongoya, 2002).

Prediction of improved fallows performance

Many studies have shown a 3 to 4–fold increase in maize grain yields after two year improved fallows. Most of these studies were conducted under research station conditions. However, when improved fallows are tested in a wide range of environmental conditions there is variability in maize grain yields. The explanations advanced for this variability is based on trial and error. There is need for a predictive understanding of how fallows perform in different agroecological conditions.

The work done for many years has shown how organic decomposition and nutrient release is affected by the levels of polyphenols, lignin and nitrogen contents of the organic inputs (Mafongoya et al. 1998). Recently we have found also that maize yields after fallows with various tree legumes were negatively related to the L+P: N ratio (Figure 4). Fallow species with high N, low lignin and low polyphenols such as *gliricidia* and *sesbania* gave higher maize yields compared to species such as *flemingia, calliandra* and *senna*. This work has clearly shown that it is not the quantity of polyphenols which is critically important but also the quality of the polyphenols as measured by their protein binding capacity (Mafongoya et al. 2000). Legume species for improved fallows can be screened for their suitability based on the above characteristics.

Soil inorganic N before a cropping season is an accepted test for soil N for soil productivity. Results of our studies in Southern Africa show that preseason inorganic N can also be an effective indicator of plant available N after different improved fallows. Our results indicate that preseason inorganic N (NO_3 + NH_4) can be more related to maize yield than preseason NO_3 alone in a tropical soil with a pronounced dry season (Figure 4). Large amounts of NH_4 can accumulate during a dry season, and it may not be nitrified when the soil is sampled at the beginning of the rainy season. We concluded that preseason inorganic N is a relatively rapid and simple index that is related well to maize yield on N-deficient soils and hence it can be used to screen fallow species and management practices.

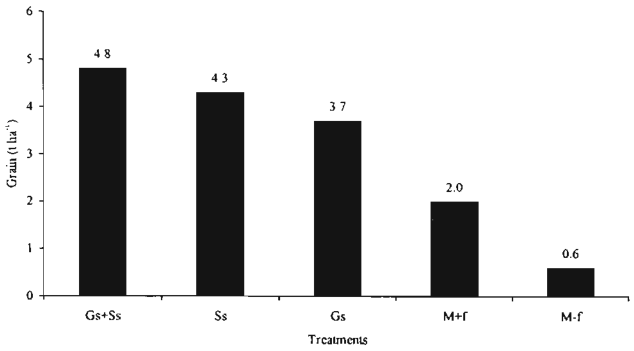


Figure 3. Grain yield (t ha^{-1}) of the first crop of maize after pure and mixed fallows at Kalunga in 2002

Improved fallows of *S. sesban* tested under a wide range of conditions showed a strong linear relationship between maize yield and standing biomass at fallow clearance (r^2=0.50). Preseason inorganic was also related to standing biomass (r^2= 0.60) and standing biomass was related to clay content of the sites (r^2=0.50). From these studies the impact of improved fallows on maize yield were clearly related

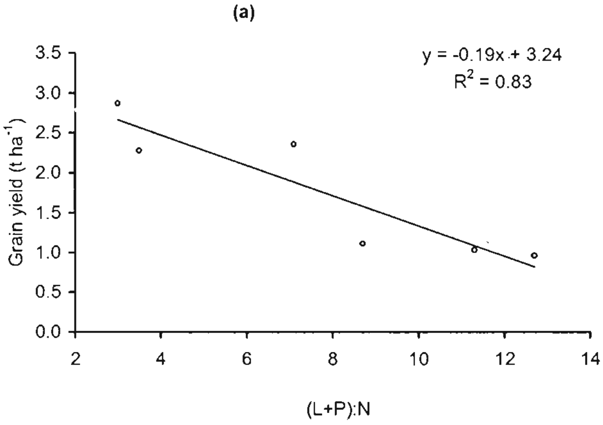


Figure 4a. Relationship between leaf biomass quality and maize grain yield after three year fallows of *S. sesban, G. sepium, L. leucocephala, S. siamea, F. mycrophylla* and *C. calothyrsus* at Msekera, eastern Zambia during 1998.

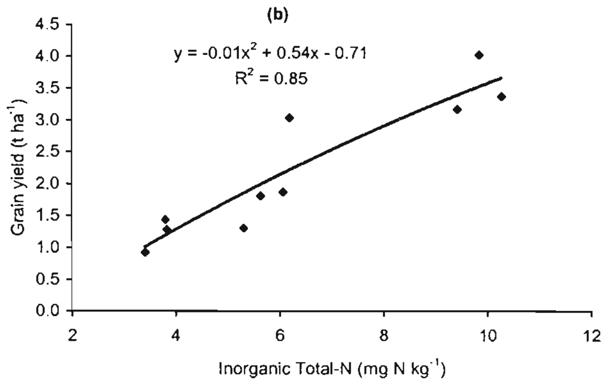


Figure 4b. Relationship between pre-season top soil (0-40cm) total inorganic N and sixth maize crop grain yield after three year fallows of *S. sesban, G. sepium, L. leucocephala, S. siamea, F. mycrophylla, C. calothyrsus* N. fallow, Fully fertilized maize, Unfertilized maize and Maize/Groundnut rotation at Msekera, eastern Zambia during 2001.

to amount of biomass, quality of biomass in terms of L+P: N ratio, litter fall, and preseason inorganic N. These results were in agreement with those reported by Mafongoya et al. 1999).

Based on these results we can safely conclude that the main predictors of fallow performance are quantity of biomass, quality of the biomass, preseason inorganic N and texture on the soil. The relevance of these predictors needs to be tested over a wide range of conditions and with different fallow species.

Soil Chemical Properties

The major soil chemical changes that take place under tree fallows are increases in labile pools of SOM, N stocks, exchangeable cations and extractable P (Rao et al. 1998). Details of the mechanisms of soil improvement by tree fallows were reviewed by (Buresh and Tian, 1998). In theory, planted tree fallows are expected to improve soils faster than natural fallows since the land is completely covered by fast growing leguminous trees for 2 to 3 years. However the magnitude of these soil improvements depends on tree species, length of fallow, soil and climatic conditions. In this section, we will concentrate on these changes as measured from experiments in southern Africa.

Biological nitrogen fixation and N cycles

The contribution of leguminous trees through N_2 fixation is well recognized, although not all legumes fix N_2. Nitrogen fixation in the humid and subhumid zones of Africa has been reviewed by Sanginga (1995). There has been little work on quantification of N_2 fixation by trees in southern Africa. This work has proved to be difficult due to constraints in the methodologies for measuring N_2 fixed. A series of multi-location trials have been set to measure the amount of N_2 fixed by different tree genera and provenances (Table 3) using the ^{15}N natural abundance method. The data on percent Ndfa shows high variability among provenances of the same species for N derived from atmospheric N_2 fixation.

Sanginga et al. (1990) found that percent Ndfa ranged from 37 to 74% for provenances of *Leucaena leucocephala*. The data shown in Table 3 falls within the range reported by Sanginga et al. (1990). These preliminary data show the huge potential of trees to fix N_2 and increase N inputs in N deficient soils. Our future analysis will focus on factors responsible for this variability in N_2 fixation across sites and how to optimize N_2 fixation under field conditions. Barrios et al (1997) measured availability of soil N following 2- and 3-year fallows a N- deficient soils in eastern Zambia. His results confirmed that tree fallows increase N availability compared to continuous cropping without fertilization. Subsequent N measurements down to 200 cm in the soil profile showed significant N inorganic accumulation at depth during the cropping phase (Figure 2).

These results show that improved fallows can create a very "leaky" N cycle after fallow clearance. Most of the N is leached beyond the rooting depth of maize and this N is released from organic inputs before peak N demand by maize. Hence there will be asynchrony between N release and N demand by maize. Consequently there is need to design systems which try to minimize N losses and increase N use efficiency, and cycling.

Based on those results we designed mixed fallows of coppicing species and noncoppicing species. The hypothesis is that the coppicing species will act as a permanent "safety net" for N when the noncoppicing fallows are cut due to resprout growth and deep root system in the soil. Results of *gliricidia and sesbania* mixed fallows have shown higher maize productivity and efficient N cycling compared to single species fallows (Figure 3).

Soil acidification and cations

There are several reports on soil pH and improved fallows. Topsoil pH decreased under fallows of *Acacia auriculiformis* (Drechsel et al. 1996). However (Jonsson et al. 1996) found no changes in soil pH after fallows. Our results over a 10-year period showed significant decrease in topsoil soil pH, 0–60 cm and an increase in soil pH with depth (Figure 5). This decrease in topsoil pH and increase in soil pH is attributed to leaching of NO_3 and cations such as magnesium as shown in Figure 6. The movements of cations from the topsoil were also confirmed by low CEC in 0–20 cm (6.25 compared with 9.50) in the 20-100 cm soil profile. These pH changes, which will take place after fallows, may have little effect

Table 3. Biological nitrogen fixation (%BNF) of coppicing species/ provenances across three sites in eastern Zambia after 1 year of growth

	Kalichero		Kalunga		Masumba	
Treatment	%BNF	N kg/ha	%BNF	N kg/ha	%BNF	N kg/ha
A. angustisma	52.1	210.4	61.8	201.4	54.8	260.8
C. calothyrsus	48.4	81.4	44.1	214.4	48.7	193.
G. sepium	79.2	212.4	71.4	408.4	70.8	297.5
L. collinsii	74.7	303.2	57.2	236.7	102.1	475.9
L. diversifolia 35/88	77.5	196.8	33.8	88.6	50.0	161.1
L. diversifolia 53/88	58.4	121.5	14.0	40.5	46.9	112.6
L. esculenta 52/87	70.9	99.3	46.6	110.1	46.7	274.5
L. esculenta-Machakos	84.7	223.6	35.2	120.2	69.0	538.0
L. pallida	58.6	87.8	33.7	125.2	44.7	168.1

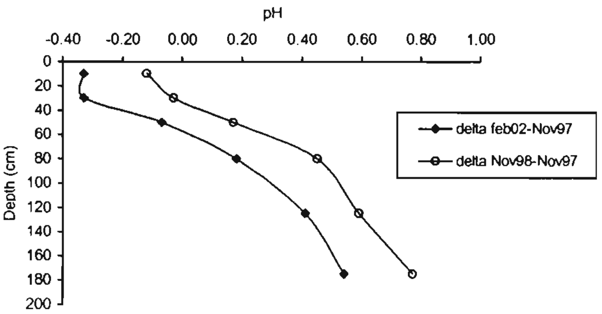


Figure 5. Changes in soil pH as affected by two-year fallow species and soil depth at Msekera, eastern Zambia

on maize productivity in base rich soils. However their long term effects on acidic, low–activity clay soils may have a major effect on crop yields and threaten the long-term sustainability of improved fallows. Management practices such as zero tillage after fallows and regular application of lime may have to be adopted to deal with such problems of decrease in pH and cation leaching.

Soil carbon and improved fallows

The debate on carbon and global warning has gained momentum. Of late, there has been increased scientific interest in measuring carbon sequestration in different land use systems to mitigate climate change issues. Agroforestry land use systems have been cited to sequester the most soil C without a lot of scientific evidence. We monitored soil C in long-term trials with improved fallows. There were significant increases in soil carbon in the topsoil as compared to deep horizons (Table 4). These results are in agreement with those of Onim et al.; (1990) in western Kenya using improved fallows. Of scientific and practical importance is how is the carbon protected against loss after fallow clearance. Our research program is looking how different soil aggregates store C and how soil aggregation is affected by soil texture and fallow management over the long term. This will enable us to model carbon dynamics and climate change.

Table 4. Amount of organic carbon (%) measured in different soil depths under a two-year non-coppicing fallow species at Msekera, eastern Zambia

Soil depth (cm)	Year 1997	2002	Percent increase
0-20	0.95	1.12	17.89
20-40	0.78	0.94	20.51
40-60	0.61	0.77	26.23
60-100	0.51	0.55	7.84
100-150	0.36	0.49	36.11
150-200	0.28	0.37	32.14
SED	0.05	0.06	20.00

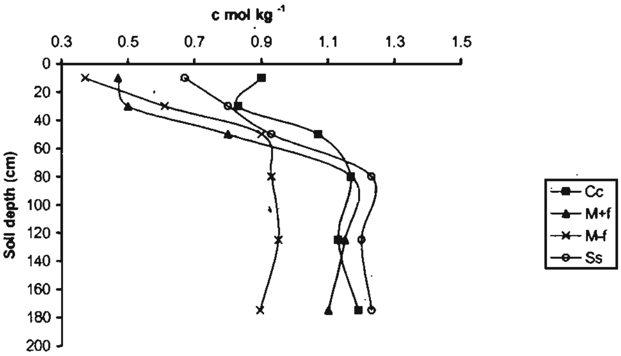


Figure 6. Soil magnesium (c.mol kg^{-1}) as affected by two year fallow species and soil depth at Msekera, eastern Zambia in February 1998

Phosphorus is a major nutrient limiting maize productivity after nitrogen in Southern Africa. Our working hypothesis was that planted trees in fallows will make phosphorus more available to soils that are marginally deficient in P. Results over 10 years of work show that there are no significant differences in extractable P under different fallows. This is consistent with results reported by (Adejuwan and Adesina 1990). However it may be important to look at different P fractions under improved fallows rather than total extractable P as suggested by (Nziguheba et al. 2002). The inability of a fallow system to meet P requirements of crops highlights the need to use inorganic P sources where soils are deficient in P. This will ensure high productivity of the soils after the high addition of N from the fallows.

Soil Physical Properties

The ability of trees and biomass from trees to maintain or improve soil physical properties has been documented. Alley cropping can improve the soil physical conditions on alfisols (Hullugalle and Kang 1990). Plots alley cropped with four hedgerow species showed lower bulk density, higher porosity and water infiltration rates compared with a no-tree treatment (Mapa and Gunasena 1995). Tree fallows can improve soil physical properties due to addition of large quantities of litter fall, root biomass, root activity, biological activities and the roots leaving macropores following their decomposition (Rao et al. 1998).

The percentage of soil aggregates >2 mm was significantly ($P<0.05$) affected by the duration of cultivation. At fallow clearing in November 1998, aggregates ranged from 83% for *sesbania* to 61% for continuous maize without fertilizer. After six months of cropping the decrease in aggregates > 2 mm was highly significant under *sesbania* (18%) compared with the natural fallow, which did not lose its aggregate stability. The decrease in aggregate stability was more pronounced under *sesbania* and maize without fertilizer as compared with *cajanus* and maize with fertilizer. Under a *sesbania* fallow system, the improvement in soil structure is more evident and this is reflected by results from our time to runoff studies. Time to runoff after fallow clearing was in the order of: natural fallow > *S. sesban* > fertilized maize. After one season of cropping, time to runoff decreased in all treatments except that the natural fallow maintained the longer time to runoff, reflecting good maintenance of aggregate stability.

Through rainfall simulation studies we evaluated effects of improved fallows on runoff infiltration soil and nutrient losses under improved fallows. Tree fallows of *sesbania, gliricidia* mixed with archer dolichos increased infiltration rates significantly compared with continuously fertilized maize plots (Figure 7). Fallows compared to no tree plots also significantly reduced soil loss (Table 5).
Improved fallows improve soil physical properties as evidenced by increase in infiltration rates, increased infiltration decay coefficients, reduced runoff and soil losses. However these benefits are short lived and they decline rapidly during the first year of cropping. This was supported by increase in soil loss in the second year (Table 5) and decrease in infiltration rates as well (Figure 7). However, mixing a coppicing species like *gliricidia* and a herbaceous legume like archer dolichos maintained high infiltration rates and reduced soil loss over two years of cropping.

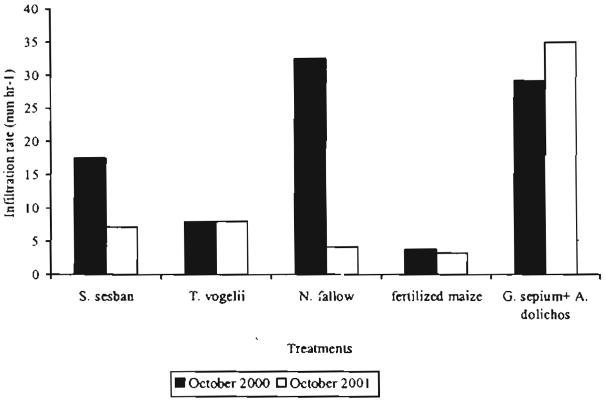


Figure 7. Infiltration rate under different fallows measured at Msekera (source; Nyamadzowo *et al* 2002)

Table 5. Soil loss (g/m^2) measured under various fallow species and maize at Kalunga Farmers Training Center in eastern Zambia

Treatment	October 2000	October 2001
Sesbania sesban	0.0	5.0
Tephrosia vogelii	4.5	15.8
Natural fallow	0.0	19.5
Fully fertilized maize	63.8	40.5
Siratro (*Macroptilium atropurpureum*)	0.0	0.7
LSD 15.3		

Source: Nyamadzowo *et al* 2002

Sustainability of Improved Fallows

Improved fallows with sesbania or tephrosia have been shown to give maize grain yields of 3 to 4 t/ha without any inorganic fertilizer addition. Palm (1995) showed that organic inputs of various tree legumes applied at 4 t/ha can supply enough nitrogen for maize grain yields of 4 t/ha. However, most of these organic inputs could not supply enough phosphorus and potassium to support such maize yields.

The question for sustainability is: Can improved fallows potentially mine P and K over time while maintaining a positive N balance? To answer that question we conducted nutrient balances on improved fallow trials at Msekera Research Station. These plots were under fallow–crop rotations for 8 years. The objectives of these studies on nutrient balances addressed the following questions:

- Can nutrient balances be used as land quality indicators?
- Can they be used to assess soil fertility status, productivity and sustainability?
- Can they be used as a policy instrument for the types of fertilizers to be imported or distributed to farmers?

The nutrient balances considered nutrients added through leaves and litter fall, which were incorporated after fallows as inputs. The nutrients in maize grain harvested, maize stover removed and fuelwood taken away at end of the fallow were considered as nutrient exports.

For all the land use systems, there was a positive N balance two years of cropping after the fallows (Table 6). Fertilized maize had the highest N balance due to the annual application of 112 kg N/ha for the past 10 years. However, unfertilized maize had lower balances due to low maize grain and stover yields over time. The tree-based fallows had a positive N balance due to BNF and deep capture of N from depth. These results are consistent with those of Palm (1995) that showed that organic inputs could supply enough N to support maize grain yields of 3 to 4 t/ha.

However in the second year of cropping (1999) the N balance was very small. This is consistent with our earlier results, which showed a decline of maize

Table 6. Nutrient balance (kg/ha) under two year non-coppicing fallow species at Msekera, eastern Zambia

	Nitrogen		Phosphorus		Potassium	
Land use systems	1998	1999	1998	1999	1998	1999
Cajanus cajan	27	5	21	8	13	-9
Sesbania sesban	22	5	39	24	-42	-32
Natural fallow	8	11	19	15	-10	-4
Fully fertilized maize	150	103	57	43	-19	-17
Unfertilized maize	31	11	29	20	19	-1

yields in the second year of cropping after two-year fallows. The huge amount of N supplied by fallows could be lost through leaching beyond the rooting depth of maize. Our leaching studies have clearly shown substantial inorganic N at depth under maize after improved fallows. These results imply that if cropping goes beyond three years after fallows there will be a negative N balance. Thus the recommendation of two years of fallows followed by two years of cropping is well supported by N balances and maize grain yield trends. Most of the land use systems showed a positive P balance. This can be attributed to low offtake of P in maize grain yield and stover. In addition, this site had a high phosphorus status. The trees could also have increased P availability through secretion of organic acids and the increased mycorrhizal population in the soil. These issues are under investigation at our site. In general, we have observed positive P balances over eight years. However this result needs to be tested on farm where the soils are inherently low in P.

Most land use systems showed a negative balance for K. For tree based systems, sesbania showed a higher negative K balance compared to pigeonpea. This is attributed to the higher fuelwood yield of sesbania with subsequent higher export of K compared to pigeonpea. The higher negative K balance for fully fertilized maize is due to higher maize and stover yield which exports a lot of potassium. This implies that the K stocks in the soil are very high and that K mining has not reached a point where it negatively affects maize productivity. However in sites with low stocks of K in the soil, maize productivity may be adversely affected.

Nutrient balances were conducted for coppicing fallows using *gliricidia* compared to non-coppicing fallows using *sesbania* for four cropping seasons after fallow clearance. *Gliricidia* fallows maintained a positive N balance. This was attributed to resprout growth, which was applied to maize as a source of nutrients and deep capture of N from depth by the well-established *gliricidia* rooting system. All land use systems showed a positive P balance. However from the third season of cropping onwards sesbania fallows, fertilized maize and *gliricidia* fallows had a large negative balance. This was attributed to removal of nutrients in stover maize or leaching of K from surface soils.

Overall, the tree based fallows maintained a positive N and P balance. However on low P status, a negative P balance would be expected. There was a negative K balance with most land use systems. It can be hypothesized that as we scale up improved fallows on depleted soils on farmer's fields, K and P balances are expected to be negative. This has implications for fertilizer policy. Compound D, which contains N, P, K, is the currently imported basal fertilizer for maize. If farmers adopt improved fallows on a wider scale these fallows will meet the N requirement of maize. Where there is K and P deficit farmers may not need to buy compound D because N is adequately supplied by fallows. They need only K and P as nutrients to supplement N in the fallows. This may require a shift in government policy on the type of fertilizer imported. There is also urgent need to conduct these nutrient budgets at the landscape level on farmer's fields to test the validity of these nutrient budgets.

Biomass Transfer Systems

This technology may be practiced in any of the following ways:

- transfer of leaf biomass produced from one field to another on the farm
- transfer of biomass produced outside the farm
- recycling of nutrients through livestock manure.

In Zimbabwe, farmers traditionally collect leaf litter from miombo secondary forest as a source of nutrients to maize (Nyathi and Campbell, 1993). In the long term, this practice is not sustainable because it mines nutrients from the forest ecosystems in order to build soil fertility in the croplands. Miombo litter collected is also of low quality and it may immobilize N instead of supplying N immediately to the maize crop (Mafongoya and Nair, 1997). An alternative means of producing high quality biomass is through the establishment of on-farm biomass banks from which the biomass is cut and transferred to crop fields in different parts of the farm. In western Kenya for example, the use of *Tithonia diversifolia, Senna spectabilis, Sesbania sesban* and *Calliandra calothyrsus* planted as farm boundaries, woodlots and fodder banks or found along the roads as a source of nutrients has proven beneficial in improving maize production (Maroko et al. 1998; Nziguheba et al. 1998; Palm, 1995; Palm et al. 2001). In a study by Gachengo (1996), tithonia green biomass grown outside a field and transferred into a field was found to be as effective in supplying N, P and K to maize as an equivalent amount of commercial NPK fertilizer, and in some cases maize yields were higher with tithonia biomass than commercial inorganic fertilizer. Recent work in Malawi (Ganunga et al. 1998) and Zimbabwe (Jiri and Waddington, 1998) have similarly reported tithonia biomass to be an effective nutrient source for maize.

Biomass transfer using leguminous species is a far much sustainable means of maintaining nutrient balances in maize-based systems as these trees are able to fix atmospheric N_2. Tithonia is not a legume, and it does not biologically fix atmospheric N_2. The transfer of tithonia biomass to fields, therefore, constitutes the cycling of nutrients within the farm and landscape rather than a net input of nutrients to the system. The continual transfer of nutrients from tithonia hedges to crop fields constitutes nutrient mining and might not be sustainable for long periods. Whereas the application of fertilizers to tithonia could ensure sustained production of tithonia, this is unlikely to be an option for resource-poor farmers. The integration of tithonia with N_2-fixing legumes may merit investigation.

Synchrony between nutrient release from tree litter and crop uptake can potentially be achieved in a biomass transfer system. The management factors that can be manipulated to achieve this are litter quality, rate of litter application, method and time of litter application (Mafongoya et al. 1998; 1999). However variability in climatic factors such rainfall and temperature makes the concept of synchrony an elusive goal to achieve in practical terms (Myers et al. 1994).

Although prunings from MPTs increased maize yield, cutting transporting and managing prunings on crop fields require high labour inputs (Jama et al. 1997; Jama et al. 1998; Mutuo et al. 2000). Where family labour is available at no additional cost, the technology can be profitable even where land is scarce (Jama et al. 1997; Mutuo et al. 2000). However, considering that farm labour is one of the most constraining inputs in smallholder agriculture, the associated cost makes this technology unattractive and may serve as a disincentive for its adoption by farmers. In monetary terms, the higher maize yield does not compensate for the high labour cost. In promoting this technology, farmers may require to be provided with additional resources to invest in labour and land. Most economic analyses have shown that it is unprofitable to invest in a biomass transfer system when labour and land are scarce. However, in areas where land is abundant and the prunings are applied to high value crops like vegetables, the technology is profitable (ICRAF, 1997).

Biomass transfer could find a niche for vegetable production in *dambo* areas of southern Africa. A *dambo* is a shallow, seasonally or permanently waterlogged depression at or near the head of a natural drainage network, or alternatively occurs independently of a drainage system (Chenje and Johnson, 1996; Breen et al. 1997). *Dambos* cover about 240 million hectares in sub-saharan Africa (Andriesse, 1986). They are some of the most productive natural ecosystems in the Southern African region. They provide water for domestic use, good soils for agricultural production, grazing grounds for livestock, fish and support a wide range of wildlife and birds (Raussen et al. 1995). *Dambos* are considered extremely vulnerable to poor agricultural practices, and hence *dambo* cultivation was illegal for instance in Zimbabwe. However, rising population pressure has caused the agricultural use of *dambos* to become increasingly important (Kundhlande et al. 1994). For example, vegetable gardens cover 15000-20000 ha (Bell et al. 1987) of the estimated 1.28 million ha of *dambos* in Zimbabwe.

However, without applying fertilizers or cattle manure smallholder farmers cannot produce vegetables successfully in some of the *dambos* (for example in eastern Zambia) that are degraded due to continuous cultivation for over 25 years (Raussen et al. 1995). The removal of subsidies and increase in interest rates in most of sub Saharan Africa has caused decline in inorganic fertilizer use, and this decline in the smallholder sector is even greater, suggesting that for many farmers the use of fertilizer is not a viable option any more. Cattle manure use could also become limited since not all farmers have animals to produce adequate quantities of manure. In addition, transport problems for the large quantities of manure needed and the spread of weeds due to the manure use may limit its utilization. Therefore, the use of biomass transfer in sustaining vegetable production in the *dambos* of southern Africa could be a viable option.

An experiment conducted with 43 farmers by Kuntashula et al (2003) showed that Gliricidia biomass transfer technologies produced cabbage, onion and subsequent maize yields comparable with the full fertilizer application (Tables 7 and 8). The biomass transfer technologies also recorded higher cabbage, onion and maize net incomes than the control, and required lower cash inputs than the fully fertilized crop (Figures 8 and 9). Like in maize based systems, net incomes of the biomass treatments in vegetable production were substantially reduced by the labour costs for pruning and incorporation of the biomass. However, in vegetables the high price of products more than compensated these costs. The study concluded that the use of gliricidia biomass

Table 7. Mean cabbage and onion yields (fresh weight) in dambos using inorganic fertilizers or organic inputs from manure, gliricidia and leucaena biomass in Chipata South district, 2001

Treatments	Cabbage yield (t ha^{-1}) n = 31	Onion yield (t ha^{-1}) n = 12
Manure 10 t ha^{-1} + half fertilizer	66.8	96.0
Fully fertilised	57.6	57.1
Gliricidia 12 t ha^{-1} †	53.6	79.8
Gliricidia 8t ha^{-1}	43.1	68.3
Leucaena 12 t ha^{-1}	32.6	--
Control	17.0	28.1
S.e.d (p = 0.05)	5.41	11.48

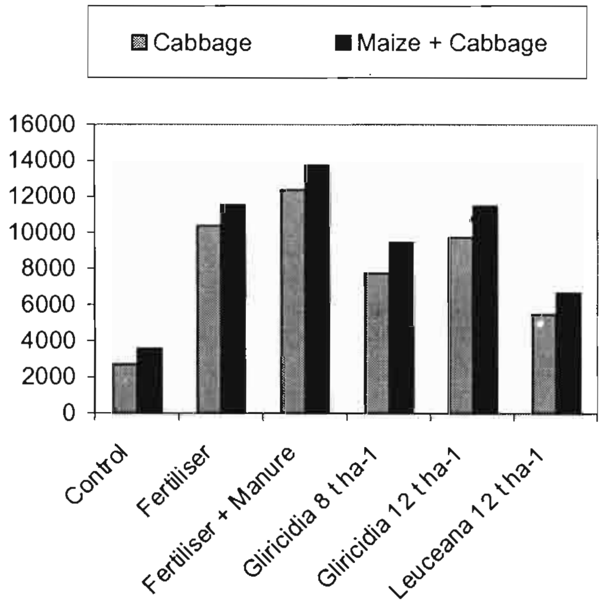
-- Leucaena 12t ha^{-1} was not used in onion trials

† Biomass treatments are reported on dry weight basis

N = Number of farmers participating in the experiment

transfer could be a viable alternative to inorganic fertilizer although farmers taking up the technology will however need adequate supply of labour.

The effectiveness of biomass transfer of nutrient sources using organic inputs from MPT species depends on their chemical composition (Mafongoya and Nair, 1997). These systems can meet the N requirement of most crops in smallholder farming systems. However, they cannot meet the requirement of P. There is need to apply inorganic sources of P in addition to organic sources. When biomass is also valued as fodder there is need to assess the trade off of applying it directly to the soil or feeding it to livestock and then applying the resultant manure.. There is evidence to indicate that depending on the quality of the biomass there may be no advantage in feeding it to livestock and then applying the manure as a source of N to crops (Mafongoya et al. 1999). However, in other instances, it has been shown that it is more advantageous to first feed the biomass to livestock and then apply the resulting manure to crops (Jama et al. 1997).



* Above net incomes are reported per hectare basis. Average actual area put to cabbage by a

Figure 8. Net income US$ ha^{-1})* from cabbage and subsequent maize on 31 vegetable gardens in Chipata South District in 2001

Table 8. Maize grain yields (t ha^{-1} at 13% moisture content) on residual plots in dambos after cabbage and onion production using inorganic fertilizers or organic inputs from manure, gliricidia and leucaena biomass in Chipata South district, 2001

Treatments	After cabbage (n = 21)	After onion (n = 10)
Manure 10t ha^{-1} + ½ fertilizer	4.2	3.1
Fully fertilized	3.9	2.5
Gliricidia 12 t ha^{-1}†	4.9	3.9
Gliricidia 8 t ha^{-1}	4.3	3.3
Leucaena 12 t ha^{-1}	3.2	--
Control	2.9	1.7
S.e.d (p = 0.05)	0.48	0.49

-- Leucaena 12t ha^{-1} was not used in onion trials

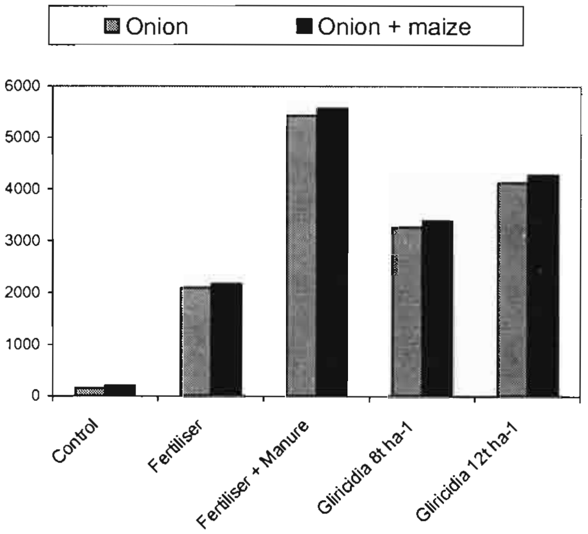
† Biomass treatments are reported on dry weight basis

N = Number of farmers participating in the experiment

In summary, the biomass transfer system has greatest potential when biomass is of high quality and rapidly releases nutrients, the opportunity cost of labour is low, the value of the crop is high and if the biomass does not have other valued uses other than as source of nutrients.

Future Research Needs

This synthesis has described the progress that has been made during the past 10 years in research ef-



* Above net incomes are reported per hectare basis. Average actual area put to onion by a farmer

Figure 9. Net income US$ ha^{-1})* from onion and subsequent maize on 12 vegetable gardens in Chipata South District in 2001

forts to understand the mechanisms involved in how improved fallows work. A lot of knowledge has been generated. However other aspects of improved fallows have received little research. These will be highlighted in future research directions.

Accumulation of litter on the soil surface and micro climate changes may lead to increased activity of soil macro fauna under tree fallows, particularly in subhumid zones of southern Africa. No reports have been published on the role of soil fauna, the functions of specific groups and the scope of their manipulation through quality of biomass produced by different species. The increased soil fauna will play a significant positive role in litter decomposition, nutrient mineralization and improvement of soil physical properties. This area deserves further research.

The work on improved fallows has focused on few species such as *Sesbania, Tephrosia, Crotalaria* and *Gliricidia*. With regard to extrapolation, further work is needed to identify more species for improved fallows. Given a large number of potential species, the selection process could be accelerated by creation of a database containing fallow performance in relation to environmental factors such as rainfall, soil type and chemistry and incidence of pests and diseases. Our recent trials across sites have shown a great potential for *Tephrosia candida* as alternative species to *Sesbania* and *T. vogelli* and equally *Leucaena collinsii* and *Acacia angustissima* as alternative coppicing fallow species to *G. sepium*.

The biophysical limits of improved fallows need be developed to facilitate scaling up with minimum research efforts. Simulation modeling, both as a research and extrapolation tool, has a potential for integrating research results, identifying key components or process that merit greater research attention, identifying ecozones where appropriate fallow species and management techniques have a good chance of success.

The debate on global warming and carbon sequestration has gained momentum recently. Agroforestry land use systems have been reported to have huge potential to sequester soil carbon. However there are few studies if any in Southern Africa, which have measured C sequestration in improved fallows. The relationship between soil aggregates and carbon storage needs further research.

As noted earlier, the interaction of pests with soil fertility is gaining widespread attention due to wider interest in scaling up of improved fallows. So far most of the research efforts have concentrated on insects pests and nematodes. Equally important are plant diseases and weeds. Little effort has been invested in these issues. With scaling up across many ecozones, the incidence of new pests and diseases will increase. Hence, there will be need to monitor pests and diseases with farmers to determine the few economic pests to deal with in a concerted research programme. Such work is now underway in southern Africa.

Many of the species currently used in improved fallows are prolific seed producers. If not managed well these species can become invasive weeds and become a menace to other ecosystems. To date there has been no concerted research effort to determine the weediness of introduced fallow species. There is urgent need to use current models to predict the potential of new species to become invasive weeds, study the reproductive biology and design management practices that will reduce the weediness of improved fallow species.

On nutrient depleted soils, two-year fallows with fast growing leguminous trees such as *sesbania* and *tephrosia* can replenish soil N stocks for the production of 3 to 4 t/ha of maize grain yield. The residual effects of such fallows extend to 2 to 3 years after fallow termination. However coppicing fallows like *gliricidia* can maintain maize grain yields of 3 t/ha over an 8-year period after fallow clearance. However, where soils are deficient in P, inorganic P sources are needed to increase productivity of the soil.

Research during the last decade has established the main mechanisms on how improved fallows work. Despite significant progress in biophysical research in improved fallows in southern Africa, the application of that science by small-scale farmers is still minimum. The main challenge now is to increase the generation of viable and acceptable fallow options that can make improved fallows more productive to increase the income and food security of small-scale farmers.

Future research issues on biomass transfer will involve the residual effect of low and high quality biomass, combination of organic and inorganic sources of nutrients, effect of biomass banks on nutrient mining, agronomic research of biomass transfer of different leguminous species, and economic analysis of the systems.

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PIGEONPEA/COWPEA INTERCROP + MAIZE + CASSAVA ROTATIONS ON SMALLHOLDER FARMS IN THE SOUTHERN COASTAL AREA OF MOZAMBIQUE

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Abstract

Low soil fertility is a limiting factor for agriculture production in Mozambique that is aggravated by unsustainable cropping systems used by smallholding farmers. They practice rainfed low input agriculture on land areas that range from 0.5 to 4 hectares.

This paper gives the background and brief information on results from a very initial set of on going on-farm rotation experiments on nutrient management carried out in Inharrime district within Inhambane province in southern Mozambique. The experiments are conducted on farmers' fields located in smallholder farming areas surrounding Nhacoongo Research Station and are based on legumes in rotation and intercropped with maize and cassava. Crop residue incorporation was considered part of the technology. Of the five sites (one farmer=one site), harvesting of cowpea took place in three sites only because of environmental stresses and yields were low. .

Key words: Legume, maize, cassava, intercrop, rotation, on farm experiment

Introduction

Low soil fertility is one of the most limiting factors for agricultural production in Mozambique, plus climatic irregularity and adversity and soil erosion, aggravated by unsustainable cropping systems used by small-holding farmers. In general, the soils of Mozambique are low to moderate fertility.

Inadequate soil fertility is one of the major biophysical constraints for crop production. Soil fertility depletion is continuous due to nutrient losses caused by poor soil husbandry and extractive traditional methods of cultivation with no replacement of nutrients by smallholder farmers. They practice rain fed agriculture in land areas that range from 0.5 to 4 hectares. On average, smallholder farmer maize yields are very low (about 200-400 kg/ha) and inorganic fertilizers are unaffordable, aggravated by constrained access to credit systems.

In addition, Mozambique's agriculture production has been greatly affected by the civil war that ended in 1992 followed by adverse conditions such as droughts and floods resulting in a large food deficit. Thus, there is a need to increase crop production, particularly at the level of small farmers. Sustainable soil fertility management practices have to be developed, recommended and adopted if the objectives of food security and sustainable natural resource management are to be achieved.

Inharrime district is located on soils that are representative of soils in the coastal belt where low fertility is the major constraint to crop yields. Sandy soils are predominant that are characterized by low nutrient reserves, low organic matter content and low cation exchange capacity. Nhacoongo research station is located within this district and it was the ideal place within Inhambane province for the experiment on rotations.

In Mozambique, about 90 percent of food production is from rainfed systems. The major food crops are maize, sorghum, millet, rice, cassava, bean and groundnut and other additional crops and fruit trees mostly intercropped. The major part of crop production is subsistence and low input/low output in nature. Commercial farming contributes only about four percent of total production. The highest human population density of the agricultural regions is in the coastal belt south of the river Save. There is no correlation, in the south, between population density and environmental conditions, particularly climate and soils. However, there is a strong correlation between climate and crop distribution. Cassava and maize are the basic staples of this area, and they are known to deplete soil nutrients. Mainly because of the environmental conditions, maize production has declined in some areas and cassava has expanded. For many areas, the introduction of new technologies for soil fertility improvement may reverse the situation.

The first steps to improve soil fertility management based on legumes has taken place through crop rotation studies with green manure cover crops including improved fallow (pigeon-pea, lab-lab and cowpea) in Nhacoongo Research Station in Inhambane Province. The rotation system consists of three main components, namely pigeon pea/cowpea intercrop (hot season), sole maize (cool season) and groundnut/cassava intercrop (in the following hot season.

Methodology

Site Description

Inharrime district, located in the south of Inhambane Province, lies from latitude 24°10'30" and 24°37'30" South and longitude 34°30'00" – 35°25'00" East. It has 76,518 inhabitants relaying on subsistence agriculture.

According to the Thornthwaite-modified classification (Reddy, 1986), the climate is wet semi-arid (Table 1). The rainfall is irregular and erratic due to occurrence of low-pressure centers. There are two growing seasons (Table 1).

Inharrime is located along the coastal zone. Most of the soils are sandy loams except the low plateau, then the middle and the high plateau. The dominant soils are arenosols (Table 1), used for most of the crop production. Locally there are fluvisols and soils with hydromorphic properties.

Material and Methods

The experiments were planted in Inharrime district (after having carried out previous studies at the research station of Nhacoongo) on five smallhold farmers in the areas surrounding the research station. In consultation with local farmers, the criteria were based on farmer's availability and interest, particularly the ones cultivating the legumes. At the trial sites, soil samples taken for chemical characteristics and texture determination showed nutrient deficiencies (Table 2).

Table 1. Experimental site details

Location	Inharrime district
Altitude	43 m above sea
level	
Average annual rainfall	800-1000 mm
Annual mean temperature	23-26°C
Potential evapotranspiration	1275 mm
Growth period	130-139 days
Main crop season	September-March
2nd Crop season	April to September
Dominant soils	Sandy soils
Research station soils	Sandy soils
Farmers fields soils	Sandy soils

Table 2. Soil analysis results of sandy soils from a representative sample of the smallholders farmer's field areas

Farm	Ca	Mg	K	Na	Bases	pH in H_2O	P Olsen	% Organic Matter	% Total N
1	0.40	0.18	0.08	0.00	0.70	6.1	1.49	0.6	0.06
2	1.11	0.25	0.08	0.06	1.50	5.8	1.08	0.5	0.09
3	0.79	0.30	0.16	0.04	1.30	5.9	1.76	0.6	0.07
4	0.69	0.22	0.12	0.04	1.10	6.0	1.35	0.5	0.07
5	0.10	0.34	0.02	0.02	0.50	5.5	1.22	0.5	0.07

The experiment was arranged in a randomized complete block design with each site being one replicate (equivalent to 1 farmer) with three treatments involving maize (*Zea mays*), cassava (*Maninhot esculenta*) and legumes such as cowpea (*Vigna unguiculata*), pigeonpea (*Cajanus cajan*) and groundnut (*Arachis hypogaea).* Maize and cassava spacing was 0.80*0.40 m and 1*1 m respectively, 0.40*0.40m for pigeonpea , 0.80*0.80m for cowpea and 0.30*0.25 for groundnut. The plot area covered 25 m^2 and the total area was 100m^2. Other inputs included nitrogen from the legumes and the crop residues.

The experimental treatments were intercrop legumes, cassava and maize in rotation as follows:

T1. Maize+Cowpea +Groundnut in the wet season followed by maize in the dry season (this in one year).

T2. Cowpea + Pigeonpea in the wet season and sole maize in the dry season.

T3. Cassava+Cowpea and Groundnut, lasting in the field with cassava until the end of the dry season. This represents the normal farmer cropping system.

40 kg/ha of P_2O_5 was applied in all treatments since the sandy soils are highly phosphorus deficient, expecting that the Nitrogen input would come from the legumes.

Results and Discussion

Ants destroyed groundnut because of late sowing and the dry season maize was not sown because of drought (long dry spell in the beginning of the season). With little rain, cowpea did produce some but very low yields. As it has been postulated by Parsons and Howe, 1984 in Giller and Wilson (1991), this grain legume has the ability to maintain lower osmotic potential in it's leaves under water stress conditions. The best performer among legumes was pigeonpea that resisted the environmental stress (rain, temperatures, low fertility).

Table 3. Means of legume grain yields (kg/ha)

Treatment	Cowpea	Pigeon pea
1	390	–
2	495	720
3	250	–

Results were not consistent because of the adverse environmental conditions. Very low yields of all involved crops were obtained (Table 3). Legumes are affected in several ways under such water deficiency conditions. Survival or rate of growth of microorganisms or other processes such as plant infection or nodule development may be affected, as may the fixation of N_2 (Giller and Wilson 1991). Furthermore, their survival is improved by the presence of clay particles and organic matter in soils at high temperatures, as happens in sandy soils.

However despite all this, farmers did want to continue with the experiment in the following season asking for a reformulation, that is, focusing the rotation on maize and legumes excluding cassava.

Soil chemical analyses (Table 2) showed severe nutrient deficiencies, including nitrogen deficiency. This showed a need to include a basal fertilization with this element in the following seasons and not only phosphorus, aiming to guarantee the initial plant growth. Measures on soil nutrient status and organic matter shall be done during the experiment implementation, to verify effects of the new technologies on management of sandy soil.

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Questions and Answers

Identification of Best Bet Legumes for On-farm Performance as Grain Legumes, Intercrops, Rotations, and Green Manures

To Webster Sakala and Wezi Mhango

Q: In the intercrop and rotation practices on maize cultivation, what levels of additional fertilizers were added apart from the green manures?
A: On average, it was half the requirement of the maize crop, which was around 40 kg N ha^{-1}, but it is difficult to give a specific figure because we looked at several studies.

Q: Results of green manures and grain legumes appear to be promising in Malawi. What is the uptake rate of these technologies among smallholder farmers? What were the yields of soyabean intercropped with maize? I thought that soyabean is very sensitive to shading.
A: The grain legumes/green manures are currently being promoted amongst the smallholder farmers. The farmers make choices depending on the resources that they have, e.g. land, so that if they have less land they go for intercropping, and for improved fallows or rotation if land is more plentiful. Soyabean is usually grown in pure stands.

Q: As early incorporation of green manures may cause an N loss due to early showers (leaching), the nutrient supply could have been better if the legumes were incorporated late, to synchronize the peak N demand of maize with nutrient release. What is your comment on that?
A: This is not a problem in Malawi because of the nature of our rainfall where after incorporation we experience a 6-8 month dry season before the next growing season. This may be a problem in countries where they receive some heavy showers before the next crop season.

To Dennis Friesen, et al.

Q: It looks like you do not have a soil fertility problem in East Africa because you get up to 6 t/ha maize grain yield. At one site you get almost 5 t/ha without fertilizer and 6 t/ha with fertilizer, displaying a low response to fertilizer.
A: Generally those high maize yields without fertilizer were obtained in trials conducted on station where the soils are better and where there has been a history of fertilizer use. Yields on farm were generally closer to the mean yields reported for the region (1-2 t/ha) – with some exceptions in high potential areas.

Q: Did you apply any fertilizer when you intercropped and how much?
A: In general, DAP is applied to the maize adjacent to the planting hole at the recommended rate, which varies in the region (generally around 46 kg P_2O_5 / ha).

Q: Intercrops are notoriously difficult to manage, and where they work can depend on various site effects. Yet some have been very successful. How can we move towards making predictions of where they will succeed, and recommendations for their management?
A: Factors that affect the growth of the intercrop such as moisture, soil fertility, light penetration of the maize canopy, can probably be used to predict intercrop growth using a modelling approach. However, farmers need rules of thumb to predict when to plant the intercrop, what maize varieties to intercrop into, etc. Perhaps modelling can help to develop these guidelines.

To Nhamo Nhamo, et al.

Q: Did you check the specific names for the cowpea varieties that the farmers received from donors?
A: Yes but we asked for the local names for these varieties, so if it was introduced by the donor and the farmers did not remember then we could have missed them.

To Pauline Chivenge, et al.

Q: It would be useful to establish how the various legumes perform under amount of rainfall. Did you conduct correlation analysis for rainfall?
A: No, the drought did not allow that.

Q: The low available P in your soil is not consistent with the high biomass yield. Could this observation suggest that the plants are obtaining P from insoluble P soil sources?
A: Quite right, but also the northern part of Zambia where these yields were obtained received very good rainfall.

To Laurence Jasi, et al.

C: One should not expect to see a significant effect of legumes on *Striga* infestation after one crop. Our experience in Western Kenya is that the effects require long term implementation of rotations since the purpose of the legumes are to 1) stimulate suicidal Striga germination, and 2) improve soil fertility and biological activity to reduce the Striga seed bank in soil. This requires several seasons of rotation.

Q: Can crop models be used to predict the result of this experiment?
A: There is some capacity in APSIM to look at crop x weed interactions and weed management issues. For parasitic weeds however, the model is not parameterized (due to limited understanding of the science) to handle parasitic weeds like *Striga*.

Q: Your treatments did not reduce *Striga* emergence below that in the control, but your conclusion is not that your hypothesis should be rejected, but that more work is needed. Why not simply conclude that green manures do not (in this case) usefully reduce Striga emergence?
A: It is too early to make a conclusion. Green manures can induce the suicidal germination of Striga. With time the Striga seed bank is reduced. In the long term, probably positive results may be obtained.

To Paramu Mafongoya, et al.

Q: When is manure supposed to be called manure? At times you have 10 t of material, of which 2 t is organic manure and 8 t of sand!
A: Analyze the manure for sand and other materials and then you can correct for sand.

Q: You have shown that incorporation of leguminous tree biomass (e.g. *Gliricidia*) increased pH significantly. There is some work from Australia indicating that growing legumes acidifies the soil significantly. Do you feel the cation/base concentration in the tree biomass justifies the increase in pH?
A: This is explained by leaching of NO_3 and accompanying Mg^{2+} during the cropping phase when there is no tree to recover N. In coppicing fallows this explained the addition of cations in tree biomass.

Q: How successful are agroforestry technologies such as improved fallows in improving soil fertility in degraded soils like those in Kagoro in eastern Zambia where ICRAF is located?
A: In Kagoro soils, mixtures of *Glricidia* and *Sesbania* gave maize yields of 3 t/ha compared to 4 t/ha for fully fertilized maize.

Q:
(1) It is good that now we are beginning to put science to the observations of the benefits of agroforestry trees that have been demonstrated over the years.
(2) How could soil loss from runoff have been measured in October as indicated by the data?
A: The data were collected by rainfall simulation techniques.

MUCUNA – MAIZE ROTATIONS AND SHORT FALLOWS TO REHABILITATE SMALLHOLDER FARMS IN MALAWI

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Abstract

An experiment was initiated in the 1999/2000 season to evaluate four different ways of improving maize yields on degraded and abandoned parts of smallholder farms in Lilongwe, Kasungu and Mzuzu Agricultural Development Divisions (ADD) in Malawi. Selected sites were farm fields abandoned by farmers due to very low maize yields. In the first season (2000/2001), two treatments were planted with maize, which was either fertilized with an area specific fertilizer recommendation or not fertilized. The other two treatments were planted either to a one-year improved fallow of mucuna or left to a natural fallow. In the second season (2001/2002) maize was planted to all the four plots without fertilizer except a control where fertilized maize followed fertilized maize. Average maize yields from the four sites ranged from 0.8 t (at Vibangalala) to 2.0 t ha^{-1} (at Zombwe). Maize grain and stover yields (3.6 t ha^{-1} and 6.8 t ha^{-1}) were highest and differed significantly where maize was fertilized with the hybrid maize area specific fertilizer recommendation compared with other treatments. For the non-fertilized plots, maize following mucuna had the highest grain and stover yields of 1.5 and 3.5 t ha^{-1} respectively. Total N yield for both grain and stover followed the trend of maize yield. Nitrogen concentration in the grain was not significantly different between treatments. These results indicate that resource poor farmers with abandoned fields who cannot afford fertilizers would benefit by using green manure improved fallows compared to continuous cropping with maize or leaving the field to a natural fallow.

Key words: Mucuna, maize rotation, short fallow, area specific fertilizer recommendation, smallholder farm, rehabilitation

Introduction

Results from initial assessments of the mucuna-maize rotation system conducted on-farm and on station in Malawi from 1997/98 to 1999/2000 showed that maize yields following unfertilized Mucuna (Kalongonda) were significantly higher than maize yields after continuous unfertilized maize (up to 3.5 t ha^{-1} vs. 1 t ha^{-1}) (Sakala et al. 2000; Gilbert and Kumwenda, 2001; Sakala et al. 2001; Sakala and Mhango, 2003). The results showed that *Mucuna* could be a good alternative source of fertilizer for maize production in Malawi for farmers who cannot afford fertilizer. In the same work, it was clear that the best way to manage mucuna in a maize based cropping system is through rotation rather than intercropping or relay cropping of mucuna with maize. The objectives of the new work described here were to i) demonstrate to more farmers that mucuna can be used for rehabilitating smallholder farms, ii) collaborate with Non Governmental Organizations (NGO) on scaling up this promising technology and iii) measure the yield and nutrient benefits of the technology on farms.

Materials and methods

The experiment was initiated in the 1999/2000 season in Ntheu, Kasungu, and Vibangalala Extension Planning Areas (EPA) in Lilongwe, Kasungu and Mzuzu ADDs. The soil characteristics at the sites are in Table 1. In the first season (2000/2001), two treatments were planted with maize, which was either fertilized or not fertilized, and the other two treatments were either planted to a one year improved fallow of mucuna or left to a natural fallow. In the second season (2001/2002), maize without fertilizer was planted to all the four plots, except the first treatment where fertilized maize followed fertilized maize. Crop residues were incorporated at the end of the first season.

The four treatments were arranged in a randomized complete block, with farmers as replicates. Each plot comprised of 10 rows spaced at 90 cm and 10 m long. Maize seed was planted at 37000 plants per ha (0.9 m x 0.9 m x 3 plants). The sole crop of maize received 35:10:0+2S (N:P_2O_5+S) per hectare from 23:21:4S as a basal fertilizer, and from urea as a top dressing. Maize yield was determined by harvesting four middle rows (each 9.1 m long) of each plot, and the yield was adjusted to 12.5% moisture content. Mucuna was planted at 74407 seeds per hectare (90 m x 15 m x 1 plant) in 2000/2001. Maize yields were analyzed using GENSTAT (Payne, 1978). Analysis of variance was the main procedure used for testing significances of differences between means.

Table 1. Soil characteristics of some selected parameters across four sites at the end of the second season in 2002

Treatment	pH	OM (%)	NO_3 (ppm)	NH_4 (ppm)
Fertilised maize	5.5	3.0	13.8	99.7
Unfertilised maize	5.5	3.5	14.1	84.2
Maize after mucuna	5.5	3.8	13.3	65.1
Maize after natural fallow	5.5	4.1	12.1	66.3

	SED	Prob	SED	Prob	SED	Prob	SED	Proo
Site	0.13	<0.001	0.49	<0.001	2.39	<0.037	15.4	<0.001
Treatment	0.13	NS	0.494	NS	2.39	NS	15.4	NS
Site x Trt.	0.264	NS	0.988	NS	4.78	NS	30.2	NS

Results

Soil chemical characteristics of the treatments

There were no significant differences at the end of the second season on soil chemical characteristics, although organic matter tended to be higher following the natural fallow and mucuna compared to unfertilized and fertilized maize monocultures (Table 1).

Effects of mucuna on soil cover compared to natural fallow

No measurements were taken on soil cover in plots with the short term fallow of mucuna and the plots left to natural fallow. However, farmers in the study sites observed that where mucuna was planted there was a good soil cover compared with the plots left to natural fallows.

Effect of treatments on maize grain and stover yield

Average maize grain yield was highest where maize was fertilized with the area specific fertilizer recommendation. For the non-fertilized plots, maize following mucuna had the highest grain yield (1.5 t ha^{-1}) and highest stover yield (with 3.5 t ha^{-1}) (Tables 2a and b). The lowest maize grain yield (0.4 t ha^{-1}) was from plots where unfertilized maize followed unfertilized maize (Tables 2a and b). Among the twenty-six sites, Vingalala site had the lowest average maize yield of 0.8 t ha^{-1} but had similar maize yield trends to the other sites.

Effect of treatments on grain and stover N yield

Nitrogen yield for both grain and stover (Figure 1) was highest for the fertilized treatments followed by the maize following mucuna treatment, with the least grain and stover yield obtained from maize that followed the natural fallow. There were significant differences in nitrogen concentration in the grain due to sites; the lowest nitrogen concentration was obtained from Vibangalala and the highest from Kasungu. The N in the maize crop after mucuna was almost double that from unfertilized maize.

Effect of sites and treatments on N concentration

There were significant differences in nitrogen concentration in the grain due to sites. The lowest nitrogen concentration was obtained from Vibangala site and the highest concentration was from Kasungu (Table 3). The N in the maize crop after mucuna was almost double that from unfertilized maize.

Conclusion

Similar yield trends were observed at all four sites and strongly indicate that resource poor farmers who cannot afford fertilizers would benefit a lot by

Table 2a. Maize grain yield (t ha^{-1}) from 26 farms located at four sites in 2001/2002

Site	No. of farms	Fertilized Maize	Unfertilized Maize	Maize after Mucuna	Maize after Fallow	Mean (t ha^{-1})
Ntcheu	6	3.6	1.1	1.6	1.4	1.9
Kasungu	5	1.7	0.8	1.2	0.9	1,1
Vangalala	6	1.4	0.4	0.7	0.6	0.8
Zombwe	5	3.6	0.9	2.4	1.3	2.0
Mean		2.6	0.8	1.5	1.0	1.5

	SED	Prob.
Site	0.248	<0.001
Treatment	0.248	<0.001
Site x Trt	0.496	NS

Table 2b. Maize stover yield (t ha^{-1}) at four sites in 2001/2002

Site	No of farms	Fertilized Maize	Unfertilized Maize	Maize after Mucuna	Maize after Fallow	Mean t ha^{-1})
Ntcheu	6	6.8	3.7	4.7	2.5	4.4
Kasungu	5	5.7	3.1	4.7	2.1	3.9
Vangalala	6	4.1	1.2	2.0	1.4	2.2
Zombwe	5	3.5	1.4	2.5	1.8	2.1
Mean		5.0	2.3	3.5	1.8	3.2

	SED	Prob.
Site	0.670	0.002
Treatment	0.670	0.001
Site x Trt	1.34	NS

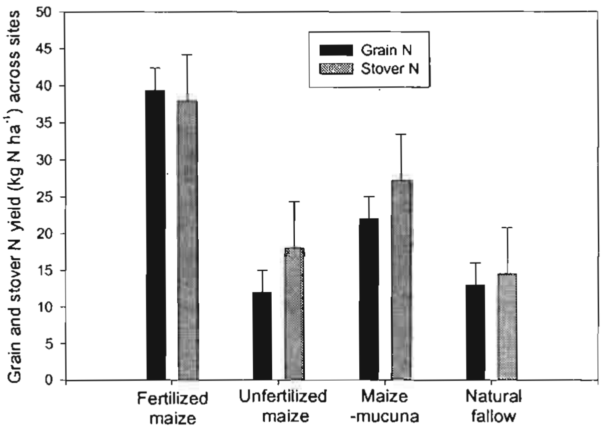

Figure 1. Grain and stover nitrogen across sites for four maize—mucuna systems in Malawi

Table 3. Percent nitrogen (% N) concentration in the grain at maize harvest

	No of farms	Fertilised Maize	Unfertilised Maize	Maize after Mucuna	Maize after Fallow	Mean
Ntcheu	6	1.4	1.3	1.6	1.1	1.4
Kasungu	5	1.7	1.4	1.9	1.5	1.6
Vangalala	6	1.1	0.95	0.9	0.78	0.9
Zombwe	5	1.8	1.55	1.5	1.5	1.6
Mean		1.5	1.3	1.5	1.2	1.4

	SED	Prob.
Site	0.15	< 0.001
Treatment	0.15	NS
Site x Trt	0.29	NS

using green manure fallows compared to continuous maize cropping or abandoning the field to a natural fallow. Percent nitrogen concentration for maize following the natural fallow was not different to with sole maize following unfertilized maize. Low nitrogen in the maize stover indicates that maize stover is not suitable for increasing soil fertility in degraded fields belonging to smallholders in Malawi.

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RESIDUAL EFFECTS OF FORAGE LEGUMES ON SUBSEQUENT MAIZE YIELDS AND SOIL FERTILITY IN THE SMALLHOLDER FARMING SECTOR OF ZIMBABWE

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Abstract

The use of forage legumes as an alternative to mineral N sources has shown potential in many integrated livestock/crop production systems. The objective of our research was to demonstrate the effect of forage legume residues (litter and roots) on maize yield and, soil N, P and organic carbon levels. On-farm trials were established in Wedza (Natural Region II and III) and Buhera (Natural Region IV) districts of Zimbabwe. The treatments were: maize only, maize/cowpea intercrop, maize/velvetbean intercrop, maize/lablab intercrop, sole lablab, sole cowpea, sole velvetbean and ley in the 1998/99 and 1999/2000 seasons. In the 2000/2001 season, all plots were planted to a maize crop.

In Natural Region II the order in which maize grain yield increased in response to the treatments was maize/cowpea > maize/lablab > velvetbean > maize/velvetbean > maize > cowpea > ley. In Natural Region III the order of highest subsequent maize yields was: cowpea > maize/lablab > ley > maize/cowpea ≈ lablab > maize/velvetbean > maize ≈ lablab. In Natural Region IV, maize/cowpea intercropping recorded the highest grain yield (1.75 t/ha). Residual soil mineral N content was lowest under continuous maize cropping in all three Natural Regions. In the drier regions, soil N content in the ley treatment was comparable to legume treatments, but it was low in NR II. In NR II, maize/cowpea intercropping and velvetbean sole cropping had the highest available soil P concentration. The same trend was observed in NR III and IV, but the residual P levels were lower in drier regions compared with that of NR II. Rotation of maize with sole velvetbean and maize/cowpea intercrop gives the highest maize yield gains. Residual N gains were higher in sole cropped legumes than intercrops in high rainfall areas whereas in drier areas ley gave the highest residual N benefit.

Key words: forage legumes, intercropping, maize yield, mineral nitrogen, organic carbon, residual effect, soil P.

Introduction

The farming system in the smallholder-farming sector of Zimbabwe is characterized by a close integration and complementarity of crop and livestock production. Continuous cultivation with no and sometimes minimum organic and inorganic fertilizer inputs has led to soil impoverishment which has been named as one of the major causes of declining crop yields. Efforts to improve the quality and quantity of grazing in the communal rangeland through methods such as veld reinforcement and good grazing range management practices have been defeated by the 'tragedy of the commons' (Scoones, 1994). The widespread use of inorganic fertilizers has been stopped by the high costs of the fertilizers while the manure is largely of poor quality and is often not available in sufficient quantities.

Integration of legumes into predominantly cereal cropping systems is one way of improving soil nitrogen (N) status of the soil through biological nitrogen fixation. The forage legumes will in turn provide additional high quality feed for livestock. In addition, through intensive cultivation, arable lands can assist in providing supplementary forage and other products for livestock feed. This will ease the pressure on already degraded less productive rangelands.

Forage legumes are known to improve soil physical and chemical properties. Data from Chalk (1996) have shown that cereals intercropped with grain legumes benefit in terms of increased grain and N yields. Literature reports that N is a key factor in the response of cereals following legumes compared with cereals following non-legumes. The legume may potentially add N to the soil N pool through symbiotic N_2 fixation, and it may also remove less inorganic N from the soil compared with the cereal.

The decomposition of legume residues during the post harvest fallow period preceding the sowing of a cereal may explain differences in the relative contribution of fixed-N to the N economies of intercropped and rotation systems (Peoples and Herridge, 1990). Thus cereals cropped in sequence with legumes derive N benefits compared with cereal monoculture.

Hybrid maize (*Zea mays* L.) is a crop that requires and extracts high amounts of nutrients, which produces optimal and/or economic yields in highly fertilized soils or soils of high inherent fertility status, provided rainfall is not limiting. Most of Africa is struggling with structural adjustment programs that have left resource poor farmers in serious economic problems. The prices of most agricultural inputs have been escalating while the financial resources of peasant farmers are dwindling. Resource poor farmers can hardly afford to buy mineral fertilizers. The effect of intercropping legumes with tropical cereals has been reported. Gryseels and Anderson (1983), Dzowela (1987), Natarajan and Shumba (1989) and Manyawu (1994) have reported the effects of the legume component on the cereal crop (maize) in intercropping. In Zimbabwe, a nitrogen equivalent of 40 to 75 kg N/ha has been realized in legume/maize crop rotations (Mukurumbira, 1985). Biological nitrogen fixation (BNF) is an enormous potential for the maintenance and improvement of soil fertility in the tropics.

The main objective of this study was to evaluate the effect of intercropping and rotating forage legumes with maize on maize yield and soil fertility. Specific objectives were to determine the residual effect of forage legumes on (a) maize grain yield (b) aboveground biomass and litter yields of the legumes (c) soil mineral N levels (d) soil organic carbon content, and (e) soil P content.

Materials and Methods

Experimental sites

On farm trials were established in Natural Regions (NR) II, III and IV of Wedza (Mashonaland East province) and Buhera (Manicaland province) districts. Two wards, Chamatendere (NR II) and Madzimbabwe (NR III), were selected in Wedza district. Another ward (Gaza Munyanyi) was selected from Buhera district. Three farmers were identified in each ward through consultation with extension officers and farmers.

Trial establishment

The treatments were as follows: sole maize, maize/cowpea intercropping, maize/velvet bean intercropping, maize/lablab intercropping, sole lablab, sole cowpea, sole velvet bean and ley. Each farmer hosted all the eight treatments. The trials were laid out so that each farmer formed the sampling unit. There was no blocking at each farmer's field. Each farmer in a ward formed the replicate. In the 1998/99 and 1999/2000 seasons, study sites were planted to sole crops and intercrops listed above. In the intercrops, the maize and legume were planted in alternate rows. Planting of the maize and the legumes was done at same time in November 1998. In 2000/2001, all plots were planted to a maize crop.

Plots measuring 10m x 10m were used at all sites. Maize in monocrops was planted at the recommended 0.9m x 0.45m while legumes in monocrops were planted at 0.45m x 0.15m. Compound D (8% N:14% P2O5: 7% K2O) and calcitic lime (96% neutralizing value, 4.5% Mg) were broadcast at 250 and 500 kg ha^{-1} respectively before planting. Maize variety SC501 (medium season variety) was planted in Wedza and SC401 (short season variety) was planted in Buhera. All the legumes were inoculated with the appropriate Rhizobia strains at planting. In the 1998/99 and 1999/2000 seasons, the maize was topdressed at knee height and tasseling with 60 kg N ha^{-1} each time. At harvest the legume aboveground biomass was taken for livestock feeding, leaving litter and belowground biomass contributing towards soil fertility. Harvesting was done in April 2001.

Measurements

Soil samples were collected from a depth of up to 30 cm. Organic carbon was determined by the Walkley-Black procedure while P was extracted by the bicarbonate method (Wanatabe and Olsen, 1965). Mineral N (NO_3^--N + NH_4^+-N) was extracted from soil by the 1M KCl/0.1M HCl solution and determined by the calorimetric procedure. Aboveground biomass and litterfall were measured for each legume. Data collected were subjected to analysis of variance using statistical analysis system (SAS) program [SAS, 1990] to evaluate treatment effects.

Results and Discussion

The results presented for 2000/01 season are used to show the rotation effect of forage legumes to subsequent maize grain yield and soil fertility parameters.

In Natural Region II, Wedza (Chematendere ward), maize/cowpea intercropping had a significantly ($P < 0.05$) higher maize yield (4.64 t/ha) compared with maize monocropping (2.27 t/ha) (Table 1). Inclusion of legumes in the plots generally increased yields more than leys and continuous maize cropping. The general order of grain yields in NR II was maize/cowpea > maize/lablab > velvet bean > maize/

Table 1. Effect of forage legumes on subsequent maize grain yields (t ha^{-1}) at Wedza and Buhera sites (2000/2001 season)

Treatment	Natural Region II	Natural Region III	Natural Region IV
Maize	2.27	1.50	0.67
Maize\cowpea	4.64	1.65	1.75
Maize\lablab	4.42	2.40	0.88
Maize\velvetbean	3.93	1.89	0.83
Cowpea	2.93	2.60	0.81
Velvetbean	4.30	1.49	1.03
Lablab	3.09	1.94	0.80
Ley	2.39	2.18	0.98
LSD ($P < 0.05$)	*	ns	*

Ward x treatment interaction was significant at $P < 0.05$
lsd 0.05 - 2.02

velvet bean > lablab > cowpea > ley > maize. In Natural Region III, Wedza (Madzimbabwe ward), neither intercropped nor sole cropped legumes had any significant effect on maize yields in the 2000/2001 season. In Natural Region IV, Buhera district, maize/cowpea intercropping recorded the highest grain yield (1.75 t/ha), which was about four-fold higher compared with that obtained in other treatment combinations (Table 1). The increased maize grain yields following forage legumes could be due to the N-sparing effects of the legumes planted in the previous season. The residual effect of the legumes on maize stover yields was not significant during the 2000/2001 season.

All the three legumes have a potential of producing high herbage yields noting that they produced more than 1 500 kg ha^{-1} across all regions and when they are intercropped (Figure 1). The three legumes chosen for the study (cowpea, lablab and velvet bean) have a wide range of attributes and adaptation (Skerman et al., 1988). They are widely used for intercropping with maize (Almseged et al., 1991). Being short-lived perennials, they are easy to manage in any of the cropping systems.

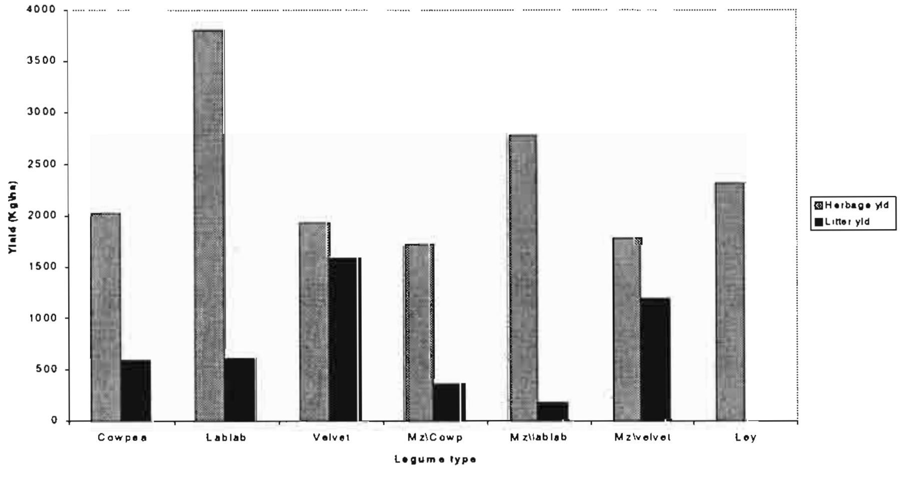

Figure 1. Forage and litter production of dual purpose legumes when intercropped with maize in Wedza and Buhera, Zimbabwe

Table 2. Effect of forage legumes on soil mineral N at Wedza and Buhera sites

Treatments	Mineral nitrogen (ppm)		
	Natural Region II	Natural Region III	Natural Region IV
Maize	2.45	9.67	5.56
Maize/cowpea	6.85	10.1	4.91
Maize/velvetbean	4.84	12.2	10.1
Maize/lablab	3.96	6.84	5.13
Cowpea	8.05	8.44	2.33
Velvet bean	6.59	8.58	6.20
Lablab	6.64	8.48	2.33
Ley	5.29	8.81	11.6
Mean	5.58	9.14	6.02
LSD ($P < 0.05$)	n.s	n.s	*

n.s. - no significant difference among treatments

The increases in mineral N were probably due to adjusted carbon/nitrogen ratios in legume-cereal intercropping systems. From Table 2, it is evident that residual soil N content was lowest under continuous maize cropping in all three Natural Regions. Therefore, incorporation of legumes in cereal cropping systems is important. In the drier Regions (III and IV), soil N content in the ley treatment was comparable to legume treatments, but it was low in NR II. This is probably due to more leaching associated with high rainfall.

Forage legumes had no significant effect on soil organic C (Table 3). A lack of significant changes in percent organic carbon would be expected given the short duration of this study. Organic carbon is reported to take over 10 years to increase by just 2.7% (Piha, 1995). Treatment effects also showed no differences across the regions.

Results in Table 4 show that the cropping system of a forage legume, such as sole cropping and legume-cereal intercropping, significantly affected available soil phosphorus concentration only in NR II, (Chematendere ward, Wedza) where maize/cowpea intercropping and velvetbean sole cropping left higher available P concentrations than the other treatments. Lablab sole cropping and maize/velvet bean intercropping generally resulted in significantly lower available soil P concentration.

Conclusion

Forage legumes had a positive effect on maize yields and the soil fertility parameters measured. The residual effects of sole velvetbean and maize/cowpea intercrop gave the highest maize

Table 3. Effect of forage legumes on soil organic carbon content (%) at Wedza and Buhera

Treatments	Soil organic carbon content (%)		
	Natural Region II	Natural Region III	Natural Region IV
Maize	0.47	0.38	0.24
Maize/Cowpea	0.50	0.36	0.38
Maize/velvet bean	0.52	0.28	0.40
Maize/Lablab	0.41	0.37	0.25
Cowpea	0.43	0.28	0.67
Velvet bean	0.39	0.30	0.29
Lablab	0.56	0.31	0.42
Ley	0.48	0.51	0.28
Mean	0.47	0.35	0.35
LSD ($P < 0.05$)	n.s	n.s	ns

n.s. - no significant differences among treatments.

Table 4. Effect of forage legumes on available soil P_2O_5 content at Wedza and Buhera sites

Treatments	Available soil P content (ppm)		
	Natural Region II	Natural Region III	Natural Region IV
Maize	7.13	9.14	8.30
Maize/cowpea	23.9	19.6	10.9
Maize/velvet bean	6.21	12.2	9.38
Maize/lablab	7.20	13.3	9.38
Cowpea	12.8	9.14	8.29
Velvetbean	20.3	21.2	11.1
Lablab	8.51	13.6	8.94
Ley	9.16	16.0	14.0
Mean	11.9	14.3	10.0
LSD ($P < 0.05$)	*	ns	ns

n.s. - no significant difference among treatments.

yield benefits. Monocropping of maize promotes unsustainable crop yields as revealed by lower maize yields. Ley gave significant residual N benefits especially in lower rainfall zones. Sole cropping and intercropping had similar effects on soil organic C build up. Residual soil P differed significantly between treatments in the higher rainfall region and seemed to depend on the demand of the crop combinations previously grown.

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TIME OF INCORPORATION OF DIFFERENT LEGUMES AFFECTS SOIL MOISTURE AND YIELDS OF THE FOLLOWING CROP IN MAIZE BASED SYSTEMS OF ZIMBABWE

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Abstract

This study reports on an evaluation of the performance of different legumes and their time of incorporation into soil on maize yields in Murewa and Shurugwi communal areas of Zimbabwe. Five legumes, Crotalaria grahamiana, Crotalaria juncea *(sunnhemp),* Mucuna pruriens, Vigna unguiculata *(Cowpea IT18) and* Glycine max *(Magoye) were planted in the 2000/01 season followed by maize in the 2001/02 season. The plots were subdivided into two, with legume incorporation at flowering in one sub-plot while legumes in the other plot were incorporated at the onset of the following season.* Mucuna *gave the highest biomass yields (4800 kg ha^{-1}) in Murewa while* Crotalaria grahamiana *had the highest yields (7500 kg ha^{-1}) in Shurugwi. Higher maize yields were obtained following incorporation of* Crotalaria grahamiana *(2900 kg ha^{-1}) than* Mucuna *(2300 kg ha^{-1}) in Murewa. However* Mucuna pruriens *had produced higher biomass in the previous season. Similar results were obtained in Shurugwi where* Crotalaria grahamiana *gave higher maize yields (1800 kg ha^{-1}) than* Mucuna pruriens *(1400 kg ha^{-1}). Generally, the early-incorporated legume plots gave higher maize yields in the second season than the late incorporated crop, although they were not statistically different. At the onset of the second season, soil was sampled from the different plots to analyze for moisture content.* Mucuna pruriens *was shown to conserve higher amounts of moisture than the other legumes, while late incorporated legumes had higher soil moisture content than early-incorporated legumes. It was concluded that* Mucuna pruriens *and* Crotalaria grahamiana *are potential best-bet legumes in the communal areas of Zimbabwe and in cases where labour is a constraint, farmers could incorporate their legumes late.*

Key words: Crotalaria grahamiana, Crotalaria juncea, Mucuna pruriens, Vigna unguiculata, Glycine max, *incorporation time*

Introduction

Declining soil fertility has undermined crop production in Zimbabwe smallholder farming systems. With the scarcity and ever-increasing prices of inorganic fertilizers, there has been a need to depend more on natural processes such as biological nitrogen fixation (BNF) in crop production systems. Soil improving herbaceous legumes have potential to improve soil fertility in various parts of the world (Fujita et al., 1992), and can be used as green manure and cover crops in areas of different agro-ecological characteristics.

Green manures have the potential to accumulate up to 250 kg N ha^{-1} per year (Giller and Wilson, 1991), and result in subsequent cereal yield increases of 600 to 4100 kg ha^{-1} (Peoples and Herridge, 1990). Evaluation of plants for soil fertility improvement remains a priority in this scenario to get the best plant species that are suitable for a particular area. Some plants have already been identified as best bets for green manuring in different situations (Buresh et al., 1993).

Proper management of plant residues for nutrient supply requires quantitative knowledge on its nutrient release characteristics. The use efficiency of the nutrients released by green manure remains a critical point in soil fertility management. Soil water dynamics and nutrient management are the main factors to consider to achieve sustainable integrated cropping systems in a semi-arid environment (Biederbeck and Bouman, 1994).

Incorporated organic materials have several functions in the soil other than supplying nutrients. They improve soil aggregation (Elliot and Papendick, 1986), reduce erosion (Young, 1989) and conserve moisture. The organic residues from green manure help to stabilize the soil structure, increase water-holding capacity of the soil, and increase the infiltration of moisture into the soil and percolation through the soil. Applying crop residues also leads to significant N and water interactions (Bolton, 1981).

Improvement in scarce available water usually triggers an improvement in the use efficiency of scarce available nutrients and *vice versa,* and this leads to improved crop production and less movement of nutrients into the environment. The OM reduces evaporation losses and hence improves N use efficiency, and provides nutrients other than N.

Under field conditions the fluctuations in soil water content affect the release of N from green manure. A quantification of this effect is essential for predicting the supply of mineral N at a particular time (Brar and Sidhu, 1995). There is a progressive decline in mineral N production within the soil with decrease in soil water level (Brar and Sidhu, 1995). In a crop rotation (intercropping or relay) that includes growing green manure plants, the cereal crop and the green manure plants are likely to compete for nutrients and moisture during the alternate season (McGuire et al., 1998). Green manure crops planted during the fallow period may use the moisture needed for seed germination at planting, however this disadvantage is counter-balanced by other benefits of growing green manure during the fallow period.

This study sought to evaluate the performance of *Crotalaria grahamiana, Crotalaria juncea, Mucuna pruriens, Vigna unguiculata* (Cowpea IT18*) and Glycine max* (Magoye) legumes, and the effects of time of incorporation of residues on maize yields in Murewa (high rainfall area) and Shurugwi (low rainfall).

Materials and Methods

The trial was conducted in two consecutive seasons (2000/01 and 2001/02). Green manure and grain legumes were grown in the first season followed by the maize in the second season. The experiment comprised of six treatments; three green manure crops (*Crotalaria grahamiana, Crotalaria juncea and Mucuna pruriens*), and two grain legumes (*Vigna unguiculata* (Cowpea) and *Glycine max* (Soyabean) and a control treatment with maize. The plots were split into two subplots for the analysis of the influence of time of incorporation of the residues at flowering and at the onset of the following season. For the maize control the plot was divided into two, one was bare (nothing grown in the subplot) and the other one had maize crops. Soil samples were taken when the plant material had been ploughed in the soil for the early incorporation subplots, while plants were still standing in the other subplots.

Plant materials for biomass production measurements were taken before residue incorporation in each subplot. Soil samples for moisture content analysis were taken in each plot from 0-10, 10-20, 20-30 and 30-40 cm depths. They were dried and the moisture content determined. The results were statistically analyzed using SAS software.

Results and Discussion

Biomass production

Green and grain legumes were grown in the 2000/01 season for biomass production, and the crop residues were incorporated into the soil at different times for a subsequent maize crop in 2001/02. Biomass production was higher in Murewa (high rainfall, @ 900 mm) than in Shurugwi (low rainfall, @ 450 mm)) in the 2001/02 season.

In Murewa, *Mucuna pruriens* produced the highest biomass followed by *Crotalaria grahamiana,* with cowpea producing the least biomass (Table 1). The N content of the residues was also determined. Adding all the *Mucuna pruriens* residues harvested was equivalent to the addition of 156 kg N per ha. In Shurugwi, *C. grahamiana* outyielded *Mucuna pruriens,* with *Crotalaria grahamiana* producing the highest biomass followed by *C. juncea* (Table 2). The biomass production of *Mucuna pruriens* was more affected by dry spells that came after crop establishment, while *C. grahamiana* produced higher biomass in similar conditions.

Soil moisture content and maize yields

In the second season (2001/2002) of the study, moisture content was determined just before planting of maize, and maize yields were determined at harvest. An analysis of variance of moisture content measurements showed that soil depth had a significant effect on moisture content. The interaction be-

Table 1. Legume biomass yields production for 2000/01 season in Murewa

Treatment	Biomass yield (kg/ha)	Total N (kg/ha)
Cowpea	1442	48.0
C. grahamiana	4535	137.0
Mucuna pruriens	4746	155.6
C. juncea	4120	118.5
Soybeans	2300	77.7
LSD	*1242.3*	*34.31*

Table 2. Legume biomass yields production for 2000/01 season in Shurugwi

Treatment	Biomass yield (kg/ha)	Total N (kg/ha)
Cowpea	1080	39.4
C. grahamiana	7507	248.3
Mucuna pruriens	4932	121.4
C. juncea	5129	144.1
Maize	2120 (grain)	
LSD	*1290.2*	*62.4*

tween factors tested in the study did not show any significant effect for moisture content (Table 3). The mean separations by $LSD_{0.05}$ (least significant difference) of depth ($LSD_{0.05}$ = 0.4975) showed that there was more moisture at 30-40 cm soil depth than other depths (Figure 1).

The effect of time of incorporation on moisture content approached significance (0.0677). The comparison of means using $LSD_{0.05}$ (0.35) shows as well that there is no significant difference in moisture content between late (4.20%) and early (3.87%) incorporation of green manure residues. Statistically, the difference between times of incorporation of crop residues was significant at 10%. The time of soil sampling might have influenced the difference between treatments on moisture conservation. Samples were taken when the soil was too dry because of early cessation of rain and late onset of rains for the following season. However, the numerical difference shows that late incorporation of green manure conserved more moisture. This might be because in early incorporation the soil is exposed to the sun, and this increases evaporation, while in late incorporation the plants continue to cover the soil, which reduces evaporation.

Table 3. ANOVA table of moisture content measurements

Source	DF	Type III SS	Mean Square	F Val	Pr > F
Treatment	5	2.01	0.40	0.36	0.8772
Depth	3	60.34	0.11	17.78	<0.0001
Time	1	3.86	3.86	3.42	0.0677
Treatment *Depth	15	16.00	1.07	0.94	0.5204
Treatment *Time	5	3.16	0.63	0.56	0.7309
Depth*Time	3	3.04	1.01	0.90	0.4460
Treatment *Depth*Time	15	8.42	0.56	0.50	0.9372
Residual	94	106.22	1.13		
Total	143	210.74			

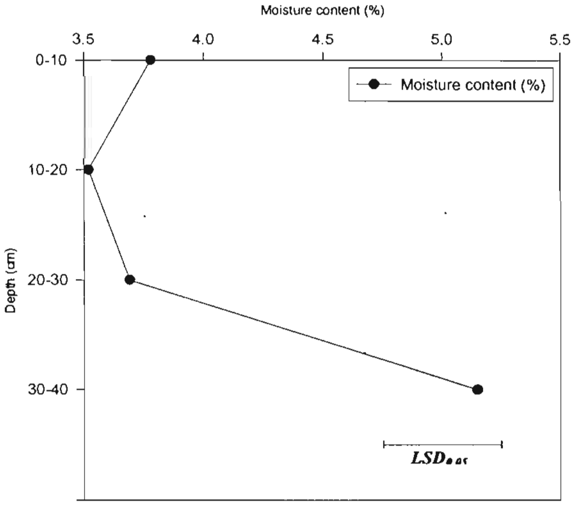

Figure 1. Moisture content at different depths after incorporation of legume residues before the onset of rains in the 2001/02 season

There was a significant difference within treatments between late and early incorporation of crop residues (Figure 2). Late incorporation of cowpea, *C. juncea, C. grahamiana* and maize conserved more moisture than early incorporation, while incorporation time of mucuna and soyabean residues did not show any significant effect on moisture conservation.

A trend of means (not statistically significant) of the different treatments shows that soyabean had the least moisture content, followed by *C. grahamiana, C. juncea,* cowpea, maize and the highest to conserve moisture was *Mucuna pruriens* (Figure 3). This might be due to how these plants cover the ground. *Mucuna pruriens* provides a good cover because of its bushy habit that in return reduces evaporation from the ground.

Addition of organic residues improves crop production through moisture conservation and nutrient supply to crops. Incorporated organic residues augment the water retention capacity of the soil by improving the structure and physical environment of soil. The maximum benefits are achieved by good timing of incorporation for growth of the subsequent crop. Consequently, there is need to conserve soil moisture to avert moisture deficits at the time of sowing, and provide much-needed nutrients at early stages of plant growth.

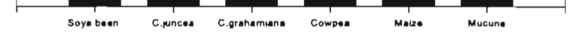

Figure 2. Moisture content prior to onset of rains following incorporation of five green manures (maize as a control) at different times of incorporation

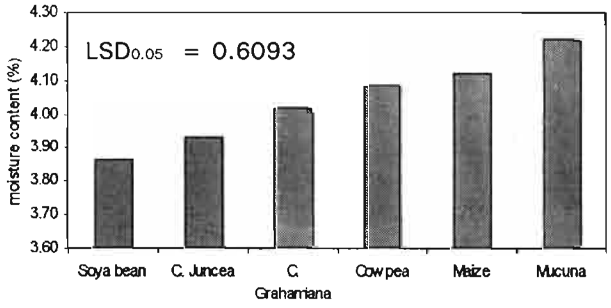

Figure 3. Effect of type of legume residues on moisture content (%)

Conclusion and Recommendation

Mucuna pruriens and *Crotalaria grahamiana* are potential best bets for soil fertility amelioration in communal areas of Zimbabwe. High biomass production was achieved for the two crops in the areas of study. *Mucuna pruriens* was more susceptible to dry spells that occurred in the middle of the growing season than *C. grahamiana*, but both crops need adequate moisture at planting for good establishment.

Higher maize yields were obtained in plots where *Mucuna* and *Crotalaria grahamiana* residues were incorporated compared to other legumes. Time of incorporation had an effect on yield of the subsequent crop; maize yields in early-incorporated plots were higher than in late incorporated plots for all legumes.

Incorporation of *Mucuna* residues conserved more moisture than other legumes, and moisture content was higher (but not significantly so) in late incorporated plots. This was probably due to the removal of plant cover in early incorporation, and hence high evaporation rates before the rains that depleted moisture in the soil.

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SOIL FERTILITY IMPROVEMENT THROUGH THE USE OF GREEN MANURE IN CENTRAL ZAMBIA

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Abstract

*Farmers identify low soil fertility as a major problem affecting crop production in Chibombo, Central Province, Zambia. This means fertilizer is a prerequisite to crop production, particularly maize. But the use of fertilizer is not often viable due to its high cost and poor availability. To boost crop production, there was need to test alternative cost-effective soil fertility improvement techniques. An experiment was therefore conducted to reduce the soil fertility problem using green manures. Sunnhemp (*Crotalaria juncea*) and Velvet beans (*Mucuna pruriens*) were grown either as sole crops or intercropped with maize (in the 1998/99 season). Continuous maize (fertilized and unfertilized) and a natural grass fallow were used as controls. Only phosphorus (50 kg P_2O_5 ha^{-1}) was applied to the unfertilized (zero nitrogen) maize while compound D (10:20:10:8 : N P K S) at 100 kg ha^{-1} was applied to the other maize treatments. No fertilizers were added to the green manure treatments. All maize plots (except unfertilized maize) were top dressed with urea at a rate of 23 kg N ha^{-1}. The dry matter yield of sunnhemp and velvet bean were determined just before flowering and all the above ground biomass was ploughed under. The maize was harvested at physiological maturity and grain weight determined. In the 1999/2000 season, maize was planted in all plots and cultural practices were the same as for 1998/99.*

Unfertilized maize had the lowest dry matter and grain yield (less than 1 t ha^{-1}) followed by maize after the grass fallow. All fertilized and green manure treatments yielded significantly more grain than unfertilized maize. There were no significant differences (p=0.05) between the maize grown after the green manures and that which received fertilizer. Incorporating sunnhemp biomass not only increased the yield of maize but also increased the organic matter content of the soil at the experimental sites.

Key words: Green manure, sunnhemp, velvet bean, profitability, sustainability, Zambia

Introduction

Low soil fertility is a major problem affecting crop production in Chibombo District of Zambia's Central Province. This has been made worse by farmers who commonly monocrop with maize year after year. This makes fertilizer use a prerequisite to crop production, particularly maize. The current prices of fertilizers are beyond the reach of most farmers in the area due to liberalization of the economy and the removal of fertilizer subsidies. The few that can afford fertilizers have reduced their application rates to far below those recommended, resulting in low crop yields per unit area cropped. This has affected both food availability and income for many people.

To boost crop production, there is a need to test alternative cost-effective soil fertility improvement techniques. An option identified by the farmers through participatory rural appraisal (PRA) was the use of green manures notably sunnhemp (*Crotalaria juncea*), velvet bean (*Mucuna pruriens*) and some agroforestry tree prunings such as *Sesbania sesban*. These practices were part of the farming systems before mineral fertilizers and most elderly farmers still recall and appreciate the usefulness of the two green manure species. *Crotalaria* and *Mucuna* have shown to be excellent N_2-fixers in a wide range of environments (Bowen, et al. 1988; Kolar et al. 1993; MacColl, 1990; Yost et al. 1985). Green manures have the potential to accumulate up to 250 kg N ha^{-1} yr^{-1} (Giller and Wilson, 1991) resulting in cereal grain yield increases of 600 – 4100 kg ha^{-1} (Peoples and Herridge, 1990). The use of a green manure may also boost the levels of soil organic matter resulting in improved soil structure, better root proliferation and soil water holding capacity. This would in turn increase crop vigour and yields. There is a need therefore to evaluate the beneficial effects of these green manures on farmers' fields in Muswishi Agricultural Camp in Chibombo District and document the results.

Project Objectives

The overall objective was to address the soil fertility problem using green manures.

Specific objectives were to:

- Test the viability of velvet bean and sunnhemp as soil fertility improvement legumes within the farming system.
- Assess the beneficial effects of incorporating green manuring into the cropping system.

Materials and Methods

The field experiment was conducted at Muswishi Agricultural Camp in Chibombo District of Central Zambia. The Mushemi soil series at Chibombo is described as a Fine Kaolinitic Isohyperthermic Oxic Paleustalf (Soil Survey, 1992). The surface soil was sampled to a depth of 20 cm, dried and ground to pass through a 2 mm sieve. This was then analyzed for soil pH (in 0.01 M $CaCl_2$), total nitrogen, organic carbon (Wakley and Black, 1934), exchangeable cations (1.0 M ammonium acetate, pH 7.0) and available phosphorus (Bray and Kurtz, 1945). The soil sample was also analyzed for particle size using the pipette method. Selected chemical properties of the soil are given in Table 1.

Field Work in the 1998/1999 Season

The following treatments were applied: Maize (zero nitrogen), sunnhemp sole crop, velvet bean sole crop, maize/sunnhemp intercrop, maize/velvet bean intercrop, maize (fertilized) and a grass (natural) fallow. Triple super phosphate was applied to unfertilized maize (zero nitrogen) at 50 kg P_2O_5 ha^{-1}. Compound D (N P K S : 10 20 10 8) was applied to the other maize/GM intercrop treatments at 100 kg ha^{-1}. No fertilizer was added to the sole green manure treatments. The natural fallow was left intact. Maize hybrid variety MM604, velvet bean (*Mucuna* cv. W. NIRS 16) and sunnhemp (*Crotalaria Juncea* cv. NIRS 4) were planted.

Maize and velvet bean were planted to give a plant population density of about 44,000 plants per hectare while sunnhemp was planted at a seeding rate of about 20 kg ha^{-1}. Plot sizes were 12 m x 8 m for all treatments. All maize plots (except unfertilized maize) were top dressed with urea at a rate of 23 kg N ha^{-1}.

Dry matter yields of sunnhemp and velvet bean were determined just before flowering and all the above ground biomass was ploughed under. The maize was harvested at physiological maturity from the fertilized and unfertilized plots and the grain weight determined.

Field Work in the 1999/2000 Season

To see the benefits of the green manure, the experiment was continued in the 1999/2000 season. Maize was planted in all plots including the natural grass fallow plot which had been left intact the previous season. All cultural practices were the same as in 1998/99. All plots (except unfertilized maize) were top dressed with urea at a rate of 23 kg N ha^{-1}. Mid way through the season, soil samples were collected from all the plots and were analysed for parameters as highlighted above.

The experiment was laid out in a randomized complete block design with farmers as replicates. Statistical analysis of the data was done using Proc GLM in SAS (SAS Institute, 1985). Where appropriate, treatment means were compared using the least significant difference method (Steel and Torrie, 1980).

Results and Discussion

Results from the first season were mainly on soil changes and yields of green manures. The second season results covered the beneficial effects of the green manures on both maize yields and improvement to soil fertility as highlighted below.

Results of the 1998/1999 season

Generally, the soils in the area were acidic with very low soil organic matter (Table 1). Unfertilized maize plots had very poor growth with subsequent low grain yields (Table 2). Additionally, the experiment was planted late, in late December, after the recommended planting date of December 21. The reason for this was because the benefit due to the green manure was the main issue being tested, i.e., the yield of maize after the green manure.

One of the problems faced was that since the sunnhemp and velvet bean were planted at the same time with the maize in the intercropped plots, maize

Table 1. Selected chemical characteristics of soils used in the demonstrations

Name of Farmer or Farming Group	% C	pH $CaCl_2$	P ppm	K	Ca	Mg
				———	me%	———
1 Kanakashiwa Club	0.50	4.9	39	0.18	2.3	0.2
2 Mr. B. B. Muteto	0.52	5.1	19	0.28	2.1	0.2
3 Mr. Chenje	ND					
4 Muswishi Women Group	ND					
5 Mr. Kamilo	0.72	4.6	72	0.20	3.2	0.2
6 Mr. Maputa	0.41	5.1	15	0.26	2.1	0.2
7 Kalangwa Women Club	0.45	5.2	28	0.15	2.0	0.3
8 Rural Resettlement Center	0.50	4.9	39	0.18	2.3	0.2
9 Shana'ngombe Queen/ Catherine	0.60	4.6	19	0.36	2.9	0.4
10 Chipaba Women Club	0.49	5.0	12	0.36	2.9	0.4
11 Mr. Katiti John	0.73	4.3	16	0.15	1.4	0.3
12 Mukuyu Women Club	0.75	4.7	10	0.13	2.5	0.6
13 Mr. Manyelekete L.	0.49	4.9	5	0.13	2.2	0.2

ND - Not determined

Table 2. Grain yields of maize and stover yields of velvet beans and sunhemp

	Name of Farmer or Farming Group	Maize Grain Yield		Velvet bean Stover Yield		Sunnhemp Stover Yield	
		No Fert	Fertilized	Inter crop	Sole crop	Intercrop	Sole Crop
		––––––––––––––kg ha^{-1}––––––––––––––					
1	Kanakishiwa Club	933	1533	1931	2133	2883	3183
2	Mr.B.B.Muteto	866	1200	1865	2067	2550	2850
3	Mr Chenje	750	950	1798	2000	2150	2450
4	Muswishi Women Group	978	1026	2142	2563	3211	3561
5	Mr Kamilo	880	1200	1878	2080	2550	2850
6	Mr Maputa	867	2000	1865	2067	3350	3650
7	Kalangwa Women Club	920	1200	1918	2120	2550	2850
8	Rural R. Centre	No Data*		1866	2556	3527	3926
9	Shana'ngombe	No Data		1864	2864	3262	3269
10	Chipaba WomenClub	1027	2733	2025	2227	4083	4383
11	Mr. Katiti John	1333	2467	2331	2533	3817	4117
12	Mukuyu Women Club	800	961	1798.0	2015.6	2150.8	2864.6
13	Mr Manyelekete L.	867	1133	1864.9	2693.5	2458.6	2786.9

*-No Data, the maize was grazed by goats

growth was reduced. As a result, maize was ploughed into the soil together with the green manures. Originally, it was expected that the maize should have been left standing. To obtain a crop of maize from the intercrop, the planting dates of the maize and the green manures should be staggered with the maize being planted first (Gilbert, 1998). Sunnhemp had generally higher stover yields than velvet bean, as can be seen from Table 2.

Results of the 1999/2000 season

To see the benefits of the green manures, maize was planted in all plots at all demonstration sites. Unfortunately, there was a drought immediately after planting which adversely affected germination at most sites, though gap filling was done in most fields. Nevertheless, the maize at three sites (Kanakashiwa club, Kamilo's and Shana'ngombe's farms) established well.

The unfertilized maize had the lowest dry matter and grain yield followed by the maize after the grass fallow (Table 3). The mean grain yield of the unfertilized maize was less than 1 t ha^{-1}. There were no significant differences (p=0.05) between the maize grown after the green manures and the fertilized maize. During the drought spell, it was noted that the maize grown after the green manure species was less affected than that after the grass fallow or even the fertilized maize. Incorporation of sunnhemp biomass increased not only the yield of maize but also increased the organic matter content of the soil at the experimental sites (Tables 3 and 4). No other effects of green manures on soil properties were observed, perhaps because a single season's inputs were not sufficient to greatly change the measured properties.

Table 3. Influence of green manures on the dry matter and grain yield of maize

Treatment	Dry matter yield	Grain yield
	kg ha^{-1}	
Maize after Grass Fallow	2720bc	1271bc
Unfertilized Maize	1884c	877c
Fertilized Maize	4137ab	2104ab
Maize after Velvet Bean	4891a	2367a
Maize after Sunnhemp	4523a	2608a
Maize after Maize/Velvet Bean Intercrop	4409a	1969ab
Maize after Maize/Sunnhemp Intercrop	3922ab	1902ab
LSD (0.05)	1545	842
%CV	43.1	47.5

Results of the Cost Benefit Analysis

Analysis of costs and benefits shows that the treatment with sole sunnhemp had the highest gross margin and returns to capital (Table 5 and Figure 1). In terms of gross margin, sole velvet bean was second while fertilizer was third in profitability.

Intercropped sunnhemp was second to sole sunnhemp in profitability using the return to capital criteria. This demonstrated the superiority of using sunnhemp as a fertility enhancing technology to substitute for mineral fertilizer. The results also show that even though using chemical fertilizer raises the gross benefits and margin, the return to

Table 4. Influence of green manures on soil fertility improvement

Treatment	% C	pH	P	K	Ca	Mg
		$CaCl_2$	ppm	––––me%––––		
Unfertilized Maize	0.54b	4.6	18.3	0.15	0.82	0.22
Maize after Grass Fallow	0.59ab	4.6	16.3	0.16	1.02	0.24
Maize after Velvet Bean	0.59ab	4.7	14.6	0.15	0.86	0.23
Maize after Sunnhemp	0.66a	4.6	16.2	0.17	0.92	0.22
LSD (0.05)	0.08	ns	ns	ns	ns	ns
%CV	16.4	4.7	36.8	17.0	35.1	35.2

Table 5. Summary table of cost-benefit analysis. Zambia K/ha)

Treatment	Economic indicator			
	Gross Benefit	Total Costs	Gross Margin	Return to Capital
Fallow	571950	224000	347950	1.6
Intercropped velvet bean	886050	266000	620050	2.3
Sole velvet bean	1065150	266000	799150	3.0
Fertilizer	963000	224000	739000	3.3
No Nitrogen Fertilizer	394650	91000	303650	3.3
Intercropped sunnhemp	855900	182000	673900	3.7
Sole sunnhemp	1173600	182000	991600	5.4

I US $ - Zambia K 2500 (1999/2000)

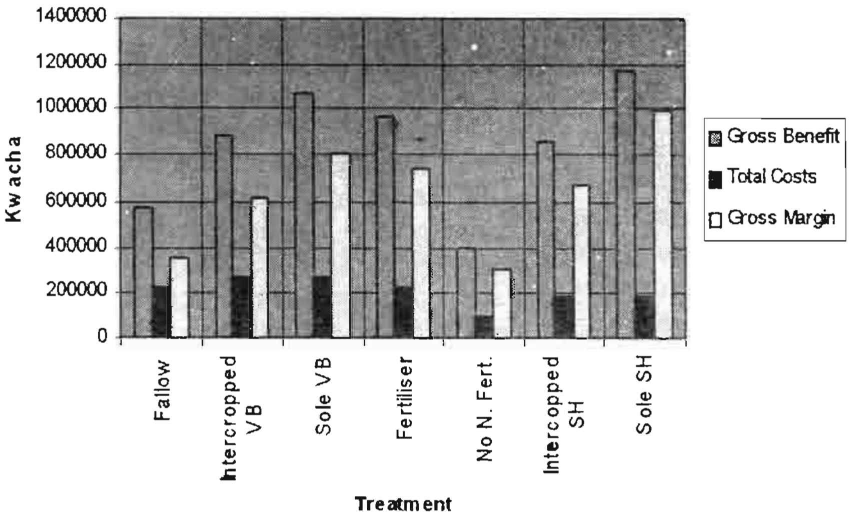

Figure 1. Cost-benefit analysis of soil fertility improvement technologies Muswishi, 1998-2000

the capital invested is comparable to not applying fertilizer.

Problems encountered, lessons, limitation of the work completed and farmer assessment of the technology

Whilst farmers appreciated the increase in yield due to the green manures, they pointed out it was very difficult for them to justify weeding green manure crops. This is because other farm operations compete for the same labour. It is possible that this problem could be overcome by planting the green manures in the same plots where maize has already been planted, at first weeding of the maize crop. Some farmers also complained about the labour involved in ploughing the green manures under, especially where there is no animal draught power.

Conclusions

The soils of Muswishi Agricultural Camp were very low in soil organic matter content rendering them infertile for most crops without external nutrient sources.

These results show that incorporating the green manures into the local farming systems has beneficial effects by increasing maize yields. However, the green manures alone may not be sufficient to provide all the nutrients needed for the maize crop to full maturity. The maize grown after the green manures need supplementing with some inorganic fertilizer at the top dressing stage. The advantage is that the rate is less than the recommended one. Further, green manures are mainly used as a source of nitrogen while other elements like phosphorus and potassium may have to be added to avoid depleting the soil further of these essential nutrients.

The number of green manure species used in the demonstration was limited. More species should be tried in the area to see if they can perform better and provide farmers with a wider selection.

Analysis of costs and benefits showed that the treatment with sole sunnhemp had the highest gross margin and return to capital. It was superior to all others. Sole velvet bean had the second highest gross margin, while fertilizer was third in profitability.

The methods employed in this project allowed farmers to participate in the project from inception to conclusion. By farmers identifying the problem of soil fertility themselves and suggesting that green manures be used and then seeing how they were used to alleviate the problem meant that farmers felt they owned the project and results. As such, they not only contributed land to the project but also labour, which was essential. Researchers also made sure that whatever maize was obtained from the project was returned to the farmers after yield determination.

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EFFECT OF SURFACE APPLICATION AND INCORPORATION OF SUNNHEMP AND VELVET BEAN GREEN MANURES ON THE PRODUCTION OF FIELD CROPS IN ZAMBIA

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Abstract

The use of green manure crops for soil fertility improvement in Zambian cropping systems is becoming increasingly important as a cheap source of biologically fixed N. Green manure crops can be used alone or supplemented with mineral fertilizer to reduce the cost of crop production. A field study on green manure placement was carried out at the University of Zambia field station during the 2001/2002 cropping season, following a request from small-scale growers through the Land Management and Conservation Farming (SCAFE) project to evaluate green manure placement. The experiment was designed to evaluate the most cost effective way to apply green manure biomass in small scale cropping systems and to determine the most appropriate green manure crop for use in these cropping systems. The experiment was conducted in two cropping seasons. The first phase (2001/2002 cropping season) consisted of production and placement of the biomass. The second phase (2002/2003 cropping season) consisted of growing a test crop of maize over the biomass treatments applied. In the first cropping season, five varieties of green manure crops were compared to a grass fallow.

The results of the first cropping season are described. Biomass production of 7.5, 5.8 and 4 t ha^{-1} *was highest (*$P < 0.05$*) for the sunnhemp spp.* Crotolaria zanzibarica *and* Crotolaria juncea, *and velvet bean variety W. Somerset respectively. The percent N content of the biomass was highest (*$P < 0.05$*) for velvet bean variety W. Green (3.2%) followed by* Crotolaria juncea *(2.98%). Sunnhemp spp. produced significantly (P <£ 0.05) more total N, averaging 211 kg N ha*$^{-1}$*, than velvet bean (which averaged 98 kg ha*$^{-1}$*) and grass biomass (10 kg N ha*$^{-1}$*). The P added to the soil (6 kg ha*$^{-1}$*) was highest for sunnhemp species, followed by velvet bean (2.8 kg ha*$^{-1}$*) and least of all the grass, with 1 kg ha*$^{-1}$*. The maximum amount of P produced by the test crops was less than 22 kg P ha*$^{-1}$*, and this was considered insignificant for normal plant growth. The major contribution of green manure crops is therefore through their supply of N to subsequent non-legume crops. For small-scale crop production in Zambia, sunnhemp green manure crops were likely to supply adequate N for cereal crops. In the case of velvet bean, half of the N will have to be supplied from mineral and organic fertilizers. The amount of P contained in the green manure biomass tested, was insignificant for plant growth. The P requirement for crop growth will have to be provided through inorganic fertilizers or organic manures fortified with P.*

Key words: Sunnhemp, velvet bean, phosphorus, Zambia

Introduction

Often small-scale farmers identify soil infertility as one of the major limitations to crop production in Zambia. The use of sufficient inorganic fertilizer is not sustainable for resource poor farmers because these fertilizers are costly and not available at the right time. Green manure crops are increasingly used in our cropping systems because the technology provides a cheaper source of biologically fixed N. Green manure crops have the potential to accumulate up to 250 kg N ha^{-1} per year (Giller et al. 1991; Peoples et al. 1990) resulting in cereal yield increases of 600 to 4100 kg ha^{-1} (Peoples et al. 1990). *Crotolaria* and *Mucuna* have been shown to be excellent N fixers in a wide range of environments (Rattray et al. 1952; Bowen et al. 1998 and Yost, 1985). *Mucuna* grows vigorously producing over 10 t ha^{-1} of above-ground biomass for incorporation into the soil. Traditionally, small-scale farmers cultivate by making ridges that allow the burying of plant residue, leaving that material on the surface, or burning the plant residues. Green manure crops were introduced for soil structure improvement and organic matter accumulation (Allison, 1973). Improvements in crop yield, soil aggregation, crumb structure and hydraulic conductivity have been observed following green manure application (Allison, 1973; Faris, 1986, Elliot et al. 1986). Farmers through the Land Management and Conservation Farming

(SCAFE) requested an evaluation of green manure biomass placement. The experiment was designed to evaluate the most cost effective way to place biomass and to determine the most appropriate green manure crop.

Materials and Methods

The experiment was planned to be conducted over two cropping seasons, with the first season (2001/2002 cropping season) consisting of production and placement of the biomass and the second season (2002/2003 cropping season) growing of a test crop of maize over the biomass treatments that were applied. Two factors were investigated in the experiment, a) a source of N from the green manures and b) placement of the biomass. The biomass was labeled with ^{15}N, a stable isotope of nitrogen, to quantitatively evaluate the contribution of N from the green manure biomass. This technique also allows evaluation of the fate of organic N in the biomass.

In the first season, the experiment consisted of six treatments, composed of two sunnhemp species (*Crotolaria juncea* and *Crotolaria zanzibarica*) and three velvet bean varieties (W. Green, W. Sam and W. Sommerset). The green manure crops were compared to a grass fallow. The experiment was laid out in a randomized complete block design in three replicates. One factor, the source of N, was evaluated in the first season. The field trial was established during the 2001/2002 cropping season at the University of Zambia Field Station in Lusaka (15° 25′ S and 28° 20′ E, at an elevation of 1250 m above sea level). The soil is a fine loam and is a isoghyperthermic oxicpaleustaff under the FAO classification. The soil pH was 6.3.

An area of land of 48 m x 17 m was ploughed and sown to five varieties of green manure crops on 1 February 2002. After ploughing the field and before sowing, a soil analysis was done for soil pH, total nitrogen, available phosphorus, exchangeable potassium, calcium, magnesium and organic matter. In the 14th week of plant growth, the biomass was cut and weighed before being ploughed under or surface applied onto the field. A sample of biomass was analyzed for nitrogen, and phosphorus by the Kjeldahl and Ammonium phosphomolybdate methods, respectively. This was to determine the contribution of nutrients contained in the above ground biomass of the green manure crops. Analysis of variance was done using MstatC computer software. Treatment means were separated using the Duncan's Multiple Range Test. The parameters of biomass yield, nitrogen and phosphorus content and total nitrogen and phosphorus yield were evaluated in the selection of the green manure crops. This paper reports the results of phase one of the trial to evaluate the most appropriate green manure crop among the five that were tested.

Results and Discussion

Above-ground dry matter production of 7.5, 5.8 and 4 t ha^{-1} was highest ($P<0.05$) for sunnhemp species *Crotolaria zanzibarica* and *Crotolaria juncea* and velvet bean variety W. Somerset respectively. This velvet bean variety produced similar biomass yield to *Crotolaria juncea*. This is illustrated in Figure 1.

The %N content of 3.2% N for velvet bean variety W. Green was highest followed by *Crotolaria juncea* at 2.98%. Grass biomass contained the least amount of nitrogen (0.6%). W. Sam, W. Somerset and *C. zanzibarica* contained similar amounts of nitrogen with an average of 2.8% (Figure 2). Sunnhemp species produced significantly ($P < 0.05$) more total N (averaging 211 kg N ha^{-1}) than velvet bean and grass biomass, which averaged 98 kg ha^{-1} and 10 kg N ha^{-1} respectively (Figure 3).

The %P content was similar for all the biomass. The P added to the soil (at 6 kg ha^{-1}) was, however, highest for the Sunnhemp species followed by 2.8 and 1 kg P ha^{-1} produced by velvet bean varieties and grass respectively (Figure 4).

The maximum amount of P produced by the test crops was less than 22 kg P ha^{-1}, and this is considered insignificant for normal plant growth.

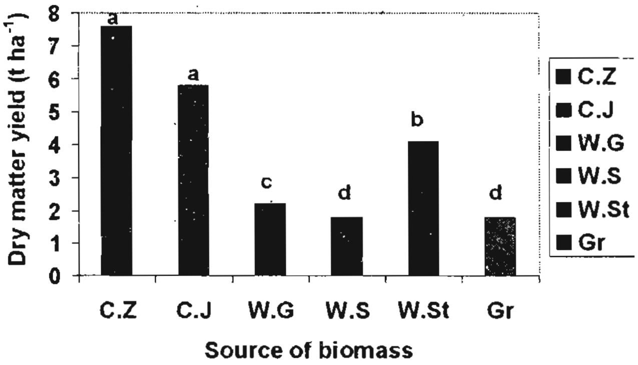

Figure 1. Comparison of biomass yield in different green manure crops.
Means followed by the same letter are not significantly different.

Key:

C.Z. - Sunnhemp species *Crotolaria zanzibarica*
C.J. - Sunnhemp species *Crotolaria juncea*
W.S. - Velvet bean variety W. Sam.
W.St. - Velvet bean variety W. Somerset.
W.G - Velvet bean variety W. Green.
Gr. - Grass fallow.

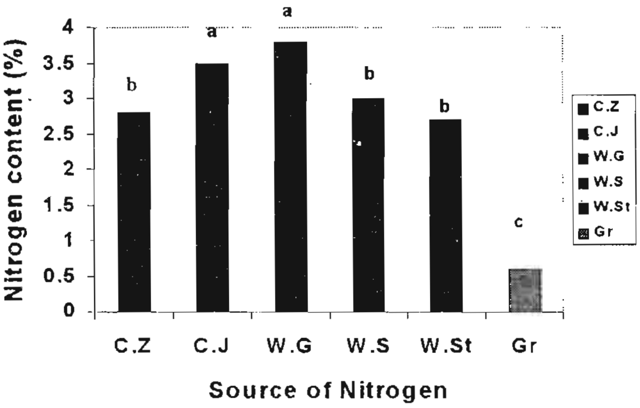

Figure 2. Comparison of N content among various types of biomass.
Means followed by the same letter are not significantly different.

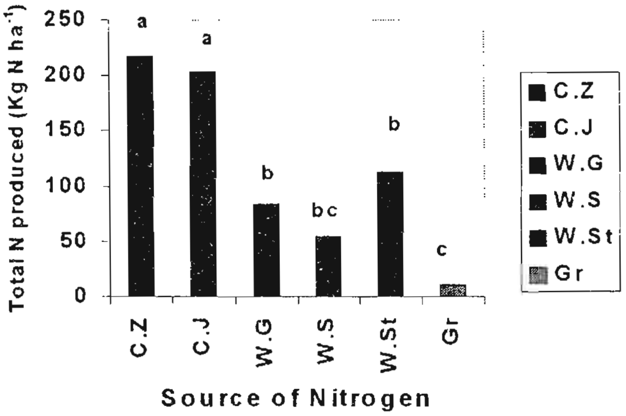

Figure 3. Total N produced by various types of biomass.
Means followed by the same letter are not significantly different.

Conclusion and Recommendations

The major contribution of the green manure crops evaluated was found to be their supply of nitrogen to the subsequent crop. For small-scale producers, sunnhemp species were likely to supply adequate nitrogen for cereal crops. In the case of velvet bean varieties, half of the total N required by cereal crops would have to be supplemented from organic and mineral sources. The amount of P contained in the biomass was insignificant for normal plant growth. External sources of P have to be added to crops at the recommended rates.

Future Research Needs

There is need to quantify the nutrient contribution to the soil by the green manure crops, i.e. evaluate the below ground effect of the green manure fallows.

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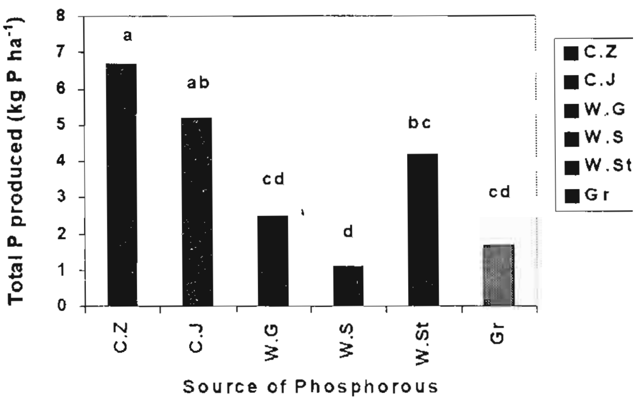

Figure 4. Total P produced by various types of biomass.
Means followed by the same letter are not significantly different.

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Questions and Answers

Legume Benefits on Maize Productivity and Soil Properties

To Walter Mupangwa, et al.

Q: Can the smallholder farmers accept the application of high rates of basal fertilizers, e.g. the 250 kg/ha Compound D used in your study? Is it not advisable to look at a lower range, e.g. 150 kg/ha of compound fertilizer?
A: Our soils are low in P yet legumes have a relatively high P demand. If the dairy farmers invest in improving soil fertility, they can recover such costs from milk sales or livestock sales. For meaningful biomass from legumes to be produced, the forage legumes have to be fed, i.e. adequate nutrients should be available.

C: High rates of manure and basal fertilizer, e.g. 250 kg ha^{-1} of basal fertilizer, seem to make it difficult to extend otherwise good technologies to some of our resource poor farmers. Isn't it advisable to look at a range of say 150 – 250 kg ha^{-1} to allow extension personnel to target their different clientele?

To Bonaventure Kayinamura, et al.

Q: What is the method of incorporation used? Can this method be used on a large area?
A: Farmers in Shurugwi acknowledged that it can be done in their fields.

Q: Mucuna without inputs failed dismally in Soil Fert Net trial plots in Murehwa/Wedza in the 1996/1997 season and was almost written off then. What were the soil characteristics of the study sites? Did you add any basal fertilizers?
A: Single superphosphate was added at 200 kg/ha. These soils are sandy and were used for maize cropping by the farmer.

C: Follow-up clarification about the Soil Fert Net mucuna trials. The experiments that failed were specifically sited on exhausted and fallowed fields. They produced little or no biomass. The aim with that work was to test rehabilitation strategies. Spatial deployment issues on farm are very important for performance.

Q: Is the moisture difference between late and early incorporation really significant? Since 2001/2002 was very dry, maize might respond to moisture benefits of late incorporation, but maize showed main benefits with early incorporation.
A: The moisture difference between early and late incorporation is not statistically different at 5% but numerically early incorporation has an advantage of releasing nutrients early, which might outdo moisture content effects on yields.

C: For your figures, there is need to keep consistency in the axes, species 1 =sunnhemp; species 2 = Crotalaria. Sunnhemp is a species of *Crotalaria*. Please use the scientific name to reduce confusion.

PERFORMANCE OF GREEN MANURES AND GRAIN LEGUMES ON SEVERELY ACIDIC SOILS IN NORTHERN ZAMBIA, AND THEIR EFFECT ON SOIL FERTILITY IMPROVEMENT

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Abstract

Green manures have been used in various parts of Zambia, especially where soils are not acidic. There the green manures have been reported to produce large amounts of biomass that leads to improved soil fertility once incorporated into the soil. We assessed the production of above-ground biomass by two green manures and the grain production of two grain legumes to see how they affect the fertility of an acidic Ultisol and an acidic Alfisol. Green manures were incorporated at flowering while grain legume residues were incorporated after harvesting the grain. On the Ultisol, sunnhemp produced the most above-ground biomass (2800 kg ha^{-1}) and velvet bean produced 2000 kg ha^{-1}. Soyabean grain production was 792 kg ha^{-1} and cowpea grain yield was just 9.2 kg ha^{-1}. However, on the Alfisol velvet bean produced the highest above-ground biomass (2100 kg ha^{-1}) and sunnhemp produced 2000 kg ha^{-1}. Grain yield was highest for soyabean (1313 kg ha^{-1}) and lowest in velvet bean (83 kg ha^{-1}). Velvet bean constantly produced high above-ground biomass on both soil types. Thus it can be used as a green manure on both soils. The results show that cowpea might be unsuitable for grain production on the Ultisol while soyabean can be used for grain production. Cowpea seems inferior on both soil types, while sunnhemp and velvet bean appear to be ideal for the production of biomass on both acid soils. Thus, these two green manures can be promoted for soil fertility improvement on these acid soils in northern Zambia.

Key words: Green manures, soil acidity, Al saturation, P-fixation

Introduction

Soils in Northern Zambia are general acidic, infertile and of low productivity. As in other parts of Southern Africa, nitrogen is the nutrient most limiting crop production on these soils. Use of the mineral fertilizers needed to increase crop yields has become an almost impossible option for smallholder farmers due to the escalating prices resulting from the removal of subsidies on fertilizers and other agricultural inputs. This has seen many farmers resorting to biological methods of soil fertility management. Green manure use is one way to increase the basket of options for small-scale farmers. Several green manure legumes have been identified for use in Southern African cropping systems. However, the boundary conditions under which they perform best have not been ascertained.

There is need to establish the soil and climatic conditions for legume adaptation so they can be used to improve soil fertility in specific environments. Increasing human population densities and the resultant pressure on land limits the growing of legumes for green manure in some areas as farmers have to grow crops that ensure they are food secure. The increase in human population has seen intensification of agriculture without replenishment of depleted nutrients. Population pressure has led to expansion of agricultural activities into marginal lands resulting in crop production declines.

Research on practical options that are affordable to farmers such as intercropping of green manures with other crops to maximize area under cultivation is necessary, as well as exploring the use of grain legumes for home consumption and for soil fertility improvement. Green manuring was an integral part of some local farming systems before inorganic fertilizers became widely used. Most elderly small-scale farmers recall and appreciate the usefulness of two green manures, *Crotalaria* spp. and *Mucuna* spp., which have shown a high potential to fix atmospheric nitrogen symbiotically in a wide range of environments (Bowen et al. 1988; Kolar, et al. 1993; MacColl, 1990; Yost et al. 1985).

Green manures have been reported to possess the potential to accumulate up to 250 kg N ha^{-1} yr^{-1}. (Giller and Wilson, 1991; Peoples and Herridge, 1990). This amount of N leads to an increase in yield of cereals, reported to be between 600 and 4100 kg ha^{-1} (Peoples and Herridge, 1990). The use of organic manures has been shown to improve soil organic matter (Mwale et al. 2000) in non-acid soils of southern Zambia. The improved organic matter status in turn leads to improved soil structure and better root aeration leading to improved water holding capacity of the soil. This directly causes an increase in crop vigour and grain yields.

The objective of this project was to evaluate the biomass production of sunnhemp and velvet bean and the grain production of cowpea and soyabean on two acid soils of Northern Zambia.

The work was designed to specifically:

- Determine the influence of soil characteristics on legume establishment, growth and biomass production,
- Assess the contribution of grain legumes and green manures to soil fertility.

Materials and methods

This experiment was conducted for two agricultural seasons: 2001/2002 and 2002/2003. The worked reported in this paper is for the 2001/2002 season. The experiment was conducted on the Misamfu soil series at Misamfu Regional Research Centre (10° 10′ S, 31° 12′ E) on an Ultisol and at Mungwi District (10° 10′ S 31° 15′ E) on an Alfisol. A composite soil sample was collected at 0-20 cm soil depth from each site of the trial. The soil sample was dried and ground to pass through a 2 mm sieve. The following properties were analyzed: pH (in 0.01 M $CaCl_2$), Al saturation, exchangeable acidity, P (Bray 1) total nitrogen (Kjeldahl), organic carbon (Walkley and Black, 1934), exchangeable cations (1.0 M ammonium acetate, pH 7.0). Particle size was also determined using the Pipette method. Table 1 shows the soil chemical data.

Sunnhemp, velvet bean, cowpea and soyabean sole crop treatments were planted. Velvet bean was planted to give a plant population density of 44000 plants ha^{-1}, sunnhemp was drilled at a seeding rate of about 20 kg ha^{-1}, while cowpea and soyabean were also drilled at about 80 kg seed ha^{-1}. The plot sizes were 5 x 5 m. The design was an RCBD replicated three times.

The above ground biomass of sunnhemp was determined at the flowering stage and then ploughed under while cowpea and soyabean grain were harvested at maturity along with the above ground biomass production for green manures and grain production for the grain legumes.

Table 1. Initial chemical soil properties of a composite sample (0-20 cm depth) of the experimental sites in northern Zambia

Soil characteristics	Misamfu	Mungwi
pH (in 0.01 M $CaCl_2$)	4.5	4.7
Organic carbon (%)	0.60	1.31
Bray 1 P (mg kg^{-1})	1.07	2.65
Exch. K (cmol$_c$kg^{-1})	0.47	0.97
Exch. Ca (cmol$_c$kg^{-1})	0.28	0.84
Exch. Mg (cmol$_c$kg^{-1})	0.03	0.08
Al saturation (%)	20	10

Results and Discussion

Both soils are acidic but the Mungwi soil is slightly more fertile than the Misamfu soil, as seen from the available P and pH (Table 1). Green manures established well at both sites. Soyabean established well on both soil types but cowpea establishment was bad on the two sites because it was attacked by pests.

Above-ground biomass produced by the two green manures was similar on both soil types (Table 2). Mungwi site produced a higher grain yield of soyabean than the Misamfu site while cowpea yield was poor throughout (Table 3). The green manures tested on these acidic soils in northern Zambia seem to have the potential to produce adequate biomass to allow a cereal crop to produce sufficient grain yield. Breman and Reuler (2002) reported a cowpea above-ground biomass of 2800 kg ha^{-1}. On the acid soils of Northern Zambia, from 2000 to 2767 kg ha^{-1} sunnhemp above-ground biomass was produced (Table 2). The total content of N accumulated by legume green manures during N_2-fixation has been measured by various authors. Up to 250 kg N ha^{-1} yr^{-1} was reported to accumulate in green legumes (Giller and Wilson, 1991; Peoples and Herridge, 1990). Assuming an average 3% N concentration, then from our experiments, sunnhemp was able to produce about 59 kg N ha^{-1} on the Mungwi soil and 83 kg ha^{-1} N on the Misamfu soil, while velvet bean produced 63 and 60 kg N ha^{-1} respectively on these two soil types. Since commercial fertilizers are expensive, a smallholder farmer would be able to produce enough maize grain yield to meet food security by planting the green manure, because they would be able to supplement part of the N fertilizer requirement of 120 kg N ha^{-1} recommended for maize in Zambia (McPhillips, 1987).

The grain yield of cowpea was very low on the Misamfu soil due to low fertility. However, soyabean performed much better on that same soil. Cowpea was also diseased and this was largely responsible for the low grain yield obtained. On the

Table 2. Means of green manure above ground biomass (kg ha^{-1}) in Zambia

Treatment	Misamfu	Mungwi
Sunnhemp	2767	1967
Velvet bean	2000	2100
CV (%)	46.09	13.17

Table 3. Means of grain legume grain yields (kg ha^{-1}) in Zambia

Treatments	Misamfu	Mungwi
Cowpea	9.2	83.3
Soyabean	792	1313
CV (%)	115.8	36
Probability	0.18	0.03

Mungwi soil, cowpea and soyabean produced a higher grain yield compared to the Misamfu site. This again follows the fertility trend of the two soil types as shown in Table 1.

Cowpea production was well short of potential. The potential rainfed production of cowpea has been reported to be 1200 kg ha^{-1} of cowpea grain, in addition to the 2800 kg ha^{-1} of folder or green manure, in the Sudanian savannah (Breman and Reuler, 2002). However, on the acid soils of Northern Zambia, less than 100 kg ha^{-1} was produced (Table 3). This could be due to high Al saturation common in these soils (Table 1), which might affect root-rhizobium symbiosis involved in N_2 fixation, as well as to low available P leading to the low grain yield. According to Breman and Reuler (2002), legumes will flourish under conditions of poor N but available P. The acid soils of Northern Zambia are low in both N and in available P (this is due to P fixation by these acid soils).

Soyabean grain yield was relatively higher on the more fertile Mungwi soil than the more acid soil (Table 3). In the less acidic soils of southern Zambia, average grain yield of 2000 kg ha^{-1} with rhizobium applications have been recorded (McPhillips, 1987). Thus even under acid soils, reasonable yield of soyabean grain can be achieved as long as seed is inoculated prior to planting.

Conclusion

Despite the soils being acidic, establishment of green manures and soyabean was good. Mungwi soil, being slightly fertile than Misamfu soil, produced a higher soyabean grain yield. Cowpea grain yield on both sites was low, not because of the acid soil, but due to pest infestation which is a major problem in the cultivation of cowpea in Northern Zambia. The benefit due to the green manures will be assessed in the next season.

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AGRONOMIC EFFECTIVENESS OF PHOSPHATE ROCK PRODUCTS, MONO-AMMONIUM PHOSPHATE AND LIME ON GRAIN LEGUMES IN SOME ZAMBIAN SOILS

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Abstract

Phosphorus deficiency severely limits crop yields in some Zambian soils. Where P fertilizer is not applied, yields of grain legume crops are reduced by as much as 50% from the optimal yields obtained with adequate fertilization. Some of the soils are inherently low in P while many others are depleted of P from lack of, or low application of P fertilizer. Re-capitalization of soil with P fertilizer requires a heavy investment, which makes greater utilization of local phosphate rock resources an economically attractive strategy. Additional savings on the cost of P fertilizers could come from utilizing accumulated P from previous applications. However, there is also limited information on the contribution of residual P to the nutrition of the subsequent crop. Field trials were conducted at nine sites in two Agro-ecological Regions to test the agronomic effectiveness of acid treated phosphate rock and to evaluate the crop response to residual P from the previous season. The treatments comprised six rates (0, 40, 80, 120, 160 and 200 kg P_2O_5 ha^{-1}) in On-Station experiments and three rates (0, 60 and 120 kg P_2O_5 ha^{-1}) in On-Farm experiments, replicated four and two times respectively and arranged in a randomized complete block design. Phosphorus was applied in the first year of the trials (2000/2001) as Mono-ammonium phosphate (MAP) and Partially Acidulated Phosphate Rock (PAPR). All experimental plots received 70 kg K_20 ha^{-1} and 26.4 kg S ha^{-1}. The disparity in N content between the two P products was balanced using urea on PAPR-treated plots, and subsequently all treatments On-Station received a topdressing of 200 kg N ha^{-1} while On-Farm the control and 60 kg ha^{-1} rates received 120 kg N ha^{-1} and the 120 kg P_2O_5 ha^{-1} got 200 kg N ha^{-1}. Maize, sorghum, cowpea, groundnut, soybean, cotton and sunflower were planted at the different sites according to the importance of the crop in the region. In the second cropping season (2001/2002) the planting rows in which the fertilizer was banded were maintained, and the residual P was evaluated from the higher rates of P application (120, 160 and 200 kg P_2O_5 ha^{-1}) where the P application was not repeated. The plots were split so that one half was limed and the other half left un-limed. The crops were rotated, and groundnut and soybean followed maize, cowpea followed sorghum. In the first year, there was a significant ($p < 0.05$) yield increase to P application, regardless of P source, and 80 kg P_2O_5 ha^{-1} appears to be the optimum rate for all crops. Application of P increased legume grain yields by more than two times the yields obtained from fields where all the major nutrients were applied except P. PAPR is as good as MAP in providing P to plants and improving yields of crops. On sandy soils, an application of more than 120 kg P_2O_5 ha^{-1} as MAP depressed yields of legume crops. In the second year, recurrent P fertilizer application at rates of 40, 60 and 80 kg P_2O_5 ha^{-1} was as effective as residual P fertilizer from the application of 120, 160 and 200 kg P_2O_5 ha^{-1} the previous season. The PAPR was significantly a superior source of P for the legumes than MAP when lime was not applied. This study suggests that applying slowly-available and simply-processed PAPR in amounts sufficient for several seasons in combination with readily available N fertilizer may provide a strategy to re-capitalize soil with phosphorus and improve crop yields.

Key words: Residual fertilizer phosphorus, groundnut, soybean, cowpea, cereal-legume rotation

Introduction

Crops in general respond quickly and quite dramatically to N, having a visible effect on crop production. For this reason the use of N fertilizer is popular with farmers and very often even to the disadvantage of other equally essential nutrients such as P and K. World fertilizer consumption by nutrients during the past 36 years up to 1995 (FAO, 1994, 1996) shows a consistent N:P_2O_5 ratio of nearly 2.5:1, illustrating the dominance of N in total fertilizer use. In Zambia, this ratio is 3:1 (FAO, 1996). To improve fertilizer use efficiency and minimize adverse environmental impacts associated with nitrogen use, the nutrient balance should be improved by promoting P and K fertilizer use.

The increase in both the costs of fossil energy and the world-wide demand for N fertilizer in food production are major reasons for the rekindled interest in biological nitrogen fixation (BNF) as an alternative, or at least a supplement to the use of inorganic N fertilizers. Nitrogen fixation, whether biological or industrial, is a highly energy-consuming process, and inadequate sources of energy is one of the major limiting factors to achieving optimum BNF.

Among BNF systems, symbiotic systems involving legume/bacteria associations have the highest N_2 fixing capability because N_2-fixing microorganisms are supplied directly from the host plant with carbohydrates as a ready source of energy for N_2 fixation. Therefore, root nodulation and N_2 fixation are more complete and efficient when all the essential plant nutrient elements are available in sufficient quantities to the macrosymbiont. This fact is not always appreciated, and legumes are generally thought to be so well endowed that that they will fix N_2 regardless of their non-N nutrition status.

Phosphorus plays a critical regulatory function in photosynthesis and carbohydrate metabolism of leaves and P deficiency can limit growth, particularly during the reproductive stage of the crop. In the N_2 fixation reaction involving the catalyzing enzyme complex nitrogenase, energy in the form of a reductant Adenosine Tri-phosphate (ATP) is essential. Giaquinta and Quebedeaux (1980) reported that the level of P supply during this period regulates the starch/sucrose ratio in the source leaves and the partitioning of photosynthates between the source leaves and the reproductive organs. This effect of P on partitioning of photosynthate is presumably responsible for the insufficient photosynthate supply to nodulated roots of phosphorus-deficient legumes and the occurrence of nitrogen deficiency symptoms in N_2-fixing legumes receiving deficient levels of phosphorus (Marschner, 1986). Root infection with Versicula-Arbsucular (VA) mycorrhizae (Aguilar et al. 1979) not only increased P uptake from soil, but also VA aided the establishment of bacteria that fix N_2 in soils that are low in available phosphorus.

Phosphorus deficiency is a major factor limiting crop production in the tropics, presumably because of the fixation of phosphate by iron and aluminum oxides. Much more P fertilizer, therefore, is required to meet crop requirements over and above the quantities that are fixed. The cost of fertilizers is often the reason for inadequate fertilization.

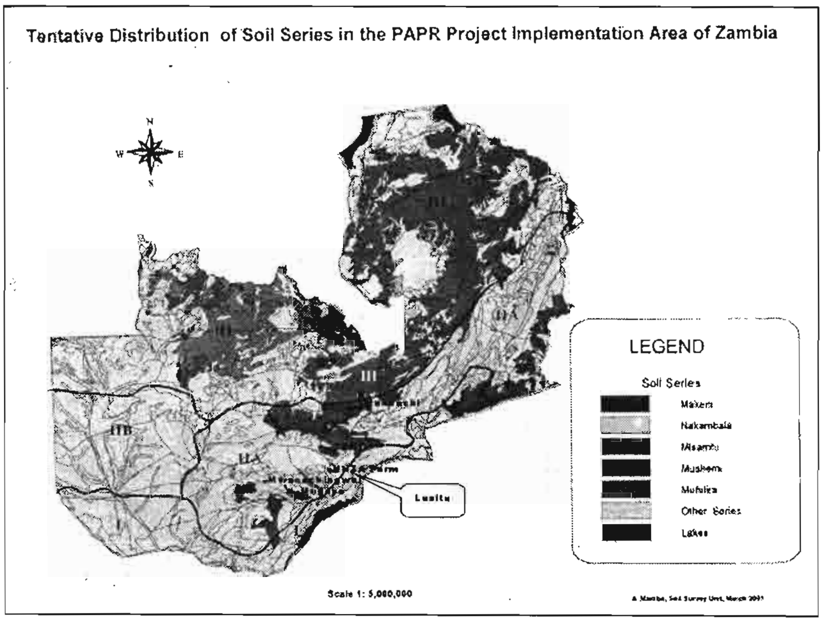

Figure 1. Agro-ecological Regions of Zambia

Many countries in Sub-Saharan Africa are rich in phosphate rock (PR)—the primary raw material for the production of phosphate fertilizers. Because of low local demand and the global surplus of P fertilizers, these deposits have not been developed. Technical, economic and conducive policy regimes are needed to initiate tapping of these resources and providing them at low cost. Direct application of ground PR would be one way to provide the PR at low cost, but this mode of application was not effective with Zambian PR. In current field trials, simply processed partially acidulated PR (PAPR) was utilized. The main objective of this study was to evaluate the agronomic effectiveness of PAPR produced from simply-processed phosphate rock products in soils of varying soil chemical properties, for grain legumes.

Materials and Methods

The field trials were conducted in two Agro-ecological Regions of varying rainfall, length of growing season and soil properties, as shown in Figure 1. In the first year (2000/1 cropping season), seven trials were conducted consisting of four On-Station and three On-Farm experiments. Three On-Station trials were planted in Agro-ecological Region II at Kafuku Farm Institute in Mukonchi, University Farm (UNZA) and Magoye Cotton Development Trust (CDT) on Mushemi, Chelstone and Nakambala soil series respectively. One On-Station trial was planted in Region I at Lusitu. All the on-farm trials were planted in Region II at Chibwe on Mushemi soil series, Golden Valley Agricultural Research Trust (GART) on Makeni soil series and at Magoye Mwanachingwala village on Nakambala soil series. The sites were selected for their low available phosphorus fertility status. The initial soil test values for P and pH are shown in Table 1. All the soils were slightly acid, to acid, and deficient in plant available phosphorus. Therefore, crop response to applied phosphorus fertilizer was expected at all these sites.

In the second cropping season (2001/2002), the tri-

Table 1. Reduction of soil acidity after liming at experimental sites.

	Acidity (cmol kg^{-1})		Lime added	pH	
Site	$Al^{3+} + H^+$	Al^{3+}	kg ha^{-1}	Initial	After liming
1. Chibwe	0.20	0.10	360	5.1	5.3
2. GART	1.00	0.66	1500	4.1	5.2
3. Magoye CDT	0.30	0.24	510	4.1	4.5
4. Mwanachingwala	0.34	0.28	450	4.4	5.1
5. Lusitu	0.12	0.10	450	4.3	5.4

als were extended to three other sites – one site in Eastern Province (Region II) and two in Northern Province (Region III).

Phosphorus was applied as mono-ammonium phosphate (MAP) as the reference fertilizer and as partially acidulated phosphate rock (PAPR) produced at the Pilot Plant of the School of Mines at the University of Zambia from Chilembwe phosphate rock. The trials were designed as On-Farm, or On-Station in which the plots were 100 m^2 and 22.5 m^2 respectively. The P application rates were 0, 60 and 120 kg P_2O_5 ha^{-1} in On-Farm trials and 0, 40, 80, 120, 160 and 200 kg P_2O_5 ha^{-1} in On-Station trials. All treatments were replicated four times in a randomized complete block design. The fertilizer was banded in the planting furrow below the seed at planting. All treatments received adequate amounts of K, S as recommended for the particular sites (70 kg and 26.4 kg ha^{-1} respectively). Nitrogen was applied as a basal application at 24 kg N ha^{-1} at On-Farm sites and 44 kg N ha^{-1} at On-Station sites. The test crops were maize, sorghum, sunflower and legumes (soybean, groundnut and cowpea). A peat-based inoculum was applied to soybean at planting using the recommended rate.

The test crops were grown for two seasons, and in all cases improved varieties of test grain legumes were planted according to the suitability and importance of the legume in the locality of the trial. In On-station trials in Region II, soybean variety Kaleya and groundnut variety MGV4 were planted. These varieties are well adapted to Region II and are very responsive to inoculation with *Rhizobium*. The MGV4 groundnut variety is tolerant to soil acidity and has low pod failure (Pops) in these soils. Soybean was grown at Kafuku Farm Institute and UNZA Farm, groundnut at Magoye CDT. Cowpea variety Bubebe was grown at Lusitu in Region I. The variety was grown because of its earliness and high yields, the former attribute being particularly important in this drought prone Region.

Soybean was drilled at an inter row spacing of 75 cm. Groundnut was grown at an inter- and intra-row spacing of 75 cm and 10 cm respectively. The spacing for cowpea was 75 cm between rows and 10 cm between plants.

During the second cropping season (2001/2002), the planting furrows from the first season were maintained. However, the crops were rotated around the plots at each site. No further applications of P were made to the higher rates of P application (120, 160 and 200 kg P_2O_5 ha^{-1}), and the residual effects were evaluated from these treatments. Other nutrients, N, P, K and S including the application of inoculum were repeated as in the first season according to the current fertilization practice. An absolute control treatment in which no fertilizer was applied was included for sites where space permitted adjacent to the current trial.

The treatments were split, and a lime treatment was included to evaluate its effect on crop growth, especially on the acid soils at Chibwe, GART, Magoye (both on-station and on-farm) and Lusitu sites. Each original treatment plot was split into two equal subplots, and one half was limed while the other was not limed. The amount of lime applied was calculated based on the exchangeable aluminium values (Table 1).

The lime was broadcast on the surface and then worked into the soil by light cultivation using hand hoes before planting. Crop growth was monitored during the season, and some plant growth parameters were recorded. Crop management both in the first and second cropping seasons was carried out according to the conventional agronomic practices for these crops.

Results and Discussion

Although various test crops were evaluated, only the results for the grain legumes are presented and discussed in this paper. These results are discussed according to crop across trial sites.

Soybean

At Kafuku Farm Institute (sited on Mushemi soil series), a response to soybean biomass and grain yield was obtained in the second cropping season only with the application of PAPR at 40 kg P_2O_5 ha^{-1}. There was a tendency for the residual effect of both MAP and PAPR to decrease with increasing P level, reaching a minimum when P was applied at 160 kg P_2O_5 ha^{-1} and subsequently increasing at the highest rate of P application. This is illustrated in Figure 2, showing the effect of source and level of P on soybean grain yield.

The soils at Chibwe On-Farm site were similar to those at Kafuku Farm Institute except that the soils were higher in initial soil P. Consequently in the first cropping season (2001/02), there was no yield

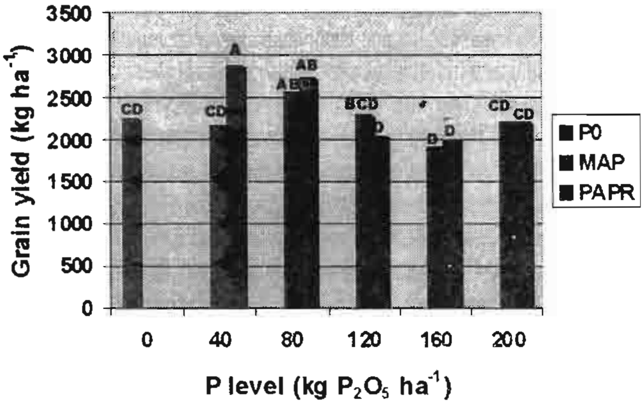

Figure 2. Effect of source and level of P on soybean grain yield at Kafuku Farm Institute. Means followed by the same letter are not significantly different.

response to applied P on soybean regardless of P source. The soil available P was adequate to meet the nutrient demand of the crop.

In the second cropping season, there was no response of biomass and grain yield on the control treatment to lime application. This is because the initial soil pH for this site of 5.1 was high and consequently the exchangeable aluminium of 0.1 cmol kg^{-1} was low to be detrimental to plant growth. Liming, therefore, did not reduce exchangeable aluminium any lower than was already in the soil to negatively influence plant growth (Table 1, Figures 3 and 4).

High biomass yields of 1.7 and 1.3 times over the control were obtained for the recurrent and residual application of MAP respectively. Similarly, high grain yields of 1.6 times over the control treatments were obtained for both the fresh and residual application of MAP. Liming increased biomass and grain yields largely in the fresh than in the residual application of MAP.

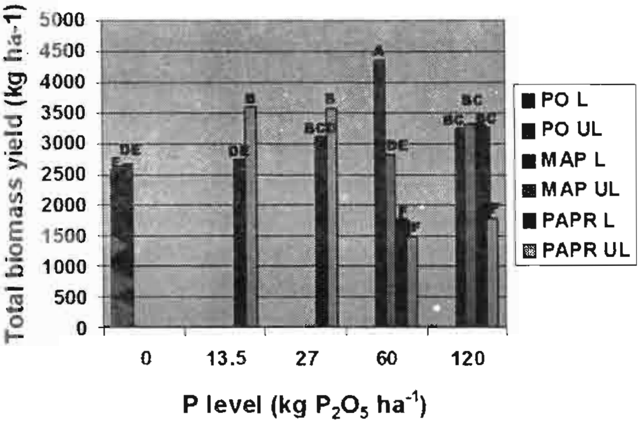

Figure 3. Effect of source of P, level of P and lime on soybean biomass yield at Chibwe On-Farm site. Means followed by the same letter are not significantly different.

With PAPR there was a response to P for soybean biomass and grain yields only to residual application of the fertilizer. Highest biomass and grain yields were obtained at the lower rate of 13.5 and 27 kg P_2O_5 ha^{-1} for biomass and 27 kg P_2O_5 ha^{-1} for soybean grain yield. Both the biomass and grain yields decreased with increased rate of P so that there was no response to P at the highest rate (120 kg P_2O_5 ha^{-1}) with and without liming for grain yield and without liming for biomass. The effect of lime for MAP was similar, except at the lowest rate of P for grain and biomass yield. The reduction of soybean grain yield with increasing rate of residual P application suggested adequacy of soil P for crop production. The residual effect of P for PAPR was thus more effective than that of the fresh and residual application of MAP because adequacy in soil P for plant growth was reached at a lower rate of P application.

On Makeni soil series at GART, higher grain yields of soybean were obtained in the first cropping season with the recommended level of P application of 60 kg P_2O_5 ha^{-1} for MAP than at the improved technology level of 120 kg P_2O_5 ha^{-1}. This is shown in Figure 5. The yields were 2.4 times more than the control treatment. In the case of PAPR, the soybean yields were similar for both the recommended and improved technology with a two-fold increase in soybean yield compared to the unfertilized control. There was a significant reduction ($p<0.05$) of soybean yield at the higher rate of MAP application.

The soil data (Figure 6) show that both MAP and PAPR maintained adequate levels of P for plant growth. The reduction of soybean yield for MAP at the higher rate of P application can be explained by the reduction of soil P at this level of P application. This is in contrast to soil P, which increased with PAPR application so that the yield was not reduced

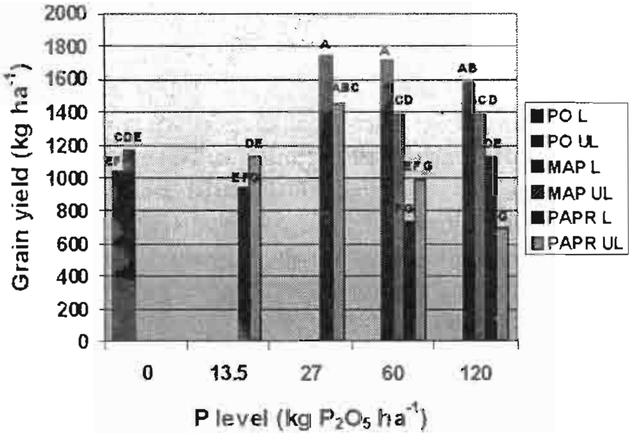

Figure 4. Effect of source of P, level of P and lime on soybean grain yield at Chibwe On-Farm site. Means followed by the same letter are not significantly different.

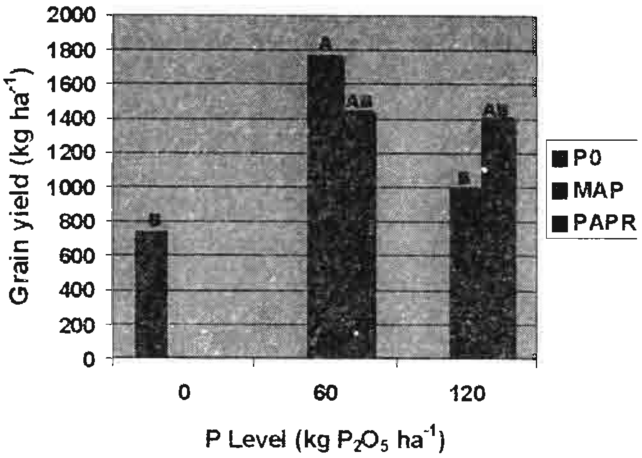

Figure 5. Response of soybean grain yield to level and source of P at GART. Means follows by the same letter are not significantly significant.

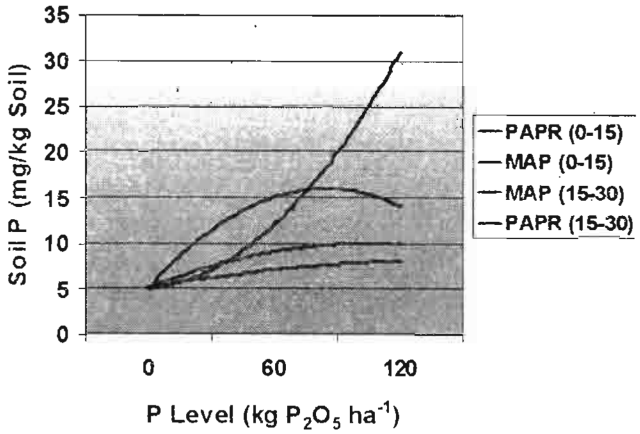

Figure 6. Effect of source and level of P on available soil P at GART.

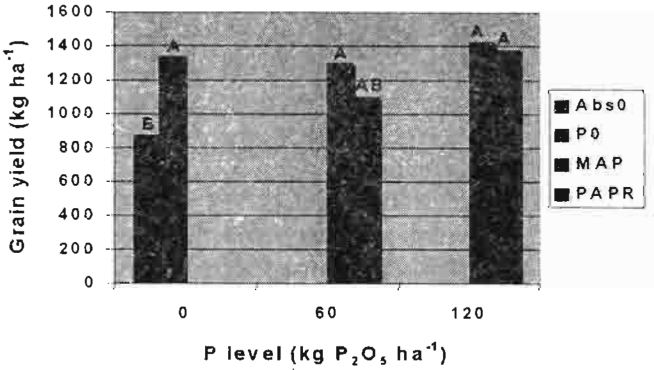

Figure 7. Effect of source of P, level of P and lime on soybean grain yield in 2001/02 season at GART. Means followed by the same letter are not significantly different.

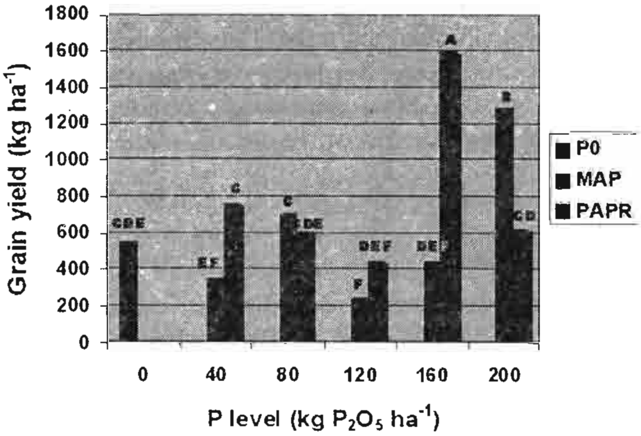

Figure 8. Response of soybean grain yield to source and level of P at UNZA Farm. Means followed by the same letter are not significantly different.

at the higher rate of PAPR application. This can be attributed to the slow release of the P from PAPR.

In the second cropping season, response to P on soybean plant growth was obtained at an earlier growth stage (flowering), only with MAP for both fresh and residual applications. Response to residual P was observed for MAP with, without liming, and for PAPR following liming.

The soybean variety (Kaleya) is not acid tolerant and the beneficial effect of lime was clearly evident in the field. At inherent soil fertility, liming increased crop productivity by 1.5 times. Liming also increased crop response to MAP at 60 kg P_2O_5ha^{-1} and increased response to residual P for PAPR. Soil pH increased from 4.1 without liming to 5.2 after liming. The increase in plant vigour after liming was because of the reduction of aluminium toxicity of 1cm kg^{-1} (which was high at this site) to a level that was not harmful for plant growth.

At harvest, response of soybean grain yield was obtained only to nutrients other than P (N, K, S) indicating that these elements limited crop growth (Figure 7). There was no effect of P on grain yield regardless of P source, whether freshly applied or residual. The effects of P and lime, which were clearly observed at flowering, were no longer evident at harvest. This was because of the possible effect of moisture stress on the crop during the drought experienced in the 2001/02 cropping season.

At UNZA Farm on Chelstone soil series, response to P on soybean grain yield was only obtained for the residual application of MAP at 200 kg P_2O_5 ha^{-1} and for PAPR at 160 kg P_2O_5 ha^{-1} (Figure 8). There was a greater response to PAPR because PAPR maintained a higher soil P concentration than MAP. At the lower P application rate, the P is probably fixed and therefore not available to the plant.

Groundnut

At the Magoye On-Station site and Mwanachingwala On-Farm site, there was no response to P application on groundnut yield regardless of P source in the first cropping season. The observed lush above-ground biomass was not translated into higher grain yields, suggesting poor photosynthate partitioning to pods. This was despite Soil P increasing with P application, reaching adequate levels for plant growth at greater than 60 kg P_2O_5 ha^{-1} for both sources of P. The low shelling percentage indicated that there was need for liming. PAPR was 2.5 times more effective in increasing the level of soil P at the highest rate of P applied (120 kg P_2O_5 ha^{-1}). For MAP, soil P decreased at this high application rate. The higher rates of P applied as PAPR tended to increase soil P values and in turn tended to produce higher grain yields and increased shelling percentage.

In the second cropping season, adding nutrients other than P (N, K, S) increased biomass yield over the absolute control, indicating that these nutrients were limiting. The effect of P on biomass yield depended on lime. Lime depressed biomass yield of the absolute zero control treatment, while increasing the yield of the P0 control where P was not applied (Figure 9). The significant depression of biomass yield of 1.4 times with liming was probably due to a Ca/Mg imbalance. Magnesium was low in these soils, and therefore adding an excess of Ca through PAPR and lime probably offsets the balance. The comparative higher yields of the unlimed compared to the limed absolute control treatment was because the exchangeable aluminium was low and not detrimental to plant growth even though the soil pH was strongly acidic. Overall, liming increased the pH from 4.4 without liming, to 5.1 with liming. The change of pH with lime was confined mainly to the topsoil. The pH was higher for PAPR than MAP when P was applied at 60 kg P_2O_5 ha^{-1} and in the sub soil of the limed plots at both 60 and 120 kg P_2O_5 ha^{-1} (Table 2). This suggests a liming effect of PAPR that did not occur at the higher rate of PAPR.

The soil P was lowest for the limed non-P fertilized control compared to the absolute control whether limed or unlimed. Crop production of maize and groundnut during the 2000/01 and 2001/02 cropping seasons depleted soil P compared to the absolute control. Recurrent applications of P as MAP or PAPR increased soil P by 3.7 and 4.9 for MAP and PAPR with liming and by 2.8 and 4.2 for MAP and PAPR without liming respectively. The increase in soil available P occurred primarily in the topsoil, especially with PAPR with liming and to a lesser extent with MAP without liming. The increase in soil P was highest for PAPR with or without liming.

Response of biomass yield to fresh applications of P over the absolute control with liming and the P0 control without liming that were observed for MAP without liming and with liming for PAPR was corroborated by the low levels of soil P for the Absolute zero and P0 controls (Figure 10). Although residual application of MAP and PAPR with and without liming did not increase soil P beyond that of the control treatments, response to residual P was, however, observed for the two fertilizers. The response was obtained for MAP without liming. For PAPR, the residual effect was greater and more effective than that of MAP without liming.

Cowpea

At Lusitu On-Station site, there was a significant (P > 0.1) response of cowpea grain yield to application of P above 80 kg P_2O_5 ha^{-1} with PAPR and above 120 kg P_2O_5 ha^{-1} with MAP (Figure 11) in the first cropping season. The yield response to P was consistent with the inherent P deficiency in the soil at this site and therefore the need for P application to increase yields. This is corroborated by the available soil P values which increased to levels adequate for plant growth with application of P above 80 kg P_2O_5 ha^{-1} for MAP and above 40 kg P_2O_5 ha^{-1} for PAPR (Figure 12). PAPR was more effective in increasing

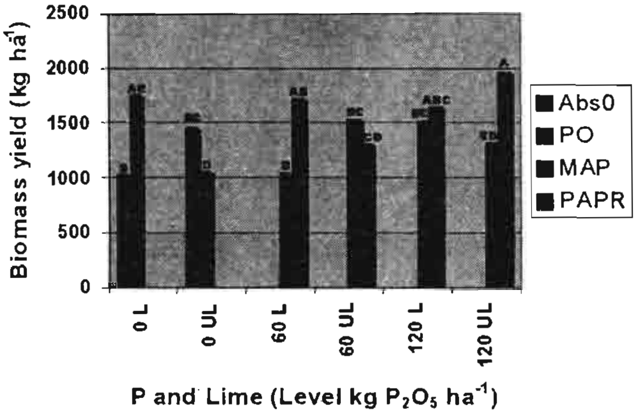

Figure 9. Effect of source of P, level of P and lime on groundnut biomass yield at Mwanachingwala On-Farm site. Means followed by the same letter are not significantly different.

Table 2. Response of soil pH to application of lime

P Level kg P_2O_5 ha^{-1}	Depth (cm)							
	(0-15)				(15-30)			
	MAP L	MAP UL	PAPR L	PAPR UL	MAP L	MAP UL	PAPR L	PAPR UL
60	4.9 bcd	4.1 fgh	5.5 a	4.6 cde	3.9 gh	3.9 h	4.7 cde	4.5 cdef
120	5.3 a	4.5 cdef	5.7 a	4.1bcd	4.6 cde	4.1 fgh	5.2 ab	4.1 fgh

CV - 4.35 %

LSD - 0.4412

Means followed by the same letter are not significantly different.

Key

MAP L - MAP Limed MAP UL - MAP Unlimed

PAPR L - PAPR Limed PAPR UL - PAPR Unlimed

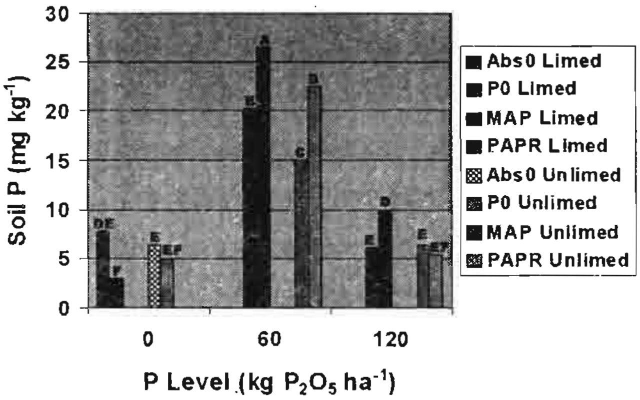

Figure 10. Effect of source of P, level of P and lime on soil available P at Mwanachingwala On-Farm site.

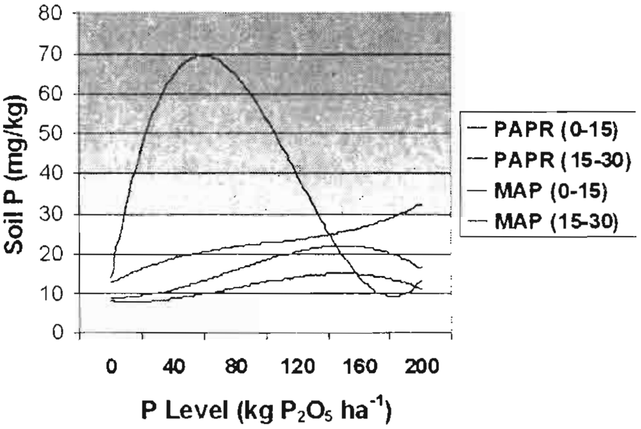

Figure 12. Effect of source and level of P on soil available P at Lusitu.

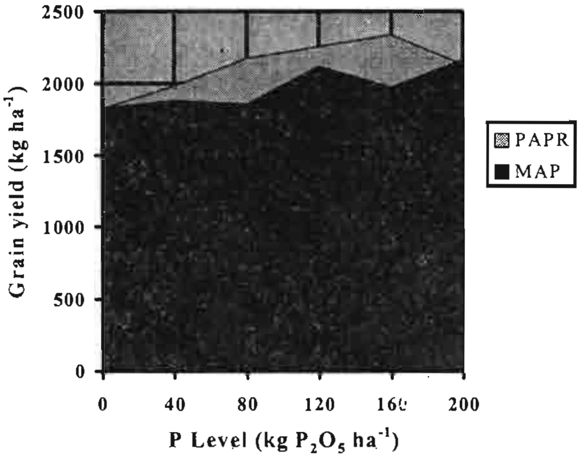

Figure 11. Response of cowpea grain yield to source and level of P at Lusitu

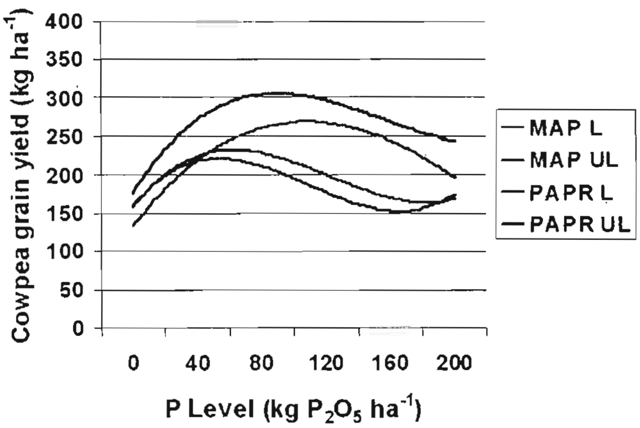

Figure 13. Effect of source of P, level of P and lime on cowpea grain yield at Lusitu.

the level of soil P at all application rates. Yields of more than 2 t ha^{-1} were obtained with the application of at least 80 kg P_2O_5 ha^{-1} compared to less than 1 t ha^{-1} without P application. PAPR was more effective than MAP in increasing cowpea yields. This is indicated by the difference between the response area graphs of PAPR and MAP (Figure 11).

In the second cropping season, response to application of MAP was obtained only at 80 kg P_2O_5 ha^{-1}, while response to PAPR was observed at a lower rate of 40 kg P_2O_5 ha^{-1}. There was a response to residual application of P only with PAPR applied at more than 120 kg P_2O_5 ha^{-1}. This is attributed to the greater effectiveness of PAPR because of the slow release of P from PAPR.

Liming increased soil pH from 4.3 to 5.5 in the limed control treatments. Application of lime decreased cowpea grain yield by as much as 1.8 compared to the unlimed control. This was probably due to an imbalance of nutrients for normal plant growth. The yields were comparatively higher in the unlimed control treatment because the exchangeable aluminium of 0.1 cmol kg^{-1} was too low to reduce crop yields. The effect of lime on cowpea grain yield at higher rates of P was different for MAP and PAPR. Cowpea grain yields increased with lime application for MAP, while in the case of PAPR the highest yields were obtained without liming (Figure 13). Lime increased cowpea grain yield by over 50% compared to the unlimed control. Cowpea grain yields were about nine times lower in 2001/02 compared to the 2000/01 cropping season because of the severe drought experienced in Agroecological Region I at Lusitu.

The first season groundnut was planted in the 2001/02 cropping season with an On-Farm and On-Station trial in Petauke and Msekera Research Station respectively. At Petauke, there was a response to P only at the higher rate of P application of 120 kg P_2O_5 ha^{-1} for PAPR (Figure 14). The yield at this level of P increased two-fold compared to the absolute control. Other nutrients apart from P were limiting in the absolute control. The level of soil P at this site was high so that the groundnut yield of the non-P fertilized control and P applied at 60 kg P_2O_5 ha^{-1} was similar.

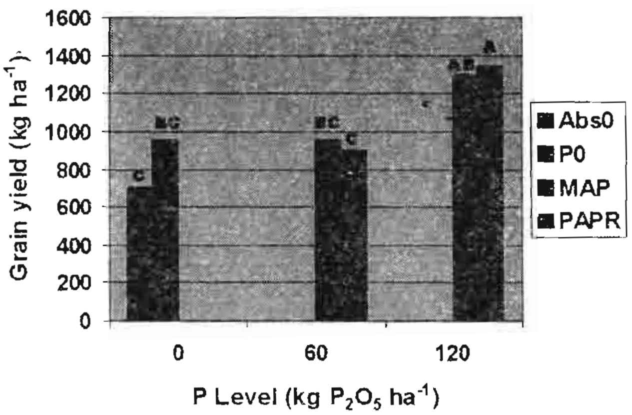

Figure 14. Effect of source and level of P on groundnut yield at Petauke On-Farm site. Means followed by the same letter are not significantly different

At Msekera Research Station, there was a response to P for MAP at 40 and 80 kg P_2O_5 ha^{-1} and the highest rate of P application of 200 kg P_2O_5 ha^{-1}. Response to PAPR was only obtained at 80 kg P_2O_5 ha^{-1} (Figure 15). MAP was superior to PAPR, especially at the lower rate of P application, possibly because the PAPR maintained a higher rate of soil P compared to PAPR.

Conclusions

The biomass and grain yields of the test legumes more than doubled with the application of P.

Simply processed PAPR (50% acidulated with concentrated H_2SO_4) was agronomically as effective as MAP and had an even better effect than MAP on acid soils. Soil recapitalization can be achieved with PAPR rather than with MAP because it does not depress plant growth at higher rates. There is greater soil residual P with PAPR than with MAP. PAPR maintains a higher level of soil available P than MAP, especially at the higher level of P. The optimal P application rate was 80 kg P_2O_5 ha^{-1}. The results of the PAPR study have indicated that nutrients other than P are limiting grain legume production. There is therefore a need to identify those that are limiting.

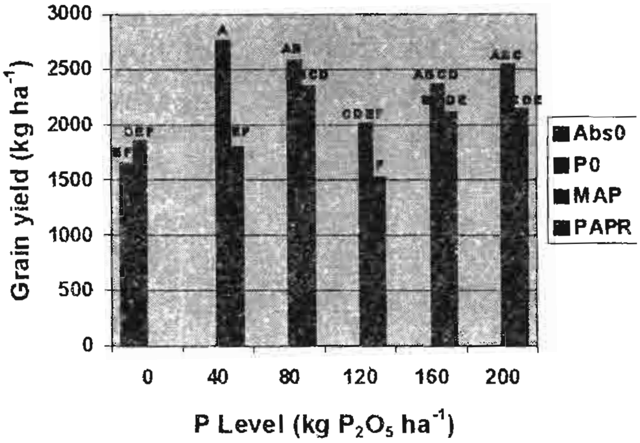

Figure 15. Effect of source and level of P on groundnut grain yield at Msekera Research Station. Means followed by the same letter are not significantly different.

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THE EFFECT OF PHOSPHORUS AND SULPHUR ON GREEN MANURE LEGUME BIOMASS AND THE YIELD OF SUBSEQUENT MAIZE IN NORTHERN MALAWI

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Abstract

A study on the effect of phosphorus and sulphur on biomass production of green manure legume crops and that of the green manures on subsequent maize yield was conducted during the 1999/2000 and 2000/2001 growing seasons. The study was undertaken at two sites in Northern Malawi. The main objective of the investigation was to evaluate the response of green manure legume crops to Phosphorus and Sulphur application in terms of dry matter production and the manure's effect on subsequent maize yield.

Three legume green manure crops: Mucuna pruriens, Cajanus cajan, *and* Tephrosia vogelii *and one cereal crop,* Zea mays, *were planted as sub-plots and each crop received three rates of P and S fertilizer; 0, 20 kg P_2O_5 and 4 kg S, and 40 kg P_2O_5 and 8 kg S per hectare. At each site, the experiment was replicated five times using five farmers' plots in a 2*4*3* split-split plot arrangement in a Randomized Complete Block Design.*

There were significant differences between the four crops (P= 0.001) in biomass production. Mucuna pruriens *outperformed the other crops (5380 kg ha^{-1}), followed by* Tephrosia vogelii *(5258 kg ha^{-1}),* Zea mays *(4972 kg ha^{-1}) and* Cajanus cajan *(2669 kg ha^{-1}) respectively. Fertilizer application significantly increased (P=0.001) biomass production. The lowest amount of biomass was recorded from the treatment without fertilizer input, and the highest was recorded from the treatment with the highest fertilizer rate. The two sites were significantly different (P=0.001) for biomass production. Mean biomass yield at Nchenachena (5650 kg ha^{-1}) was higher than from Champhira (3490 kg ha^{-1}).*

In the subsequent growing season, the maize grain and total dry matter produced were significantly different at (P < 0.01) and (P = 0.001) respectively and were attributed to the type of crop preceding them. Maize grain and biomass after Mucuna pruriens *was the highest (1104 kg ha^{-1} for grain and 5170 kg ha^{-1} for biomass). This was followed by those after* Cajanus cajan *(880 and 4430 kg ha^{-1}),* Tephrosia vogelii *(785 and 3915 kg ha^{-1}) and then* Zea mays *(627 kg ha^{-1} for grain and 3059 kg ha^{-1} for total dry matter produced).*

Key words: Green manure legume, short-term fallow, phosphorous, sulphur, maize, northern Malawi

Introduction

The problem of declining soil fertility in smallholder farms is recognized as the fundamental cause of declining per capita food production in African agriculture (Gilbert, 1998; Smaling, 1993; Mokwunye *et al*., 1996). Major causes of declining soil fertility include continuous monocropping, low use and inappropriate application of organic or inorganic fertilizers, lack of fallows, and lack of proper soil and water conservation practices. These factors have contributed to lower average crop yields in most smallholder farmers' fields.

One intervention identified to address the problem of soil fertility decline, particularly in low-input and limited land resource base agricultural systems, is the use of a short-term fallow system with fast growing herbaceous legumes planted in rotation with major food crops, such as maize (*Zea mays* L.). Some of the promising legume green manure crops in such a system include pigeonpea (*Cajanus cajan*), fish bean (*Tephrosia vogelii*), *Sesbania sesban* and velvet bean (*Mucuna pruriens*). Sole cropped green manure legumes have the potential to accumulate up to 250 kg N ha^{-1} yr^{-1} (Giller and Wilson, 1991) resulting in subsequent cereal yield increases of 600–4100 kg ha^{-1} (Peoples and Herridge, 1990).

Most interventions involving green manure crops have emphasized the role of the legumes in the maize-based cropping systems without looking at improving the legume itself. It is important to note that for the leguminous crops to fix nitrogen, they need good phosphorus and sulphur nutrition, in addition to other nutrients. The aim of supplying green manure legume crops with phosphorus, sulphur and zinc is to boost early root development that would take up soil nutrients for plant development, and subsequent biomass production and biological nitrogen fixation (BNF). With low soil nutrient contents, most legume manure crops do not produce sufficient quantities of biomass to supply the required levels of nutrients upon mineralization (Palm et al. 1997). Many organic materials when applied in modest amounts, i.e. 3-5 t ha^{-1} dry matter contain sufficient N to meet the requirements of a 2 t maize crop. However, they cannot supply the P requirements of maize, hence legumes must be supplemented by P in areas where P is deficient (Palm, 1995). Application of inorganic fertilizer to legumes would thus improve biomass production and nutrient recycling, thereby releasing higher amounts of plant nutrients upon decomposition.

The objectives of the experiment were (a) to evaluate the effect of phosphorus and sulphur application on biomass production by three legume green manure crops; *Mucuna pruriens, Cajanus cajan and Tephrosia vogelii* and (b) to screen a green manure legume crop that can result in higher yields for the subsequent maize crop.

Materials and Methods

Experimental sites

The on-farm, farmer-managed, researcher-designed experiment was conducted in two Extension Planning Areas (EPAs) of Mzuzu Agricultural Development Division in Northern Malawi. The sites were Champhira EPA in Mbawa Rural Development Project and Nchenachena EPA in Rumphi Rural Development Project.

Soils of Champhira (Loudon series) are classified as weakly Ferallitic Latosols and those of Nchenachena (Nchenachena series) are Ferrisols (Young and Brown, 1962). Champhira lies at an elevation ranging from 1216 to 1338 m above sea level and located 12° 24′ S and 33° 40′ E while Nchenachena is 1216 to 1307 m above the sea level and located at 10° 30′ S and 33° 50′E.

Experimental design

The experiment was laid out in a split-split plot arrangement in a randomized block design. The two sites of the experiment were the main plots. In Year 1 (1999 - 2000), three green manure legume crops, (i) Pigeon pea, hybrid variety ICP 9145 (*Cajanus cajan* (L) Mellsp.), (ii) Velvet bean (*Mucuna pruriens*) and (iii) Fish bean (*Tephrosia vogelii*) and (iv) Maize hybrid MH 18 (*Zea mays* (L.)), were the sub-plots. The sub-plots measured 15 m long with five ridges spaced at 0.90 m apart (67.5 m^2). There were three sub-sub plots for each crop with five ridges each 5m long and spaced at 0.90m (22.5 m^2). Treatments for sub-sub plots were (i) without phosphorous and sulphur, (ii) 20 kg phosphorus ha^{-1} plus 4 kg sulphur ha^{-1} and (iii) 40 kg phosphorus ha^{-1}plus 8 kg sulphur ha^{-1}. Plant density was as shown in Table 1.

Immediately after harvest (3rd week of May and 2nd week of June, 2000 for Champhira and Nchenachena respectively) in year 1 (1999-2000), the green manure and maize stover were ploughed into the soil in the individual treatment plots. In Year 2 (2000 - 2001), a maize crop (MH 18 hybrid) was grown in all the plots to assess the residual effect of the green manure legume crops.

Soil sampling

Soil sampling was done at each site before the start of the experiment. Soil samples were randomly taken from 0-15 cm and 15-30 cm soil depths from each of the smallholder-farmers' plots using an auger. From each farmer's plot, five samples were taken at each of the soil depths. The soils from the same depths with the same farmer were mixed and after several splits, about 500 g of the soil was obtained and stored in plastic bottles. The initial soil samples were for characterizing the two sites. These samples were analyzed for general soil physical and chemical properties (Table 2). All soil samples were air-dried, sieved through a 2 mm sieve and stored in plastic bottles before laboratory analyses.

Plant sampling

Three plants from the middle ridge of each treatment plot were sampled eight weeks from planting and at mature harvest for both seasons. These samples were oven-dried at 65 °C for 48 hours, then ground to powder (passed through a 0.1 mm sieve) using an electric grinder and stored in plastic bottles. The samples were analyzed to determine nitrogen and phosphorus in the plant tissue.

Biomass was estimated at harvest for both the legume and maize stover after the end of the first sea-

Table 1. Spacing of the crops between and within ridges (cm)

Crop	Within ridges	Between ridges	Plants per station
Maize	50	90	2
Mucuna	15	90	1
Pigeon pea	90	90	3
Tephrosia	75	90	3

Table 2. Initial properties of soils at the two sites before the start of the experiments

Parameter	Champhira	Nchenachena
Soil pH (1:2.5 H_2O)	5.3	5.26
Organic carbon %	0.56	1.032
Total nitrogen %	0.2	0.634
C:N Ratio	3.21	1.63
Mehlich-3 P (ppm)	0.054	0.078
Clay %	30.5	26.7
Silt %	8.3	13.3
Sand %	61.2	60.0

son and for maize stover only at harvest for the second season. Grain yield was also determined at 12.5 % moisture content at harvest of both seasons. During the first growing season, only maize grain yield was recorded. This was because *Mucuna pruriens* and *Tephrosia vogelii* were incorporated at flowering, when the crops attained their potential maximum dry matter production. Pigeonpea grain yield was very poor, mainly due to poor crop establishment, and as such the available data were inadequate for statistical analyses. The net plot from which yield data was obtained was a four-metre section of two of the innermost ridges from the five ridges of the sub-sub plots i.e. 2 * 0.90 m * 4 m (7.2 m^2). Rainfall data was recorded from Champhira and Nchenachena meteorological centres (Figure 1).

Treatment management

Agronomic operations such as weeding, harvesting, and sampling, was done at almost the same time for each site. Planting was earlier in Champhira EPA (within the 3rd week of December) than in Nchenachena EPA (2nd week of January) owing to differences in the onset of the rainy season between the two sites (Fig. 1). In the first season, fertilizer was applied two weeks after planting using 23:21:0:4S compound fertilizer. The rates were derived using the following calculations:

From a 50 kg bag of fertilizer, there is 21 % P_2O_5 and 4 % S that translates to:

(0.21 * 50 kg) = 10.5 kg P_2O_5. Similarly, for S = (0.04 * 50 kg) = 2 kg S.

Quantity to apply per unit area using the fertilizer formulation at hand was obtained from the simple proportion calculation below:

Example 20 kg P_2O_5 ha^{-1} treatment

= (20 kg P_2O_5 ha^{-1} * 50 kg bag^{-1}) / 10.5 kg P_2O_5 bag^{-1} = 95 kg ha^{-1} of the fertilizer. In this there is approximately 4 kg S.

The fertilizer was banded along the ridge. Weeding was done twice: before applying fertilizer and eight weeks from planting.

In the second year of the trial, 50 kg N ha^{-1} was top dressed using a high analysis straight fertilizer, Urea, in all the maize plots. To get the 50 kg N ha^{-1}, the following calculations were done: Each bag of Urea has 46 % N, that translates to 23 kg N. The required quantity = (50 kg N ha^{-1}* 50 kg bag^{-1})/23 kg bag^{-1} = 108.7 kg ha^{-1} Urea. A banding method was used.

The purpose of the second season was to evaluate maize yield in response to the incorporated green manure legume crops. The nutrients released from decomposition of incorporated green manures were expected to have a residual nutrient replenishment effect.

Data from the experiment was statistically analyzed using the Genstat 5 Release 3.2, (1995) computer package.

Results and Discussion

First Season Results

Characterization of the soils at the two experimental sites showed that soils at Nchenachena had higher percent total nitrogen and organic carbon than soils at Champhira (Table 2). The soils at Nchenachena have been cultivated for less time than those at Champhira.

Rainfall recorded during the study period. During both growing seasons, Champhira received earlier rainfall, but it stopped about one month earlier than at Nchenachena. This meant different times of planting at the two sites. Total annual rainfall was higher at Nchenachena (932 mm) than Champhira (558 mm) during the first season but in the second season the difference was not substantial, i.e. 1061 mm for Champhira and 1120 mm for Nchenachena. However, Champhira EPA received more rainfall than normal during the second season (Figure 1).

Nitrogen and phosphorus in plant species at harvest. The four crop species showed significant differences (P= 0.001) in N content of their tissues at harvest (Table 3). The highest mean was for *Tephrosia vogelii* followed by *Mucuna pruriens, Cajanus cajan* and *Zea mays*.

Leguminous crops fix atmospheric nitrogen in their tissues thereby ensuring the supply of this important nutrient for their metabolism. Maize relies on inherent soil nitrogen and the external supply of this nutrient element. There were also significant differences ($P < 0.05$) in the content of phosphorus of the four crops at harvest. Maize had the highest P content followed by *Tephrosia vogelii, Mucuna pruriens* and then pigeonpea (Table 3).

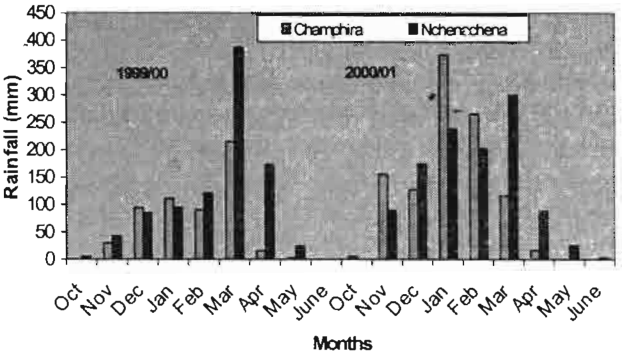

Figure 1. Monthly rainfall totals for the study sites in Malawi during the study period

Table 3. Nitrogen and phosphorus content in plant samples at harvest

Plant species	Nitrogen %	Phosphorus %
Zea mays	1.009 ^{a}	0.314 ^{b}
Mucuna pruriens	2.836 ^{b}	0.206 ^{a}
Cajanus cajan	2.545 ^{ab}	0.146 ^{a}
Tephrosia vogelii	2.885 ^{b}	0.257 ^{a}
SED ±	0.1918	0.0481
CV %	13.1	32.9

Key: SED ±; Standard error of difference, CV; Coefficient of variation;
NB: Means followed by same letters are not statistically different

The application of inorganic fertilizer had a non-significant effect on the N and P content of plants at harvest.

Nitrogen and phosphorus (kg ha^{-1}) in plant tissue at harvest. The concentrations of N and P obtained from plant samples at harvest were multiplied by the crop specie biomass produced on a dry matter basis to determine the total N and P accumulated. There were significant differences ($P < 0.001$) in N accumulation among the different crops. *Tephrosia vogelii* had the highest N accumulation in its tissues followed by *Mucuna pruriens, Cajanus cajan* and *Zea mays* (Table 4).

Green manure legumes outperformed the cereal crop in accumulating nitrogen. This is because unlike cereals, they fix atmospheric nitrogen in their tissues through a symbiotic association with *Rhizobia* spp. of bacteria. Similarly, there were significant differences ($P < 0.05$) in P accumulated among crop species. *Tephrosia vogelii* accumulated the most P, followed by *Zea mays, Mucuna pruriens* and *Cajanus cajan* (Table 4).

The rate of inorganic fertilizer influenced nitrogen, but not phosphorus, uptake by the plant. There were significant differences ($P = 0.001$) in N uptake due to fertilizer application (Table 5).

The rate of fertilizer applied correlated positively with amounts of nitrogen in dry matter. There was a marked increase in nitrogen accumulated by plants from where fertilizer was not applied to where 20 kg P_2O_5 + 4 kg S ha^{-1} was applied. There was also an increase from the latter rate to the rate of 40 kg P_2O_5 + 8 kg S ha^{-1}, however, this increase was less pronounced (Figure 2). This confirms the general observation that application of large amounts of inorganic fertilizer, particularly nitrogen, tends to depress biological nitrogen fixation (Eaglesham and Ayanaba, 1984).

Figure 2 shows that although there were non significant differences among means of phosphorus accumulated, the quantity accumulated is more strongly influenced ($R^2 = 0.99$) by the rate of inorganic fertilizer than by that of nitrogen ($R^2 = 93$). This could be because the soils in the study are deficient in P. Hence the crops responded to the application of inorganic fertilizer.

Effect of rate of inorganic fertilizer applied on N accumulated at harvest in different crop species (kg ha^{-1} dry matter). Although there was a non-significant interactive effect ($P< 0.05$) between rate

Table 4. Nitrogen and phosphorus accumulation in the dry matter of crop species (kg ha^{-1})

Crop species	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})
Zea mays	49.5^a	17.4^b
Mucuna pruriens	152.2^b	11.1^b
Cajanus cajan	72.4^{ab}	4.9^{ab}
Tephrosia vogelii	156.1^b	18.4^a
SED ±	16.07	4.38
CV %	23.6	53.5

SED ±; Standard error of difference; CV, Coefficient of variation
NB: Means followed by same letters are not statistically different

Table 5. Nitrogen and Phosphorus accumulated in plant matter as affected by the rate of fertilizer

Rate of fertilizer	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})
No fertilizer	80.3^a	9.2
20 kg P_2D_5 + 4 kg S ha^{-1}	114.8^b	12.5
40 kg P_2O_5 +8 kg S ha^{-1}	127^b	17.1
SED±	7.74	3.69
CV %	22.8	90.2

Key: SED±; Standard error of difference; CV, Coefficient of variation
NB: Means followed by same letters are not statistically different

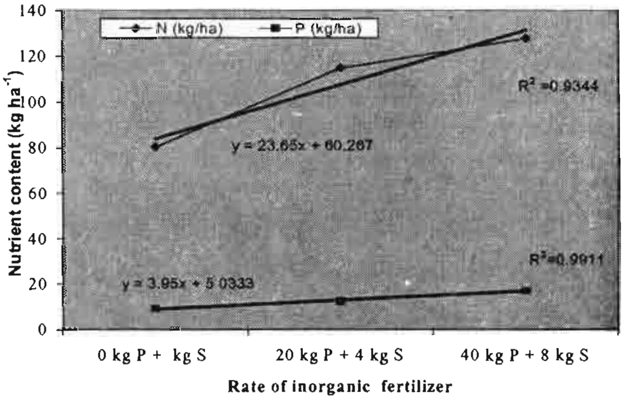

Figure 2. Relationship between rate of inorganic fertilizer and amount of N and P accumulated by plants at harvest

of inorganic fertilizer and the crops, the green manure legumes appeared to respond better than maize to the increasing rate of inorganic fertilizer (Table 6). The differences in response to inorganic fertilizer application among the crop species are graphed in Figure 3.

Biomass production in the first year (1999/2000 season). The four crops produced different amounts of biomass across the two sites (P= 0.001). *Mucuna pruriens* had the highest biomass followed by *Tephrosia vogelii*, *Zea mays* and *Cajanus cajan* (Table 7). In general, all legumes except pigeonpea outperformed maize. The difference in dry matter production between maize, mucuna and tephrosia was not significant. Pigeonpea had lowest dry matter, probably due to poor crop establishment.

With nitrogen being a limiting plant nutrient in most Malawian soils (Kumwenda and Gilbert, 1998), green manure legume crops are likely to outperform cereals in their dry matter production. Additionally, some legumes explore a deeper volume of soil owing to their tap root system and therefore can extract nutrients that may have been leached to lower soil depths. *Mucuna pruriens* produces a dense vegetative cover, mainly leafy biomass, that include a mass of creeping stems, during its vegetative growth stages. Kumwenda and Gilbert, (1998) found similar results.' *Mucuna pruriens* had the greatest mean biomass and a greater response to the added phosphorus than *Cajanus cajan* and *Tephrosia vogelii*. The other green manure legumes crops, pigeonpea and *Tephrosia vogelii*, have a slower early growth rate and tend to lose much of their leafy biomass by the time they attain physiological maturity (Giller and Cadish, 1995; Sakala, 1994).

Table 6. The effect of rate of inorganic fertilizer on N accumulated (kg ha^{-1} dry matter) in different crop species at harvest

Crop species	Rates of inorganic fertilizer (kg ha^{-1})		
	Nil S	20 kg P_2O_5 + 4 S	40 kg P_2O_5 + 8 S
Zea mays	40.8	53.4	54.3
Mucuna pruriens	124.8	162.0	169.9
Cajanus cajan	50.3	70.8	96.0
Tephrosia vogelii	105.2	172.9	190.2

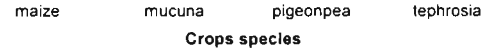

Figure 3. Nitrogen (k ha^{-1}) accumulated by crop species as affected by rate of inorganic fertilizer

Table 7. Dry matter production (kg ha^{-1}) of crops at harvest in the first growing Season (1999-2000)

Crop Species	Champhira	Nchenachena	Mean
Maize	4204 ^{a}	5741 ^{b}	4972 ^{a}
Mucuna pruriens	4352 ^{a}	6407 ^{b}	5380 ^{a}
Pigeonpea	1906 ^{b}	3432 ^{c}	2669 ^{b}
Tephrosia vogelii	3497 ^{a}	7020 ^{ab}	5258 ^{a}
SED ±			576.6
CV %			20.0

Key: SED ±, Standard error of difference; CV, Coefficient of variation;
NB: Means followed by same letters are not statistically different

Application of inorganic fertilizer increased biomass production. There were significant differences (P = 0.001) in biomass production among the crops due to inorganic fertilizer. The higher rate of inorganic fertilizer applied had the highest mean dry matter produced followed by the second rate and the treatment without any inorganic fertilizer gave the lowest dry matter yield (Table 8). This positive response to inorganic fertilizer application is indicative of the need to supplement the green manure crops with external nutrients and that the soils need nutrients.

Maize had the best response to the inorganic fertilizer applied, giving a difference of 2764 kg ha^{-1} between the treatment without inorganic fertilizer and the treatment with 20 kg P_2O_5 + 4 kg S of inorganic fertilizer. This was followed by *Tephrosia vogelii*, (2050 kg ha^{-1}), *Mucuna pruriens* (1069 kg ha^{-1}) and pigeonpea (1005 kg ha^{-1}). The difference in biomass produced between treatments that received 20 kg P_2O_5 + 4 kg S and those that received 40 kg P_2O_5 + 8 kg S was generally lower. The apparently smaller response to inorganic fertilizer application by green manure legume crops compared with maize is because legumes are relatively independent of external nutrient supply, particularly nitrogen, and hence require relatively smaller doses.

Second Season Results

The type of preceding crop significantly ($P < 0.01$) influenced maize stover nitrogen content at harvest. Maize grown after *Mucuna pruriens* had the highest

Table 8. The effect of rate of fertilizer on biomass production (kg ha^{-1}) across the sites

Rate of fertilizer (kg ha^{-1})	Champhira	Nchenachena	Mean (kg ha^{-1})
No fertilizer	2357	4133	3245^a
20 kg P_2O_5 + 4 kg S	3908	6013	4961^b
40 kg P_2O_5 + 8 kg S	4204	6803	5503^b
SED ±			306.2
CV %			21.2

Key: SED ±, Standard error of difference; CV, Coefficient of variation; NB: Means followed by same letters are not statistically different.

stover N, followed by after pigeon pea, *Tephrosia vcgelii* and maize respectively (Table 9).

This could be because *Mucuna pruriens* contributed the highest N through its easily mineralizable leafy residues. Generally, maize following green manure legumes had higher stover N than the continuously grown maize. This was expected since the green manure legume plots provided more N that the subsequent maize crop benefited from after mineralization.

Maize grain yield. The type of preceding crop significantly influenced ($P < 0.01$) maize grain yield across the two experimental sites. The highest maize grain yield followed *Mucuna pruriens* (1104 kg ha^{-1}), then after *Cajanus cajan* (880 kg ha^{-1}), *Tephrosia vogelii* (785 kg ha^{-1}) and continuous *Zea mays* (627 kg ha^{-1}) (Table 10).

These results are consistent with those by Kumwenda and Gilbert, (1998). Their studies on green manure legumes in rotation with maize on exhausted soils of Malawi found that maize grain yield was the highest after a *Mucuna pruriens* fallow, followed by *Crotalaria* spp. and *Tephrosia vogelii* fallows. Maize grain yield average for the second season could have been higher but lack of timely weeding at Nchenachena EPA and high rainfall received during the 2000/2001 season, at Champhira EPA, adversely affected crop growth.

The rate of fertilizer in the first season significantly influenced ($P < 0.015$) maize grain yield. The highest maize grain was from the treatment that received 20 kg P_2O_5 + 4 S ha^{-1} followed by 40 kg P_2O_5 + 8 kg S ha^{-1}, The treatment without inorganic fertilizer had the least mean maize grain (Table 11). This suggests an optimum fertilizer rate at 20 kg P_2O_5 + 4 S kg ha^{-1}. The higher rate of inorganic fertilizer, 40 kg P_2O_5 + 8 kg S, slightly reduced grain production. High N fertilizer promotes succulence and more vegetative plant material at the expense of reproductive organs.

Table 9. The effect of a preceding crop on N content in maize stover at harvest

Fallow sequence	Maize stover nitrogen (kg ha^{-1})
Maize after maize	37.7^{a}
Maize after *Mucuna pruriens*	69.5^{b}
Maize after pigeonpea	55.9^{ab}
Maize after *Tephrosia vogelii*	44.6^{ab}
SED ±	8.79
CV %	26.8

Key: SED ±, Standard error of difference; CV, Coefficient of variation; NB: means followed by same letters are not statistically different

Table 10. The effect of preceding crop species on subsequent maize grain yield (kg ha^{-1}) at Champhira and Nchenachena

Fallow sequence	Champhira	Nchenachena	Mean
Maize after maize	986	268	627^{a}
Maize after *Mucuna pruriens*	1783	424	1104^{ab}
Maize after Pigeonpea	1402	359	880^{a}
Maize after *Tephrosia vogelii*	1273	297	785^{a}
SED ±			126.3
CV %			23.5

Key: SED±, Standard error of difference; CV, Coefficient of variation; NB: Means followed by same letters are not statistically different; Sites 1and 2 are Champhira and Nchenachena

The response of the second season maize crop to the application of inorganic fertilizer showed that yield of maize grain after *Mucuna pruriens* was the highest followed by that of pigeonpea, *Tephrosia vogelii* and maize (Figure 4). Maize grain yield after maize and pigeonpea was depressed at the higher rate of fertilizer application (40 kg P_2O_5 + 8 kg S ha^{-1}). This may be because the compound inorganic fertilizer used has nitrogen, which when applied at high rates tends to enhance vegetative growth and succulence at the expense of grain production. The other possible reason, particularly for maize, is that maize residues incorporated at harvest after the first season had a low N content, unlike *Mucuna pruriens*, pigeonpea and *Tephrosia vogelii* (Table 3). The low N content could have caused net immobilization of nutrients, particularly nitrogen, from its residues. Crop residues of low quality, i.e. less than 2 % nitrogen can result in poor growth of the succeeding cereal crop since the N requirement of the crop is not in synchrony with N mineralization (Nandwa et al., 1995).

Table 11. Effect of inorganic fertilizer rate on maize grain yield

Rate of fertilizer	Maize grain yield
	-----(kg ha^{-1})-----
No fertilizer	708^{a}
20 kg P_2O_5 + 4 kg S	921^{b}
40 kg P_2O_5 + 8 kg S	918^{b}
SED ±	78.8
CV %	29.4

Key: SED±, Standard error of difference; CV, Coefficient of variation; NB: means followed by same letters are not statistically different

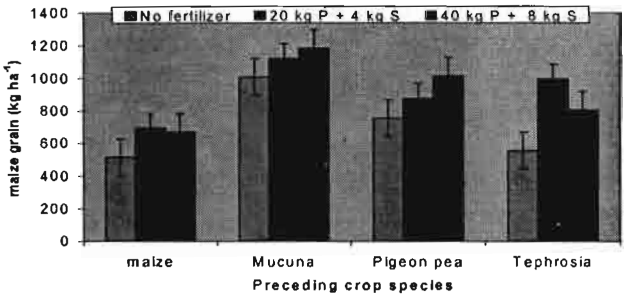

Figure 4. Subsequent maize grain yield as affected by rate of inorganic fertilizer

Maize grain yield after the green manure legumes was higher compared with that after maize, but among the three green manure legume crops it was maize after *Mucuna pruriens* that gave the highest grain yield. The likely reason is that *Mucuna pruriens* produced the most biomass, besides having residues that had a relatively high N content.

Conclusions

The green manure legume crops tested in this study responded to the application of inorganic fertilizer and an increased rate of inorganic fertilizer produced more dry matter. The response to fertilizer was greatest between the unfertilized control and the lower rate of fertilizer application (20 kg P_2O_5 + 4 kg S ha^{-1}).

Among the three candidate green manure legume crops tested, *Mucuna pruriens* is the superior, giving the highest dry matter production. It is therefore the best candidate green manure legume crop for improving soil fertility. Another good candidate was *Tephrosia vogelii,* which at the time of incorporation gave the highest nitrogen content in its tissue.

Maize gave the greatest response to inorganic fertilizer among the four crops tested whereas *Tephrosia vogelii* responded most favourably among the green manure legume crops. *Cajanus cajan* was the least responsive. Maize residues however, had the least content of nitrogen, a factor disqualifying it as a potential green manure crop in low input systems and soils with low fertility. Maize grain yield after the short-term fallow was higher after the green manure legume crops than after maize. Maize grain and biomass produced was highest after *Mucuna pruriens.*

Inorganic fertilizer, particularly at the lower rate, had a positive residual effect on maize grain yield. The higher rate of inorganic fertilizer gave the most remarkable positive effect on total maize biomass production.

Recommendations

Application of modest amounts of phosphorus and sulphur fertilizer (20 kg P_2O_5 + 4 kg S ha^{-1}) to green manure legume crops should be adopted to improve the litter quality of these organic fertilizers as well as enhance their growth and subsequent dry matter production.

Straight inorganic fertilizer sources of phosphorus, sulphur and nitrogen should be used in further studies to isolate the individual effects of these nutrient elements as well as their interactive effects. Other critical nutrient elements such as zinc and molybdenum have to be tested in experiments where green manure legumes are screened for response to inorganic fertilizers.

Mucuna pruriens should be promoted as a potential soil fertility-improving crop where soil fertility is low. The effect can be seen in as short a fallow as one season.

Long-term studies of the residual effects of green manure legume crops on soils, as well as on cereal crop yields, should be conducted to ascertain sufficient information about the benefits of the short-term fallow system.

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MANAGEMENT OF AN ACID SOIL USING MINE TAILINGS AS LIME FOR SOYBEAN PRODUCTION

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Abstract

*Soil acidity is the most limiting constraint in acid soils of the high rainfall area (Region III) of Zambia. These soils are not suitable for growing most arable crops including soybean (*Glycine max *L.) without adjustment of soil pH. Nampundwe mine tailings (NMT) are an abundant and readily available dolomitic limestone source in Nampundwe area, 60 km west of Lusaka. The objective of this work was to evaluate the effectiveness of NMT in managing soil acidity for soybean production in Region III of Zambia in comparison with commercial agricultural lime (AgLi). Results for the 1995/96 season show that AgLi significantly ($P < 0.05$) increased soil pH from 4.3 to 4.8 and exchangeable calcium of the study soil from 0.12 to 0.50 cmol$_c$ kg^{-1} more than NMT. AgLi significantly reduced exchangeable aluminium from 0.82 to 0.40 cmol$_c$kg^{-1} less than NMT. The residual effect of both NMT and AgLi significantly ($P = 0.05$) increased soil pH to 4.8 and 5.0 in the 1996/97 season. In addition, the residual effect of NMT significantly increased exchangeable magnesium from 0.10 to 0.30 cmol$_c$kg^{-1}. However, AgLi maintained its superiority in significantly increasing exchangeable calcium to 1.30 cmol$_c$kg^{-1} over NMT and the control treatment. The results in 1996/97 show a linear response to liming rates for NMT with the maximum yield of 1.1 t ha^{-1} obtained at 3.0 t ha^{-1} while AgLi produced 900 kg ha^{-1} at the same rate. Both liming materials did not increase soybean grain yield in the first and second seasons. It is concluded that to exploit the full potential of NMT in controlling soil acidity effectively for soybean production, we need a study of residual effects over a long period.*

Key words: glycine max *[L.] merril, exchangeable aluminium, agricultural lime, soil pH*

Introduction

Soybean is an important source of protein, particularly in rural areas where animal protein is both scarce and expensive. Recently, research has promoted soybean production countrywide, including in regions with strongly acid soils. Levels of production could be affected by soil acidity since soybean is very sensitive to changes in soil pH. Adams (1984) reported the critical soil pH levels to be 5.0 to 5.7 for soybean. Application of lime increases soil pH, reduces the toxic effect of aluminium and manganese and improves the general growth of soybean in acid soils, including root growth (Grundon 1982; Mapiki 1997, unpublished). Application of lime could also improve phosphorus availability in acid soils (Mapiki 1997, unpublished), and this could promote biological N fixation (BNF) mainly because of the increased availability of phosphorus. However, the most frequently used source of lime in research trials in Zambia has been calcium carbonate ($CaCO_3$), which provides Ca as a plant nutrient. In very few cases, dolomitic limestone been used as a lime source. Dolomitic limestone has the advantage of supplying Mg that is also deficient in strongly acid soils, and can enhance photosynthetic activity in plants (Mengel and Kirkby 1987). The pyrite mine at Nampundwe is located in a massive dolomite, and milled dolomite remains on extraction of pyrite. This remaining dolomite could be used as a source of lime.

The objective of this study was, therefore, to evaluate Nampundwe mine tailings (NMT) as a source of dolomitic lime for soybean production in acid soils of Zambia.

Materials and Methods

The trial was established in the 1995/96 season at Misamfu Regional Research Centre. The study soil is classified as a clayey, mixed isohyperthermic oxic paleustult (Soil Survey Staff, 1992) and is locally known as Mufulira soil series (Soil Taxonomy and Agrotechnological Transfer Report 1985) The textural class is silty loam (11% clay, 12% silt and 77% sand). At the beginning of the experiment the plough layer (0-20 cm) had a soil pH of 4.3 ($CaCl_2$) exchangeable Al, Ca, Mg, and K contents of 1.0, 0.1 0.1, 0.04 cmol$_c$ kg^{-1}, respectively, a Bray-1 available phosphorus of 11 mg kg^{-1} and an organic carbon content of 0.88 %. The study soil was also analyzed for particle size using the pipette method (Day, 1965). The tailings and AgLi were analyzed for their chemical characteristics using established methods (Page et al. 1982) as shown in Table 1.

Plot size used was 0.5 m × 5 m and the treatments were arranged as a randomized complete block design with four replicates. The treatments were control, NMT and AgLi (reference). The quantity of lime applied was based on exchangeable aluminium and calculated using the formula by Kamprath (1967); where one t of lime = 2.0 × Exchangeable Al. The quantity of lime applied was 2.0 t ha^{-1}of soil. Lime was applied to the soil surface by hand and incorporated into the soil with a hand hoe and rake during November 1995, before the onset of the rains. Soybean seed (Cv, SC1) was inoculated and planted with an initial 30 kg N ha^{-1} as D-compound to boost initial crop growth. Four weeks after germination, the soybeans were thinned. At physiological maturity, the grain yield was assessed from a net plot area of 2.0 m^2. The grain yield was adjusted to 12.5% moisture content. After harvesting, soil samples were collected from all plots, air-dried and ground to pass through a 2 mm sieve and analyzed as above (Page et al 1982). The plots were maintained to study the residual effects of the liming material applied in the previous season.

The trial was repeated in the 1996/97 season, with some modifications. A new location within the same experimental field, having the same soil type, was planted to determine the optimal liming rate for the study soil. Liming rates used were 0, 1.0, 2.0, and 3.0 t ha^{-1}. All other management practices were similar to those used in the 1995/96 season except that the variety of soybean used was 'Santa Rosa' instead of 'SC1'. Statistical analysis of the data was done using Proc GLM in SAS (SAS Institute, 1995). The treatment means were compared using the least significant difference method (Steel and Torrie, 1980).

Results and Discussion

NMT did not significantly ($P = 0.05$) increase soil pH nor decrease exchangeable aluminium of the study soil in the first year of the study (1995/96 season) (Table 2). Comparatively, AgLi significantly increased soil pH ($P > 0.05$) and reduced exchangeable aluminium more than NMT and the control treatment. However, the increase in soil pH was still below the optimal soil pH range of 5.0 and 6.5 (Mapiki 1997, unpublished) for most crops, including soybean. AgLi significantly ($P < 0.05$) contributed more exchangeable calcium to the study soil than NMT and the control treatment. The NMT did not significantly ($P > 0.05$) contribute exchangeable magnesium to the study soil during the first season, as expected. Application of calcitic limestone has been known to increase soil pH and exchangeable calcium more quickly than dolomitic limestone. Ananthanarayana and Hanumanthараju (1993) in their study on efficacy of different liming materials in neutralizing soil acidity reported that calcium oxide, calcium hydroxide and calcium carbonate increased soil pH and reduced soil acidity more quickly than dolomitic limestone. Particle size and neutralizing value are some of the factors that contribute to the reaction of lime in the soil (Coleman and Thomas, 1967). AgLi has a 63 µm mesh size and higher neutralizing value than NMT. Therefore, AgLi was more soluble and reactive, increased soil pH and reduced exchangeable aluminium of the study soil.

During the 1996/97 season (second year of the study), both NMT and AgLi significantly ($P = 0.05$) increased soil pH of the study soil over the control treatment. NMT significantly ($P < 0.05$) increased exchangeable magnesium over AgLi and the control treatment (Table 3). However, NMT gave significantly ($P < 0.05$) higher exchangeable magnesium than AgLi and the control treatment. This was expected because the magnesium content in NMT is higher than in AgLi, whilst AgLi maintained its superiority in significantly ($P < 0.05$) increasing exchangeable calcium. NMT also significantly increased exchangeable calcium and soil pH. Soil pH rose to 4.8 after NMT, which is the established critical pH value for soybean production for most soils in the Zambian high rainfall area (Munyinda 1984).

Table 1. Chemical characteristics of NMT and AgLi used in the study

ELEMENT	UNIT	AgLi	NMT
Ca	(%)	32	14.2
Mg	(%)	1.8	10.1
Free cyanide	(%)	< DL	< DL
Cd	(%)	< DL	< DL
Pb	(%)	< DL	< DL
As	(%)	< DL	< DL
N.V.	(%)	97	75
Fe	(mg kg^{-1})	16.7	1500
Zn	(mg kg^{-1})	1.8	89

NV. - Neutralizing value

< DL - below detectable limits

Table 2. Effects of liming sources on soil pH, exchangeable aluminium, calcium and magnesium of Mufulira soil series during the 1995/96 season

Treatments	pH (CaCl$_2$)	Al^{3+}	Ca^{2+} (cmolckg^{-1})	Mg^{2+}
Control	4.3b	0.80a	0.12c	0.10a
NMT	4.4b	0.95a	0.28b	0.15a
AgLi (Reference)	4.8a	0.40b	0.50a	0.10a
LSD (0.05)	0.25	0.14	0.13	0.06

Means in vertical column followed by the same letter are not significantly different at P = 0.05.

Table 3. Residual effects of liming sources on soil pH, exchangeable calcium and magnesium for Mufulira soil series during the 1996/97 season

Treatment	Soil pH ($CaCl_2$)	Ca	Mg
		(cmolc kg^{-1})	
Control	4.3b	0.45b	0.10b
Nampundwe tailings	4.8a	0.82b	0.30a
Agricultural lime	5.0a	1.3a	0.18b

Means in columns followed by the same letter are not significantly different at P = 0.05.

Both NMT and AgLi produced a linear increase in soil pH with increasing rates of liming (Figure 1). However for AgLi, no further increase in soil pH occurred beyond 2.0 t ha^{-1}. The soil pH at the new site was raised more quickly than that at the old site established in 1995/96. It appears that management practices of the research field in which the trial site was located could be the reason for differences in the overall soil chemistry of the two locations belonging to the same study soil. The pH result for 1996/97 strongly indicates that 2.0 t ha^{-1} is the optimal liming rate for this soil. This confirms the finding by Munyinda (1984) that 2.0 t ha^{-1} was the optimal liming rate for the Mufulira soil series.

The liming materials did not significantly increase soybean grain yield in the 1995/96 season (Figure 2). However, the residual effect of both NMT and AgLi applied in the 1995/96 season did not significantly ($P < 0.05$) increase soybean grain yield. It appears that despite the increase in soil pH of Mufulira soil series from 4.3 to 5.0, and the increase in exchangeable calcium by AgLi and exchangeable magnesium by NMT, the soil conditions for healthy growth of soybean were not attained. Mufulira soil series is dominated by the kaolinite type of clay mineral with a substantial amount of amorphous iron and aluminium oxides. Since under most conditions complete neutralization is not achieved when acid soils are limed, hydroxyl compounds of aluminium and iron could remain (Coleman and Thomas, 1967). There is a time lag between a change in soil pH and subsequent changes in the concentration of aluminium (Munyinda, 1984) before significant yields are realized. It follows that though the soil pH of Mufulira soil series was increased from 4.3 to 4.8, the aluminium polycomplexes were not instantaneously reduced to their chemical inert forms, which reduce slowly over several years. Thus, at a soil pH 4.8 that was attained by NMT it appears that monomeric exchangeable aluminium that remained un-neutralized could have affected the soybean yield. Coleman and Thomas (1967) indicated that the products of complete neutralization that are attained at a pH higher than 8.3 are exchangeable calcium and magnesium and inert hydroxides of aluminium and iron. Therefore, to attain near or complete neutralization of soil acidity for soils of the Mufulira series requires a longer period of residual effect than the two-year period of this study.

NMT increased soybean grain yield linearly with increasing liming rates, with the maximum yield of 1.1 t ha^{-1} obtained at 3 t ha^{-1} lime (Figure 3). The soybean grain yield obtained is similar to yields obtained by Goma et al. (1990) at the liming rate of 2.0 t ha^{-1} on a related soil series. NMT significantly increased soybean grain yield over AgLi and the control treatment. The trend in soybean yield after the AgLi treatment was not consistent. At 2 t ha^{-1} AgLi produced a lower grain yield than NMT. The depressed soybean yield could have been due to the loss of AgLi through water erosion in two AgLi treated plots that had a slope.

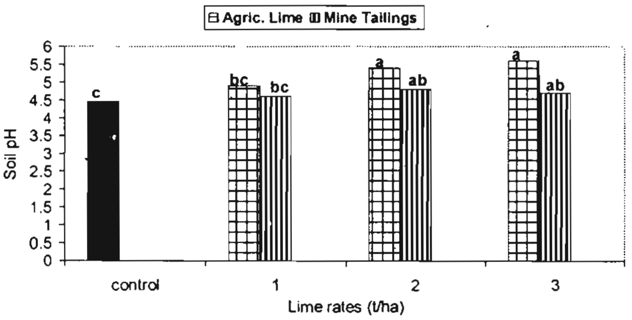

Figure 1. Effects of liming rates on soil pH, planted in 1996/97 season

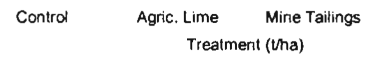

Figure 2. Effects of liming sources on soybean grain yield for 1995/96 and 1996/97 seasons

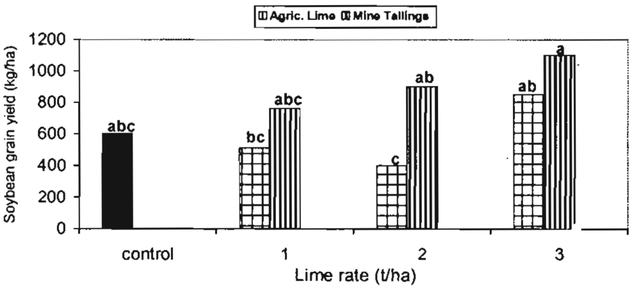

Figure 3. Effect of liming rates on soybean grain yield (Cv. Santa Rosa) for the new site planted in 1996/97 season

The significant soybean yield could have been due to differences in management of the research fields where the trials were located. It appears the location used for the 1996/97 trial to test the rate effect of the two liming materials could have been managed so that soil fertility was improved and that influenced soybean yield.

Conclusion and Recommendation

The residual effect of NMT increased the soil pH and exchangeable magnesium of the study soil. However, the increase in soil pH and exchangeable magnesium did not increase soybean grain yield. It is recommended that a study of the residual effect be conducted for a longer time for NMT to completely react to conclusively evaluate its effectiveness for soybean production in acid soils of the high rainfall area of Zambia.

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Questions and Answers

Improving the Productivity of Grain Legumes and Green Manures

To Obed I. Lungu and Kalaluka Munyinda

Q: Was the reduction in yields after adding MAP not due to N_2 fixation reduction by the presence of N in the MAP?
A: No, all treatments received optimal N, and N_2 fixation was not being evaluated in this study. PAPR has no N, but these treatments received N from either urea or ammonium nitrate.

Q:
1) Were these trials conducted on station or on farm?
2) If on farm, do farmers still get the benefits of PAPR if they plant late or weed less effectively?
3) What is the cost of getting P_2O_5 per unit of nutrient by applying PAPR compared to DAP, considering the bulk of PAPR is inert material?
A:
1) The trials were researcher–designed and farmer managed. They were both on farm and on station.
2) PAPR is just a substitute or alternative to MAP, TSP, etc. Farmers would therefore manage their crops with PAPR in the conventional way.
3) At only 10% P_2O_5 in PAPR, the material is bulky. The product that will be promoted will be beneficiated by a physical process to at least 15% P_2O_5 as already demonstrated.
Additionally, the utilization of PAPR is being promoted for areas close to the deposits of PR.

Q: Should RP work still be considered a priority given that so much work has been done, but these materials are most often not available nor sufficiency reactive?
A: Yes, PR work is still needed, but there should be a shift from basic research on–station to promotion and demonstration on–farm. Soils are acutely deficient in P, and adequate P application is in excess of 80 kg P_2O_5 ha^{-1}, which is beyond what small farmers can afford especially since imported fertilizers in the region cost at least four times their cost outside Africa. The local product would be developed and made available to farmers if there was the political will and the policy and institutional support.

To Atusaye Mwalwanda, et al.

Q: I do not think the effect of S increase was studied, when looking at your treatments?
A: The fertilizer source used was unfortunately a compound fertilizer 23:21:0:4S, hence it is difficult to isolate the individual effects of nutrients. However, the response to the inorganic fertilizer is an indication of the deficiency of the elements in the soils at the study sites.

Q: In your first conclusion your attribute an increase in yield to P and S, but what is the economic return for the extra yield versus the cost of nutrients?
A: Economic analysis was not done in this study. There is need to do that analysis to get the benefit from using inorganic fertilizer compared with not using.

To Lackson K Phiri, et al.

Q: Ca and Mg are usually leached into the sub–soil. In your assessment of the residual effect of the liming materials tested on soil Ca and Mg levels, what was the justification for tracing the two bases down to 20 cm soil depth only?
A: I agree that there is the possibility of Ca and Mg leaching in a high rainfall environment such as where the trial was located. But the trial was only in the second year so our interest was to see what was happening in the rooting depth (0 – 20 cm) and later assess the leaching of these cations down the soil profile. Unfortunately funding ended prematurely.

Q: Your results do not mention the effect of increasing lime material on available phosphorous, but only mention pH and exchangeable Al^{3+} effects. Why did you not mention P availability since it is very much influenced by Al^{3+}?
A: Certainly P is critical. Indeed in the middle of the trial in the 1995/96 season, P deficiency symptoms were observed such that an additional 20 kg P_2O_5/ha had to be added to correct P deficiency.

General Discussion

C: How much yield benefit after a fallow is necessary for the system to yield more than with two years of cropping? The naïve answer is "twice as much". But maize next year is not worth as much as maize in your hand – an effect economists call "discounting". This means the yield improvement must be more than two times for the fallow to be viable. On the other hand, the fallow may take less labour and may benefit long term–fertility or reduce weed populations, which implies that less than twice the yield is necessary. We have to consider these effects clearly and cost them.

C: Both leaving land fallow with non–food legumes or growing maize after maize may face a problem of adoption. There are agronomic management systems that minimize competition and improve the compatibility of components in intercropping systems. Growing legumes under early maturing maize may give better opportunities to minimize risk and increase profitability per unit land area over seasons.

C: Almost all the papers presented on legumes (grain or green manure) assume that the crop residue is incorporated into the soil by farmers. But often livestock is a major component of the systems, and farmers give priority to their livestock rather than soil fertility when it comes to decision making. We have to reconsider our work to integrate and evaluate it as it affects the whole production system.

C: Various nutrient deficiencies occur in tropical soils and this may confound responses to the application of only a limited number of nutrients. In practice it is important to apply sufficient levels of all nutrients except the one being investigated to obtain predictable and explainable responses. There are many options with providing N, e.g. manures, N_2 fixation, N fertilizer, if all other nutrients are adequate.

C: Often in the presentations we hear the statement "the treatments were not significantly different, but they were different". If we are going to ignore the results of our statistical tests, why bother doing them? Also we should not accept a significant difference as meaning a treatment is viable – the question is, does it show a significant economic benefit?

EVALUATION AND PROMOTION OF VARIOUS CLASSES OF ANNUAL LEGUMES WITH FARMERS IN CHIOTA, ZIMBABWE

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Abstract

Nitrogen is one of the most limiting crop nutrients in crop production. It is important, therefore, to identify and utilize all available sources of nitrogen, particularly those that are readily available and generally affordable by resource poor farmers. Green manure and cereal - legume rotations can be practiced to supply nitrogen.

Green manures must be managed well to produce a significant fertilizing effect on the following crop. This is particularly important for the smallholder farmer who is sacrificing a food crop for one year through this practice. Smallholder farmers have practiced cereal - legume rotations for many years using legumes such as groundnut, bambara nut and field bean. Despite this practice of crop rotation, the problem of low soil fertility has persisted resulting in low maize yield. Generally, the use of mineral fertilizers has declined over the years due to high input costs. Hence, the objective of this work was to introduce better N-fixing legumes to improve soil fertility. Velvet bean, sunnhemp and soyabean were introduced.

Farmer participatory research methods were used for three years. Research and extension worked with identified farmer groups in a multidisciplinary approach. The evaluation and promotion of technologies was carried out during farmer feedback sessions and field days.

The major problems encountered in the promotion of these legumes included the unavailability of seed material locally, and lack of knowledge on the management aspects of the legumes to attain the optimum biomass. Legume cereal rotations were widely accepted, whilst green manures were accepted to a lesser extent. The results from the pilot project indicated that 29% of the farmers used the green manure and 57% the soyabean + cereal rotation. Maize yields from different sites increased by 15-70% for green manures and by 40-100% for the rotations.

Farmers take up technologies within given domains so there is a need to come up with green manure or legume fertility packages for different farmers in their agro-ecological zones. An impact assessment would best indicate the results of this multidisciplinary approach.

Key words: Annual legumes, farmer participatory research and extension, technology promotion, adoption potential, impact

Introduction

Nitrogen reserves in the soil are difficult to build due to its liability to leaching losses. It is important, therefore, to identify and utilize all sources of nitrogen, particularly those that are readily available and generally affordable by resource poor farmers. Green manure and cereal legume rotations can be practiced as important ways to supply nitrogen.

Green manures must be managed well to produce a significant fertilizing effect on the following (usually cereal) crop. This is particularly important for the smallholder farmer who is sacrificing a food crop for one year through this practice. Smallholder farmers have practiced cereal-legume rotations for many years, particularly focusing on grain legumes such as groundnut, bambara nut and edible bean. The area allocated to bambara nut is so insignificant that it can give little impact (AGRITEX, 1998-2002). Despite crop rotation, the problem of low soil fertility persists and maize yields continue to decline. Generally, the use of inorganic fertilizers has declined since the early 1990s, mainly due to high input costs. Hence there was need to introduce better performing legumes that have good nitrogen fixation abilities. For green manures, velvet bean (*Mucuna spp.*) and sunnhemp (*Crotolaria juncea*) were introduced. With cereal-legume rotations, soyabean was introduced as a new legume.

A pilot project was set up with Soil Fert Net to evaluate Best Bet soil fertility technologies with farmers from Chiota Communal Area of Mashonaland East Province in Zimbabwe. The major goal of the project was to expose approximately 4000

Table 1. Maize and Grain Legumes Production Statistics -Results from the Chiota Pilot Project

CROP	1998-1999		1999-2000		2000-2001		2001-2002	
	Area (ha)	Yield (t/ha)	Area (ha)	Yield (t/ha)	Area (ha)	Yield (t/ha)	Area (ha)	Yield (t/ha)
MAIZE	8784	0.5	7125	1.8	6973	2	7733	0.2
GROUNDNUT	546	0.5	439	0.6	399	0.8	420	0.1
SOYABEAN	5	0	12.8	0.6	9	0.8	28	0.1
EDIBLE BEAN	420	0.6	163	0.8	280	0.8	680	0.4

Source -[AREX- Fortnightly Crop and Livestock Reports]

farmers to the Best Bet soil fertility technologies in two years. Table 1 shows production statistics from the pilot area during 1998-2002.

Data from Fortnightly Crop and Livestock Reports - AREX (Division of Agriculture Research and Extension) indicate production levels of major cereals and legumes before the inception of the project in 1998-1999, during the project and after the project in 2001-2002.

Methods Used

Farmer participatory research

Farmer participatory research methods were used. These methods call for a systematic dialogue between farmers, research and extension. In participatory research, scientists work with informants (farmers providing information) and experimenters (farmers who perform experiments and evaluations) (Bellon, 2001). The community usually identifies these farmers with the assistance of extension staff.

The group extension method is one of the extension methods used. Farmer group members were selected based on the following criteria:
- farmers` ability to grow a variety of crops
- farmers` reputation and workmanship
- Sex, age
- Land holding.

In 1998-1999, a Participatory Rural Appraisal was undertaken to find out about farmers` understanding of the soil fertility status in their areas. Research and extension facilitated the identification of suitable interventions from a list of existing technologies. During the project cycle, monitoring and evaluations were carried out through demonstrations, field days and farmer feedback sessions. Research, extension and farmers participated at all stages.

Demonstrations and field days were also used as evaluation and promotion sessions. Demonstrations were research designed but farmer managed. Each host farmer served as a replicate of the experimental unit. Each host farmer had a single plot measuring 0.2 ha (Figure 1).

Figure 1. Layout of demonstration plots

MAIZE/ MAIZE 0.1ha.	MAIZE/ LEGUME 0.1ha.

Demo-plots of maize after a grain legume and maize after a green manure were compared with the farmer practice of planting maize after maize. In some cases more than one grain legume was established.

Twenty-three sites of cereal - grain legume rotations and 10 sites of green manures were established. Soyabean, groundnut, bambara nut and cowpea were established in rotation as sole crops. Velvet bean and sunnhemp were established as either intercrops or as sole crops. Maize yield from the demo plots was compared.

Field days were held at all established sites. The field days served as sessions for the sharing and exchange of ideas between farmers, research and extension. In some cases, farmer feedback sessions were arranged.

Results

Farmer participation

The farmers who used at least one of the technologies after a year were considered to be adopters. These farmers were both from within the groups and outside the groups. Field days played an important role in the promotion of the technologies. In some cases, farmers used more than one of the technologies on offer. Adoption of the technologies also depended on the socio-economic status of the farmer.

More farmers adopted the cereal-legume rotations (57%) compared with 29% of farmers that adopted the green manure technology (29%).

Demonstration plots

Several shortcomings occurred during implementation at some sites. The results from these plots were discarded. For example, plots with different pre-establishment treatments were compared (unlimed plots were compared with limed plots). This increased the number of factors, thus complicating the demos from the farmers` point of view. Variability in the results occurred due to different management abilities of the farmers and the competency of the extension agent, even though pre-planting demonstrations had been held.

Table 2. Maize yields from the cereal - grain legume rotations, 2000-2001.

	Maize/ maize (t/ha)	Maize/soya (t/ha)	Maize /groundnut (t/ha)	Maize /bambara (t/ha)	Maize/ Cowpea (t/ha)
Site 1	3.3	5.8	-	-	5.4
Site 3	2.6		4.2	4.1	-
Site 3	4.0	4.5	4.3	-	-
Site 4	4.3	4.6	4.5	-	-
Site 5	2.0	4.0	3.8	-	-
Site 6	1.5		3.0	-	2.7
Site 7	2.0	3.5	2.5	-	-
Site 8	1.6		3.0	-	-
Average	3.2	4.7	4.2	-	-

Table 3. Maize yields from the green manure demonstration plots, 2000-2001.

	Maize/maize (t/ha)	Maize/velvet bean (t/ha)	Maize/ sunnhemp (t/ha)
Site 1	2.1	3.7	-
Site 2	1.6	-	3.5
Site 3	1.5	-	3.5
Site 4	2.0	2.0	-
Site 5	-	2.5	3.0
Site 6	1.1	-	1.4
Site 7	0.9	1.0	-
Site 8	1.1	1.3	-
Site 9	2.0	2.0	-
Site 10	2.5	3.0	-
Average	1.5	1.6	1.4

Maize after a legume outperformed maize after maize at all sites (Table 2). With the green manure technology, farmers preferred sole cropping to inter-cropping, mainly because of the constraints encountered during harvesting. The demonstrations were held for two years only and no arrangements were made for the third year because project funding had terminated. The data collected was from the sole cropping.

The average grain yield of maize after maize was out-yielded by maize after a green manure (Table 3). Results from Table 3 indicate that the yield increase over the two years did not compensate for the yield lost during the first year.

Farmer feedback sessions

Attendance at field days was overwhelming. Attendance ranged from 50 to 160 people at some sites. At least 14% and up to 60% of the targeted farmers used annual legumes (such as velvet bean and soyabean) as soil fertility interventions. However, farmers cited the following setbacks (AGRITEX, 2000; 2001):

Table 4. Participation of Chiota farmers in legume production, 2000-2001.

LEGUME	TOTAL NO. OF PARTICIPATING FARMERS	ADOPTERS WITHIN THE GROUP		ADOPTERS OUTSIDE THE GROUP
		No.	%	No.
ROTATION	1433	818	57	381
GREEN MANURES	631	185	29.3	94

- Lack of planting material.
- Lack of knowledge on the utilization of legumes for human consumption and stock-feed.
- Lack of knowledge on other uses of velvet bean and sunnhemp.
- Lack of knowledge on the residual nutrient levels because of the rotation and green manure.
- The concept of input reduction costs was not properly demonstrated.
- Generally, management of the green manure was poor.

"Adopters" were considered to be those farmers who used the technology. The table above shows the total number of adopters over two years. The number is expected to rise through farmer-to-farmer contacts.

There was need to repeat the demonstration in the second year, but this could not be carried out due to unfavourable weather conditions and other socio economic circumstances. However, the following issues in management of green manures are to be considered for future demonstrations:

- Sowing and site selection - Plant populations were low due to plant destruction by wild animals. This resulted in very low biomass.
- Fertilizer use - without fertilizing it is not possible to achieve a closed green stand and biomass quantities obtained will be low. Farmers considered that it was not practicable to fertilize fallows.
- Incorporation - rarely was the green manure incorporated at the best stage. The method of incorporation was also not ideal because the green manure was not fully covered and the environmental conditions were not always good.
- Seed procurement - Seed was not readily available locally.

The pilot project built a sense of awareness amongst the farmers. An impact assessment will reveal the best steps forward.

Recommendations and Conclusion

In view of the setbacks given, other options can be tried out. These include:

Biomass transfer - plant material can be transferred from its place of growth in other fields and be incorporated into the soil as green manure.

Green manuring with roots - the green material can be used as fodder whilst roots remain in the soil. The benefit from this practice depends primarily on the quantity of root material remaining in the soil after harvest. In work done at Makoholi on sandy soils, maize yields obtained after sunnhemp tops were removed were similar to those obtained when everything was incorporated (Nyakanda, 1996).

The farmer participatory research and extension methods used strengthened farmer research and extension linkages. This linkage is important in the promotion of technologies. However strong back-up from policy makers is required to ensure continued implementation of the technologies. There is also need to carry out an economic analysis of the results and give farmers some feedback. In most cases the researcher is interested in just the results and no feedback is normally given back to other stakeholders. On the other hand, extension normally uses narrative and qualitative analysis of data, which is not always ideal.

Farmers are concerned about the dollar they have in the pocket today rather than the three dollars they may have tomorrow, whereas benefits derived from rotation and green manures are derived 2-3 years later. Our recommendations should also consider farmers` circumstances. Farmers differ in their socio-economic status and they mainly take up technologies that suit their circumstances. Farmers require continued support as back up services from both research and extension if the promotion of various annual legumes is to make an impact. Additionally a more sustainable approach should be considered. At present, all our efforts are left hanging or have been suspended. Now that farmers are aware of the technologies, what is the way forward?

Despite the shortcomings, the pilot project in Chiota Communal Area played a pivotal role in implementing the farmer participatory research methods. The experiences can be adopted by extensionists and researchers working with resource-poor farmers. Promotion of annual legumes with farmers requires a participatory approach at all stages of the project cycle.

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FINANCIAL AND RISK ANALYSIS TO ASSESS THE POTENTIAL ADOPTION OF GREEN MANURE TECHNOLOGY IN ZIMBABWE AND MALAWI

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Abstract

Smallholder farmers in southern Africa face acute food insecurity as the productive capacity of their soils have declined. These resource poor farmers cannot afford to use inorganic fertilizers. Consequently, Soil Fertility Management and Policy Network researchers in Southern Africa engaged in developing best-bet soil fertility technologies have recommended green manure technologies as possible options to improve soil fertility to increase maize yield.

In the sandy soil sites in Malawi and Zimbabwe, agronomic results showed that the incorporated mucuna biomass substantially improves maize yields. Mucuna was grown and the biomass incorporated in the first growing season and maize was then grown in the two subsequent seasons.

The objectives of this paper are : (1) to verify the financial incentives to farmers for investing in mucuna as a green manure technology (as defined above) by quantifying its Net Present Value (NPV), (2) to assess the possible effects of likely changes in the cost and benefit elements of the technology on the NPVs and (3) to compute the risk that farmers might face in investing in mucuna (i.e. chances of getting a negative NPV). Analysis was done for cases where land is fallowed (land fallowing farmers) and where maize production is forgone in the first year for non-fallowing farmers, who would be prospective users of mucuna.

Financial analysis reveals that under the current inputs and output prices there are positive payoffs to investing in mucuna for both Malawian and Zimbabwean farmers. Considering uncertainty, land constrained farmers face more risk than land adequate farmers in adopting mucuna. In both countries, the NPVs are sensitive to changes in the discounting rates, maize grain price and yield. This implies that policy interventions to decrease the discounting rate and/ or an increase in output price would create incentives to access credit to invest in soil fertility technologies and increase farmers' income, respectively. Research efforts to improve maize yield response to mucuna residue incorporation would greatly contribute to increased profitability and make the technology more attractive.

Key words: Financial analysis, Net Present Value, green manure, technology adoption, policy

Introduction

The Problem Setting

About 70% of the population of Southern Africa resides in rural areas where they subsist on small farms (Mabeza-Chimedza, 2000). For many of these resource poor farmers, maize is the staple crop. Problems of food insecurity persist in the region, with the 2001-02 year being one of the worst in history. Over 13 million people are currently threatened with food shortages in Lesotho, Malawi, Mozambique, Swaziland, Zambia and Zimbabwe (SADC Food Security Bulletin July, 2002).

Crop yields in Sub Saharan Africa have been declining steadily over the years. It is becoming increasingly acknowledged that low and declining soil fertility reduces maize yield even when normal rainfall is received (Kumwenda et al. 1996). The soils have become depleted of nutrients in many smallholder systems where nutrient outputs exceed nutrient inputs, leading to mining of soil nutrients (Buresh et al. 1998). Reduced access to inorganic fertilizer sources explains this depletion of soil nutrients from smallholder farming systems. Increased human population pressure has resulted in land scarcity and shortened fallow periods limiting the use and benefits from traditional soil fertility management practices like cattle manure, fallowing and slash and burn in replenishing soil nutrients. Reduced access to inorganic fertilizers derives from unfavourable grain /fertilizer price ratios, driven by poor infrastructure, and unsuitable input and product pricing policies, and uneven performance of private sector companies (Mwangi, 1997).

Proposed Interventions

Researchers have attempted to come up with alternative soil fertility management strategies that can arrest the decline in soil fertility in southern Africa. An inventory of soil fertility practices known as 'best bets" being suggested to farmers include among others, inorganic fertilizer regimes, lime use in acidic soils, improved animal manures, grain legumes for rotations, green manure legumes, agroforestry/trees in cropland, and biomass transfer systems. Each of these technologies has its advantages and limitations depending on the biophysical conditions in which it is applied and socio-economic attributes of the farmers. It is generally accepted that the extent and intensity of technology adoption is governed by how well technology attributes fit into farmers' farming systems, its profitability and contribution to reduce risk and income variability (Mekuria and Waddington, 2002).

Green manures look promising for such poor farmers. Green manure biomass is rich in N and therefore has potential of supplying N; the most commonly limiting nutrient to cereal production in both Zimbabwean and Malawian smallholder soils. Results from trials conducted in both Malawi (Kumwenda 1998; Sakala, 1998) and Zimbabwe (Muza 1998) concur in confirming that *Mucuna pruriens* compared to other green manure species produces the highest amount of biomass.

Mucuna pruriens is a herbaceous legume that has the ability to fix nitrogen from the air into the soil. A healthy mucuna plant can grow vigorously to produce 10 t/ha of biomass and can leave over 100 kg N/ha in the soil. If it is to be used solely as a green manure, mucuna can be incorporated early when it is still green or late after flowering if the seeds are to be harvested. To achieve fertility benefits, mucuna biomass has to be incorporated and in the following seasons maize is grown. It is generally agreed that maize yield increases are obtained for a maximum of three years (S Waddington, 2002 personal communication) thereafter the biomass is almost totally degraded. For farmers to benefit from mucuna, they have to use it on fallowed land or have to forgo one season of maize production. Thus, the mucuna technology requires additional labour and some modest cash amounts for seed purchase in the first year. To some land constrained farmers, it means forgoing one season's harvest of maize. The decision to adopt mucuna can be difficult for poor smallholder farmers who are pressed with the need to produce the staple maize crop every season and at the same time are faced with declining soil fertility and maize yields every year because of continuous cropping.

Objectives of the Study

The paper seeks to assess the potential returns and incentives for investing in mucuna as a soil fertility management technology by smallholder farmers in Zimbabwe and Malawi. Additionally, the paper undertakes risk analysis to assess how some changes in the cost and benefit elements of this technology will influence the attractiveness and therefore likely investment in mucuna as a soil fertility technology. It draws lessons for policy intervention and research strategies.

Data Sources

Maize yield data from on-farm trials generated for three seasons from 1997 to 1999 in Malawi (provided by Webster Sakala of DARTS Malawi and summarized in Sakala et al. 2001) and Zimbabwe (provided by Tendai Gatsi and Lucia Muza of Agronomy Institute, DR&SS and summarized in Muza, 2002) (see Appendix 1) was used in the analysis. In Zimbabwe, the on-farm trials were conducted in two communal sites, Chihota and Zvimba, which are typical smallholder farming areas in the north central sub-humid rainfall belt with poor sandy soils. In Malawi, the on-farm trials were conducted in two sites in central Malawi representing sandy soils of the country. Mucuna was grown in the initial year and incorporated early in both Zimbabwe and Malawi. The maize yields for the subsequent two seasons were compared to a control of continuously cropped maize. Secondary sources of information were used for prices, costs and labour data.

Growing of mucuna for incorporation of its biomass is a farm investment activity whereby effort and money are spent with the anticipation of a future stream of benefits as increased maize yields due to improved soil fertility. Before encouraging farmers to adopt mucuna, it is necessary to assess whether the incremental income from mucuna investment will be large enough to compensate them for the additional effort and risk they will incur.

Analytical Procedures

The study used financial cost-benefit analysis to determine the financial effects of using mucuna as a soil fertility technology on the smallholder farms. In addition, sensitivity analysis was employed to evaluate the risk associated with the technology.

Financial Analysis

For a sound financial analysis, it is important to properly identify costs and benefits of an investment activity (Gittinger, 1982). A 'with' and 'without' technology approach was used to capture the incremental costs and benefits associated with mucuna as a green manure technology.

The 'without' technology scenario was defined as growing maize continuously for three years without use of any soil fertility intervention, a practice that has become common among many poor smallholder farmers in Malawi and Zimbabwe. The 'with' technology deals with a mucuna-maize-maize 3-year crop rotation.

The incremental costs for using mucuna are perceived to be different for farmers who are able to fallow some portions of their field and those who are not able to do so due to land constraint. For those who fallow land, the incremental costs are additional labour and seed costs associated with growing mucuna. For farmers who have to forgo maize production on the portion of their land planted to mucuna in the investment year, the incremental cost is the opportunity cost in terms of value of forgone maize production. Benefits were measured as the value of the incremental maize grain yields in the subsequent two seasons which was derived as the difference between continuously cropped maize yields and the maize yield after mucuna incorporation. To value the costs and benefits of mucuna, 1999 market prices of inputs and outputs in both countries were used (see Appendix 2).

NPV

The Net Present Value (NPV) was used to quantify the net financial gains to farmers for investing in mucuna. NPV is the difference between the sum of discounted benefits (incremental maize yields in two seasons) and the sum of discounted costs (cost of mucuna production/forgone maize grain harvest). NPV is an absolute measure of the present worth of an income stream accruing to the individual farmers; which is what the farmers are more interested in (Gittinger, 1982).

The NPV was calculated per one hectare unit of land. If NPV is greater than zero it is worthwhile investing in mucuna and if it is less than zero it is not worthwhile investing in mucuna. The larger the value of NPV the higher the financial returns to investing in mucuna.

Sensitivity and Risk Analysis

Sensitivity analysis shows to what extent the returns (NPV) to investing in mucuna is influenced by variations in the major quantifiable elements. This is important for identifying those elements whose changes have the largest impact on viability of the technology. Monitoring and management of such elements is critical in ensuring viability of the technology.

Risk analysis shows the probability outcomes of the NPV derived from the changes in its elements. The probability that the NPV would be negative can be used as an indicator of the degree of risk in adopting the technology.

Both sensitivity and risk analysis were performed using @RISK (a risk analysis software). @RISK uses distribution functions instead of constant values and can simulate 1000s of possible outcomes of NPV. Because of a lack of historic data, triangular distributions were used to estimate the distribution functions of all the parameters used in computing NPV (see Appendix 3).

In sensitivity analysis the regression and correlation coefficients for the relationship between the changes in NPVs and changes in the cost and benefit elements are computed. The larger the regression coefficient of an NPV element the more important it is in accounting for changes in the expected NPV. The correlation coefficient simply shows the nature of the relationship (positive or negative) between changes in expected NPV and the element. In risk analysis, a cumulative distribution curve for the simulated NVP outcomes is generated.

Results

Financial Incentives

For both farmers who fallow and those who can not fallow, the NPVs in both Zimbabwe and Malawi are positive, implying positive pays-offs for investing in mucuna for the two types of farmers (Table 1). The NPVs are larger in Zimbabwe than in Malawi. This means that there is less additional returns for investing in mucuna in Malawi than in Zimbabwe, largely explained by the much higher maize yield responses to mucuna in Zimbabwe compared with Malawi (see Appendix 1).

In Zimbabwe, investing into mucuna yields higher returns (NPV) to farmers who forgo maize production than for those who fallow their lands (Table 1). The difference between NPVs for the two types of farmer is accounted for by the difference in

Table 1. NPVs ha^{-1} for investing in Mucuna as a green manure (US Dollars)

	Zimbabwe (Discounting at 50%)		Malawi (Discounting at 34%)	
(in US$)	Non-Fallowing farmers	Fallowing farmers	Non-fallowing farmers	Fallowing farmers
Total costs	37.11	57.46	56.64	50.76
Total benefits	189.88	189.88	70.11	70.11
NPV	152.77	132.42	13.48	19.35

Source: calculated by authors from on-farm trial data the investment costs incurred. The investment cost for farmers who forgo maize production (opportunity cost of the land in terms of forgone maize grain) is less than for those who fallow their lands (mucuna production cost). This is due to very low maize yields achieved on the soils that are degraded.

In Malawi, the opportunity cost of forgoing maize production is more than the production cost (on labour and seed) of growing mucuna in the investment season. This explains why, unlike in Zimbabwe, investing in mucuna is more attractive (better NPV) for farmers who fallow than for farmers who have to forgo maize production.

The fact that NPV is positive is not the only criterion or factor that farmers may consider in their decision to adopt mucuna. The magnitude of the NPV and the riskiness of the technology are additional factors farmers may consider in adoption of the mucuna technology.

Significance of NPV

To assess the magnitude of the NPV and its significance to farmers, the maize grain equivalent value can be a simple benchmark indicator. In Zimbabwe the NPVs ha^{-1} for both types of farmers are worth about 1.1 t of additional maize grain to the farmer's household over the mucuna-maize-maize rotation period (3 years) while in Malawi the NPVs ha^{-1} are worth about 0.25 t of additional maize grain. Whether these additional pay-offs are worthwhile or not will vary from farmer to farmer depending on their various socio-economic characteristics. However, an additional tonne of maize can be very meaningful for many farmers who are faced with food insecurity and limited choices. Note that the additional cash demands for labour and seed for investing in mucuna are very modest compared to input costs for growing maize.

Sensitivity and Risk Assessment

Farmers operate in an environment of risk and uncertainty. In reality the expected maize yield increase associated with mucuna, maize grain price and labour costs are not fixed but subject to changes . This makes it necessary to subject NPVs to sensitivity analysis to take into account the uncertainties inherent in the elements of the NPVs.

Results of risk analysis show that in general the technology is more risky to farmers who forego maize production than farmers who fallow in both countries (see Appendix 4). There is a 30% and 38% chance in Zimbabwe and Malawi, respectively, that the NPV is negative for farmers who forgo maize in the investment year. For farmers who fallow, chances that the NPV is negative are about 10% in both countries. The risk level of 30 and 38% of getting negative returns can be high to many smallholder farmers who are generally risk averse. This level of risk can be prohibitive to mucuna adoption by land constrained smallholder farmers in Malawi and Zimbabwe who are pressed with the need to produce maize every season. Farmers who alreaady fallow land are therefore more likely to adopt mucuna as their investments in mucuna are less risky than for farmers who have to forego maize production.

The sensitivity analysis reveals that changes in the benefit elements are more important in determining the NPV than changes in the cost elements for fallowing farmers (Table 2). For farmers who fallow land in Malawi, changes in the maize grain price have the most influence on NPV. The changes in year 1 maize yield increment, discounting factor and year 2 maize yield increment are ranked in that order as the additional factors positively related to NPV. For farmers who fallow land in Zimbabwe, the discounting factor is the most important factor positively related to NPV

Table 2. Sensitivity of NPVs to changes in costs and benefit elements

Malawi				Zimbabwe			
For non-fallowing farmers							
Rank	Element	Regr	Corr	Rank	Element	Regr	Corr
#1	Forgone maize harvest (kg)	-0.67	-0.72	#1	Forgone Maize harvest (kg)	-0.60	-0.66
#2	Discounting factor	0.40	0.49	#2	Year 1 maize yield increase (kg)	0.55	0.57
#3	Year 1 maize yield increase (kg)	0.36	0.42	#3	Year 2 maize yield increase (kg)	0.41	0.15
#4	Year 2 maize yield increase (kg)	0.31	0.27	#4	Discounting Factor	0.40	0.33
#5	Maize Grain price (K/kg)	0.09	0.06	#5	Maize grain price ($/kg)	0.21	0.07
For farmers who fallow land:							
#1	Maize Grain price (K/kg)	0.64	0.52	#1	Discounting factor	0.64	0.47
#2	Year 1 yield increase (kg)	0.57	0.67	#2	Maize Grain price ($/kg)	0.57	0.42
#3	Discounting factor	0.40	0.35	#3	Year 1 yield increase (kg)	0.45	0.37
#4	Year 2 yield increase (kg)	0.35	0.25	#4	Year 2 yield increase (kg)	0.41	0.42
#5	Wage rate (K/day)	-0.07	-0.12	#5	Mucuna labour (hrs)	0.00	0.12
#6	Mucuna labour (days)	0.00	-0.06	#6	Land prep cost ($)	0.00	0.03
#7	Seed rate (Kg/ha)	0.00	0.08	#7	Wage rate ($/hr)	0.00	0.05
#8	Mucuna seed costs (K/kg)	0.00	-0.06	#8	Seed rate (Kg/ha)	0.00	-0.02
				#9	Mucuna seed costs ($/kg)	0.00	0.02

for mucuna. Other important factors are maize grain price, Year 1 maize yield increment and year 2 maize yield increment, in that order of importance.

For farmers who forgo maize production in the investment year, the most critical element in determining NPV is the maize yield forgone in both countries. This is a cost element and as expected is negatively related to NPV. This means that mucuna adoption can easily be more attractive where forgone maize yields are low and the converse is true. Holding other factors constant, mucuna would be more attractive on those pieces of land where continuously cropped maize yields are already very low. For farmers who forgo maize production, maize grain price is the least important determinant of NPV. This means that an increase in the maize grain price does not increase the attractiveness of investing in mucuna for non-fallowing farmers as much as it does for farmers who fallow land. This is because an increase in maize grain price increases both the costs and benefits of investing in mucuna technology for non-fallowing farmers, hence minimizing the net effect on the NPV.

Conclusions

The pay-offs to investing in mucuna as a green manure in both Zimbabwe and Malawi were positive though modest in magnitude for both categories of smallholder farmers. After investing their labour and some modest amount of cash to buy mucuna seeds, farmers stand to gain a net present income worth an additional 1.1 t ha^{-1} of maize over the 3-year mucuna-maize-maize (investment-benefit-benefit) period in Zimbabwe and 0.25 t ha^{-1} in Malawi.

Although adoption of mucuna could generate higher returns (positive NPVs), it is necessary to look into the uncertainties inherent in the NPV elements of mucuna technology, such as maize yield responses, prices and discounting rates. The study has shown that the mucuna technology is not free from risk. The risk of farmers encountering losses after investing in mucuna was substantial for the category of farmers who have to forgo one season of maize to grow mucuna. The chances for farmers to realize negative returns to their investment in mucuna were calculated to be 30% in Zimbabwe and 38% in Malawi. Mucuna has few other uses (the seed is not edible) and so has a low monetary value. The risk of negative returns can expose land-constrained farmers to increased food insecurity. These two aspects of mucuna technology could strongly deter its wide adoption by smallholder farmers, many of whom are land constrained and need to produce maize every season.

The regression results from sensitivity analysis have shown that the maize grain forgone had the greatest influence on the expected NPVs for non-fallowing farmers in both Zimbabwe and Malawi.

For such farmers, mucuna would give relatively better pay-offs on lands where maize yields are very low than where they are relatively high. In other words, mucuna pays off better for the non-fallowing farmers on those pieces of land where they sacrifice little grain by choosing to plant mucuna instead of maize.

This implies that minimizing the amount of maize grain sacrificed by farmers in the first season would increase pay-offs of mucuna to land constrained farmers. This calls for increased research efforts into ways of minimizing the amount of maize forgone in the first season for example by exploring intercrop arrangements of mucuna with maize. Research should also focus on improving the maize yield response to mucuna incorporation and the alternative end use possibilities for human consumption.

Maize grain prices and discounting factors were ranked the most important determinants of expected NPVs for farmers who fallow in both countries. Policy instruments can be used to make these two economic parameters favorable for mucuna adoption. For example, in Zimbabwe where the cost of borrowing was very high, reducing the discount rate has the most significant effect in increasing attractiveness of investing in mucuna by farmers who fallow land. In Malawi, a policy measure to increase maize grain price would easily increase incentives for investing in mucuna as a soil fertility improving technology by those farmers who fallow land. In both countries, a combined effect of policy instruments to reduce the discount rate and to increase the grain price of maize would create more incentives for investing in mucuna as a soil fertility technology.

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Appendix 1. On-Farm Trial Maize Yields (kg/ha) after mucuna in Zimbabwe and Malawi

	Year 0	Year 1	Year 2
Zimbabwe:	(1996/7)	(1997/8)	(1998/9)
Maize after maize	225	454.7	260
Maize after mucuna	0	1400.3	2456
Malawi:			
Maize after maize	951.5	828	1075
Maize after mucuna	0	2178	1381

Appendix 2. Rates, Prices and Costs used in the cost benefit analysis (US$)

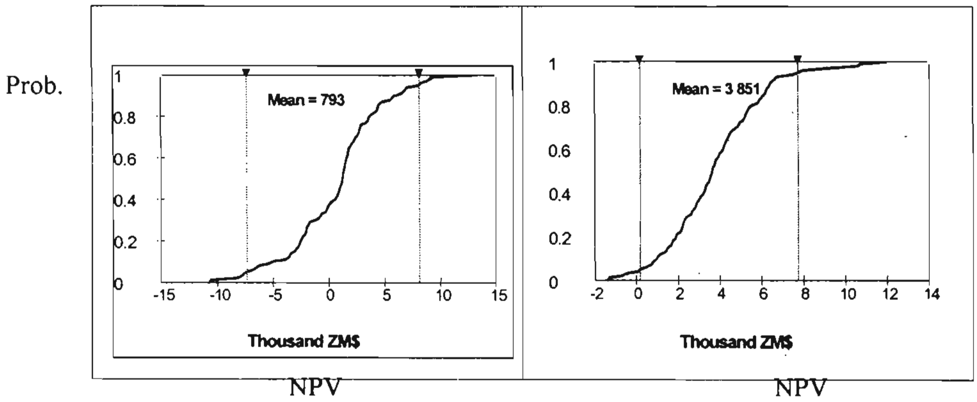
Zimbabwe:		
Maize Grain price ($/kg)	4.5	0.12
Mucuna labour (hrs)	107.2	
Land prep cost ($)	900	23.7
Wage rate ($/hr)	6.75	0.18
Seed rate (Kg/ha)	80	
Mucuna seed costs ($/kg)	7	0.18
Malawi:		
Maize grain price (K/kg)	5	0.06
Mucuna seed cost (K/kg)	26	0.31
Wage rate (K/day)	26	0.31
Mucuna labour (labour days)	84	
Mucuna seed rate (kg/ha)	80	

Note in 1999 1US$ - ZM$38 and 1US$ - MK84

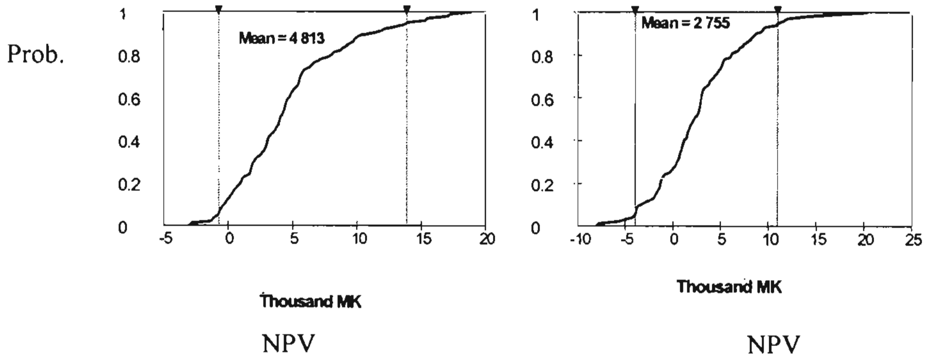
Appendix 3. Distribution Functions for uncertain *Mucuna* cost and benefit elements used in simulating NPV distributions for Zimbabwean and Malawian farmers

Zimbabwe		Malawi	
Parameter	Distribution function	Parameter	Distribution function
Benefits:		*Benefits:*	
Year 1 maize yield increase (kg)	Triang.(0 945 2500)	Year 1 maize yield increase (kg)	Triang.(0 1350 2500)
Year 2 maize yield increase (kg)	Triang.(0 2196 2500)	Year 2 maize yield increase (kg)	Triang.(0 305 2000)
Discounting factor	Triang.(0.5 0.666 1)	Discounting factor	Triang.(0.5 0.746 1)
Maize Grain price ($/kg)	Triang.(3 4.5 10)	Maize Grain price (K/kg)	Triang.(3 5 12)
Costs:		*Costs:*	
Mucuna labour (hrs)	Triang.(105 107.18 110)	Mucuna labour (days)	Triang.(82 84 86)
Land prep cost ($)	Triang.(800 900 1500)	Wage rate (K/day)	Triang.(24 26 35)
Wage rate ($/hr)	Triang.(5 6.75 10)	Seed rate (Kg/ha)	Triang.(78 80 82)
Seed rate (Kg/ha)	Triang.(78 80 82)	Mucuna seed costs (K/kg)	Triang.(20 27 30)
Mucuna seed costs ($/kg)	Triang.(5 7 9)	Maize harvest forgone (kg)	Triang.(800 951.5 1500)
Maize harvest forgone	Triang.(300 313 1000)		

Appendix 4. NPV Cumulative distribution curves in Zimbabwe and Malawi generated by @ risk4.5



Non-fallowing farmers **ZIMBABWE** **Fallowing farmers**



Fallowing farmers **MALAWI** **Non-fallowing farmers**

A SOCIO-ECONOMIC ANALYSIS OF LEGUME PRODUCTION MOTIVES AND PRODUCTIVITY VARIATIONS AMONG SMALLHOLDER FARMERS OF SHURUGWI COMMUNAL AREA, ZIMBABWE

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Abstract

The impacts of poor soil fertility in Zimbabwe's communal farming systems have great implications on the food security and livelihoods of communal households. This study identifies opportunities for using legumes in replenishing soil fertility to improve agricultural production in the communal sector through an assessment of social and economic factors that affect legume production. The study also identifies the economic potential of green manures on farm. Interviews with individual farmers and focus group discussions were conducted to establish perceived roles for legumes in soil fertility improvement. Data were also collected from the on farm trials. Analytical tools such as frequency analysis, regression analysis, descriptive analysis and cost benefit analysis were used to test proposed hypotheses.

The motives for legume production were indicated to be food, cash and sometimes soil fertility improvement. It was also shown that the area under legume production, legume crop prices and labour availability are important factors affecting legume productivity. Legume production as indicated by the area cropped, yield, income and home consumption is very low. The constraints raised by farmers of limited cropping area, lack of markets, seed unavailability and lack of sufficient labour greatly contribute to the low status of legumes in the smallholder cropping system. The potential exists to intensify the use of legumes in the communal areas. The approach required to do this needs to be holistic and take into account their multiple use purposes, input and output markets, and promote new legumes.

Key words: socio-economics, grain legume, motives for legume production, soil fertility

Introduction

Diminishing soil fertility remains the most limiting biophysical constraint to smallholder agricultural production in Zimbabwe. Increasing scarcity of locally derived nutrient sources and the changing socio-economic environment has rendered soil fertility improvement in smallholder farming systems in semi-arid and sub-humid Africa more difficult and complicated. External options for improving soil fertility have failed over the years because of inconsistency with the current circumstances of the farmers.

The major sources of N available to farmers include animal manure, mineral fertilizers, woodland leaf litter and termitarium soil. Cattle manure, which is the commonly used source of organic fertilizer, is often limited in its supply by lack of cattle among farmers. Where available it is often of low quality due to the poor state of the rangelands and lack of adequate proteins in the animals' diet. Use of mineral fertilizers, especially ammonium nitrate (34.5% N), which is the major alternative source of N, is limited in the communal sector due to high costs, unavailability, risk and low returns to investment due to poor crop prices. Furthermore, the traditional sources of N, which include woodland leaf litter, have been depleted due to rapid population increases. There is an opportunity for nitrogen–fixing legumes to be used as cheap alternative sources of soil fertility improvement to help reverse the worsening poverty in these farming systems.

Though traditional legume crops such as groundnut are widely grown in the smallholder farming system, areas planted and yields are very low. Thus, there is need for intensive promotion of these crops for them to be significant sources of N to enhance agricultural production. This study explores the motivation behind legume production among smallholder farmers, the important factors affecting legume productivity and the economic potential of green manures under the current farming system in Shurugwi, Zimbabwe. It was hypothesized that consumption requirements rather than reasons for income and soil fertility improvement motivate legume production.

Research Methodology

Data Collection

The study drew on primary data obtained through a farm survey of 100 randomly selected households in Mfiri ward of Shurugwi. The survey was carried out in January and February 2002. All survey information was collected by interviews with individual farmers using a standard questionnaire. Prior to the field survey, a pre-test of the questionnaire was undertaken to improve the questionnaire design and enhance quality of responses obtained from the farmers. Discussions were held with a group of 15 farmers to establish constraints being faced by farmers in legume production, and identify opportunities for increasing the role of legumes in soil fertility management.

Data Analysis

The data were analyzed using the Statistical Package for Social Scientists (SPSS). Cross tabulations were used to determine important factors affecting area under legume production. Frequency analysis and descriptive statistics were used to analyze motives for production, and regression analysis and descriptive statistics were used for analyzing important factors affecting legume productivity. Measures of project worth (Net Present Value and Internal Rate of Return) and gross margin analysis were used to identify the economic potential of green manure legumes.

Results and Discussion

Comparative assessment of motives for legume production among smallholder farmers

There are three motives for legume production; household consumption (100% of households), sales (78%) and soil fertility (12% of households).

All households interviewed indicated that they grow legumes for household food requirements. This shows that farmers are aware of the potential role of legumes as a source of food for the family. Legumes can be promoted in the farming systems as alternative sources of protein in place of animal protein sources. Svubure et al (2000) also found that the primary reason for producing legumes in Wedza and Buhera was for household consumption, although yield levels are very low.

Cash was the second reason for growing legumes, with 78% of the respondents citing it as the motive for growing legumes. The relatively high percentage of farmers conscious of the cash-generating role of legumes indicates that promotion of legumes can be built on this role. This will need efficient marketing structures for the commonly grown legumes. Hildebrand (1996) also found that both input and output markets are very important if farmers are to increase legume production for the market. Thus if farmers are assured of good output markets for their legumes, they are likely to increase production of legumes for both consumption and for the market. Currently there is no formal market for selling legume products in the area and most of the produce is sold in the local market at very low prices.

In Mfiri, farmers do not deliberately grow legumes for soil fertility improvement, though there is some appreciation of a residual benefit through retained residues. Only 12% of the responses indicated that they grow legumes for soil fertility improvement. This is probably due to a scarcity of land resources resulting in legumes being allocated small pieces of land in relation to maize, the major food and cash crop. Although farmers indicated that they do not grow legumes for soil fertility improvement, they are aware of some soil fertility benefits of growing legumes. Eighty-six percent of farmers were deliberately and consciously aware that legumes add nutrients in the soil. The farmers reported notable changes in crop growth on areas where legumes were previously grown, especially with maize. The fact that farmers are aware that legumes add nutrients in the soil suggests that they are likely to increase their use of legumes in soil fertility improvement if appropriate extension messages are provided.

Economic analysis of grain and green manure legume options for soil fertility improvement

Tables 1 and 2 show the gross margin analysis and measures of project worth (NPV and IRR) for the green manures.

Sunnhemp and mucuna had negative overall 2-year gross margins per hectare using the official grain prices from the Grain Marketing Board (GMB), the sole buyer of maize in Zimbabwe. Cowpea had the highest positive overall 2-year benefit, Z$ 16 198, compared to other options, maize without fertility inputs (Z$3 003), crotalaria (Z$3 542), mucuna (Z$-2 701), and sunnhemp (-Z$3 384). Gross margins at local prices of grain, Z$36.39/kg, were much higher and positive overall for all options. At a GMB price of Z$18.34/kg, the NPV values for mucuna, crotalaria, sunnhemp and maize without fertility

Table 1. Gross margins from the different treatments at the gazetted price for grain sold to GMB (Z$18.34/kg) and at local market prices (Z$36.39/kg)

Treatment	Gross margin per ha (Z$/ha)				Overall 2 year benefits per ha (Z$)	
	First Year (legume)		Second Year (maize)		At GMB price	At local price
	At GMB price (Z$18.34)	At local price (Z$36.39)	At GMB price (Z$18.34)	At local price (Z$36.39)		
Maize after maize, no fertility	1501.46 (maize)	16123.42	1501.46	16123.42	**3002.92**	**32246.84**
Cowpea followed by maize	4526.44	26414.44	11671.50	36303.68	**16197.94**	**62718.12**
Mucuna followed by maize	-13320.56	-13320.56	10619.31	34215.84	**-2701.25**	**20895.28**
C. grahamiana followed by maize	-13320.56	-13320.56	16862.29	46603.70	**3541.73**	**33283.14**
C. juncea followed by maize	-13320.56	-13320.56	9936.09	32860.14	**-3384.47**	**19539.58**

Table 2. Net Present Values for the different treatments at the opportunity cost of capital (20% interest)

Treatment	Net Present Value (NPV)		Internal Rate of Return (IRR) %	
	GMB price	Local price	GMB price	Local price
Maize after maize, no fertility	-1786.47 (maize)	20552.63	7%	84%
Cowpea followed by maize	8344.93	43690.62	37%	204%
Mucuna followed by maize	-7800.75	8585.72	22%	21%
C. grahamiana followed by maize	-3465.35	17188.40	9%	40%
C. juncea followed by maize	-8275.21	7644.27	24%	19%

inputs were all negative, except for cowpea. At a discount rate of 20%, the IRR was significantly improved by selling grain on the local market where the price of grain was higher. Using the discount rate of 120%, which is the current inflation rate for Zimbabwe, only the cowpea option had a small positive NPV.

Econometric analysis of factors affecting legume productivity across smallholder farmers

Average yields per hectare for the commonly grown legumes were compared to the staple maize. As shown in Table 3 for the commonly grown legumes, grain yield levels are very low (ranging from 18 kg/ha to 164 kg/ha). Maize grain yields range from 464 kg/ha to 550 kg/ha. Although average maize yields are higher than those of commonly grown legumes, the yield levels of all crops are generally low. This might be due to low soil fertility and consistent dry spells in the area, allied with lack of working capital to buy purchased inputs such as improved seed and chemicals to control pests and diseases. Working in Wedza and Buhera, Svubure et al. (2000) also found that yield levels for legumes were very low and cited low and erratic rainfall and poor soil fertility as the major factors contributing to low yields.

Table 3. Average crop yields per hectare for the past three seasons

Crop	Average yield per hectare for past three seasons (kg/ha)			Approximate area under crop/household (Mean household size = 3.2ha)
	1999	2000	2001	
Groundnut	154	164	146	15%
Bambaranut	28	34	31	2%
Cowpea	18	19	20	Intercropped with maize
Maize	464	550	510	75%

Source: survey data

Analysis of important factors affecting legume productivity

To determine the important factors that affect smallholder farmers' legume productivity, a simple regression equation was estimated from the survey data. Only factors affecting groundnut productivity were analyzed because it is the major legume grown by communal farmers, accounting for about 20% of the total arable land area.

The following model was used:

$\text{Yieldg}_t = \beta_0+\beta_1\text{area}_t+\beta_2\text{gprice}_t+\beta_3\text{mprice}_t+\beta_4\text{amount of labour}+\epsilon_i$

Where, Yieldg_t= groundnut yield per hectare in a given year (kg/ha)

area_t=area under legume production in a given year (acres)

gprice_t =selling price groundnut in a given year ($/kg)

mprice_t=selling price of maize in a given year ($/kg)

labour = amount of permanent labour to work in fields

β_0 =constant parameter

$\beta_1,\beta_2, \beta_3, \beta_4,$ = coefficients of the variables

ϵ_i =disturbance or error term

From the results, 58% of the total variation of the groundnut yield per hectare for the 2001 season was explained by the regressors included in the model as indicated by the adjusted R-square. This therefore implies that the remaining 42% of total variation was unaccounted for by the regressors, but by other factors not included in the model, perhaps by land shortage, seed unavailability and natural variability of production due to rainfall patterns. Land area, groundnut selling prices and labour availability were important factors affecting groundnut productivity (Table 4).

Table 4. Summary statistics for OLS Estimation for factors affecting groundnut productivity

Variable	Coefficient	t-value	Significance
Constant	-28.458	-1.014	0.313
Area under groundnut production	0.395	5.434	0.000
Selling price of groundnut	0.466	6.508	0.000
Amount of permanent labour to work in fields	0.162	2.332	0.022
Selling price of maize	-0.028	-0.415	0.679

R-Square adjusted - 0.58 F - 34.82 Significance - 0.000

Source: Survey data

Conclusion

Consumption requirements of the household were shown to be the primary reason for producing legumes, followed by income and lastly soil fertility reasons. Farmers do not deliberately grow legumes for soil fertility improvement despite the fact that they are consciously aware of some soil fertility benefits from growing legumes. The potential for expanding legume production has not been realized due to a shortage of land resources and lack of knowledge, among other factors. Legume productivity was generally low in the area. Area under groundnut production, labour availability, and groundnut output prices are important factors affecting legume productivity in the smallholder farming systems. Cowpea, which is a multipurpose grain legume, was more attractive compared to green manures. This indicates that legumes with multiple uses have a higher adoption potential than green manures.

There is need for extension services, non-governmental organizations and marketing agencies interested in the production of legumes to provide incentives and improve access to inputs (e. g. seed, fertilizers) to encourage farmers to increase land area under legume production. Benefits of legumes need to be explained to farmers, especially by health and community workers, as they can help contribute to fight against malnutrition reported in many communal areas of Zimbabwe. Increasing the availability of credit can enable farmers to purchase the needed inputs in legume production such as hiring labour and purchasing seeds. This could help relieve farmers from some major constraints such as labour shortages and so increase legume productivity that would benefit farmers through more consumption, farm incomes and soil fertility improvement through effective maize-legume rotations.

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LINKING TECHNOLOGY DEVELOPMENT AND DISSEMINATION WITH MARKET COMPETITIVENESS: PIGEONPEA IN THE SEMI-ARID AREAS OF MALAWI AND TANZANIA

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Abstract

Legumes have long been grown in smallholder farming systems throughout Southern and Eastern Africa in intercrops and rotations with cereals. Legumes play an important role as food and cash crops, livestock feed, as a soil fertility amendment through biological N_2-fixation (BNF) and for firewood. Because of recent increases in international and domestic prices of inorganic fertilizers, there has been more interest to expand legume plantings and management in smallholder areas especially in the semi-arid areas in order to provide a low-cost supply of nutrients. This paper uses the sub sector approach to explore two hypotheses. First that farmer uptake of pigeon pea-based technologies is driven by improvements in input and output markets. Second that linking technology development and uptake pathways with increasing competitiveness of pigeon pea products in international and domestic markets drives adoption of improved crop management practices, thereby enabling farmers to capture the potential soil fertility benefits of pigeonpea. The hypotheses are tested using farm survey and case study data from Malawi and Tanzania.

The analysis shows that pigeonpea markets are now highly globalized and competitive. Pigeonpeas from Malawi and Tanzania are losing their competitiveness to pigeonpea from Myanmar and yellow pea substitutes from Canada and France. To increase the competitiveness of African pigeonpea and pull technologies through the system, crop variety improvement, choice of variety, seed distribution, production practices and more-efficient marketing arrangements need to be established targeting the needs and competitive patterns of specific identified markets.

Key words: Pigeonpea-based technology, sub sector approach, competitiveness, uptake pathways, globalization

Introduction

Legumes have long been grown in smallholder farming systems throughout Southern and Eastern Africa in intercrops and rotations with cereals. Legumes play an important role as food and cash crops; they also provide livestock feed and firewood, and improve soil fertility through biological nitrogen fixation (BNF). Despite these multiple benefits, most households only allocate between 10 and 30 percent of their total cropped area to legumes, mostly for subsistence food requirements (Rohrbach, 2001; Twomlow, 2001; Freeman, 2001; Semgal, 2001). Farmers explain that legume cultivation is limited by seed and land shortages, lack of money to buy inputs, high labor requirements, lack of cash markets, pests and diseases, and low yields. Starting in the mid-1990s, prices of inorganic fertilizer escalated because national currencies depreciated and subsidies were removed under structural adjustment programs. The escalation of inorganic fertilizer prices has forced farmers and scientists to look for cheaper substitutes. Researchers have hypothesized that because legumes provide a low-cost means of supplying N to the cropping system, increasing the area under legumes and improving legume residue management will enable smallholder farmers to reduce inorganic fertilizer use and still maintain soil fertility.

Researchers have identified pigeonpea as the "best bet" legume for semi-arid areas because the crop has a deep root system that makes it drought tolerant. It mobilizes unavailable soil phosphorus; it has high nitrogen fixation; it adds organic residues through leaf fall; it recycles nutrients lost from the rooting zone; and it is semi-perennial, which reduces yield and production risk (Nene, 1991; Singh, 1991). Research investments by national programs, ICRISAT, and other CGIAR centers have resulted in the development and release of superior varieties and better crop management options, including intercropping combinations, plant spacing, patterns and dates of planting, fertilizer management, and control of weeds, pests and diseases (Silim, Johansen, and Chauhan, 1991; Silim, 1992; Soko et al 1995; Daudi and Makina, 1995; and Mbwaga, 1995). But adoption of these technologies remains limited. Surveys have shown that for farmers to adopt improved technologies and intensify legume production, collateral investments are needed to improve input and output markets. In addition, legume intensification needs to target poor households for food for home consumption and wealthier households for cash income from the sale of surplus produce.

This paper analyzes opportunities and constraints for improving the adoption and impact of pigeonpea technologies by linking technology development and dissemination with increasing competitiveness of pigeonpea products in domestic and international markets. The study draws on pilot studies carried out by ICRISAT with national programs, NGOs, and private sector partners in Malawi and Tanzania. The studies on pigeonpea in Malawi and Tanzania also provide lessons that can be applied in other countries and on other legumes such as groundnut, cowpea, lablab, mucuna, common bean, and bambaranut.

Objectives

This paper aims to analyze the determinants of competitiveness of pigeonpea in international markets and identify strategic interventions that can improve competitive advantage (and thus technology adoption). The specific objectives are to:

- Describe the pigeonpea subsectors in Malawi and Tanzania;
- Identify opportunities and constraints for increasing competitiveness of pigeonpea in international markets, including targeting of investments;
- Assess the profitability of adopting new pigeonpea technologies; and
- Draw lessons for other legume sub-sectors and semi-arid areas in Southern Africa.

Research Approach: Theory, Hypotheses and Methods

The conceptual framework that guides this study is derived from business strategic management theory and agricultural commodity subsector analysis. Over the past two decades, these have emerged as useful tools for analyzing the performance of agricultural markets, diagnosing constraints and institutional innovations to resolve them and prioritizing potential interventions.

Conceptual Framework

The marketing of agricultural products is subject to the law of demand and supply. Falling trader barriers and globalization of agricultural markets have led to standardization of consumer preferences, and price formation forces now operate at international rather than national or regional levels. Competition has intensified, implying lower returns to investments by farmers, processors and traders.

Porter (1980; 1985; 1986; 1990) has developed a conceptual framework for identifying major determinants of competitiveness in globalized industries. Industries achieve and sustain competitive advantage through innovation, including new technologies, new product design, new production processes, new marketing approaches, and new ways of trading. To gain competitive advantage, a firm must perform activities in its value added chain better than its competitors. Because activities at any stage depend on activities in the upstream and downstream stages, value-added chains of different firms interact at the different stages of technology development-input supply-production-distribution-consumption sequence. Therefore, firms need to coordinate and harmonize their activities at different stages of the vertical chain to match supply and demand throughout the vertical stages at prices consistent with the costs of production of least cost producers. To be globally competitive, an agricultural and food industry cannot be organized in an *ad hoc* way. Vertical coordination is imperative.

To analyze vertical coordination of a whole sub sector, identify opportunities for improving economic performance, diagnose constraints and prescribe technological and institutional changes to resolve the constraints one can use the subsector approach (Shaffer, 1973; Marion et al 1986; Staatz, 1996). Sub sector analysis views effective demand as the pump that pulls goods and services, including new technologies such as cultivars, nutrients, and farm equipment innovations through the vertical system. Therefore, the approach emphasizes understanding the dynamics of how demand is changing at both the domestic and international levels (including the evolution of different niche markets) and the implications of that evolution for sub sector organization and performance.

Hypotheses

This study explores three hypotheses:

1. Tanzania and Malawi can increase the domestic and international competitiveness of their pigeonpea sub-sectors by pursuing niche markets; linking quality characteristics required by buyers in premium markets with farmers' choice of varieties, crop production management practices, harvesting, and post-harvest handling during the physical movement to markets; improving marketing efficiency, and reducing costs of production and transportation.
2. Investments to increase the competitiveness of Tanzania and Malawi's pigeonpea sub-sectors will generate high payoffs if targeted to promote the use of best varieties, extension of crop management advice, market information systems and reduction of transaction and transportation costs.

3. If households are linked to produce specifically for cash domestic and export markets then there is significant adoption of technologies, which permits farmers to capture soil fertility improving benefits.

Methods

In-depth interviews were conducted with selected participants – traders, processors, policy makers, and others – in order to obtain their subjective evaluations and perceptions of constraints and opportunities. Additional interviews were conducted with traders, processors and government officials in India, United Kingdom, Kenya, Malawi and Tanzania during the 2001/02 cropping seasons to generate data on quantity demanded, quality standards required by international buyers, and competition from alternative suppliers and alternative products (Lo Monaco, 2002). Rapid reconnaissance surveys were conducted in Tanzania and Malawi to follow the flow of pigeonpea down the marketing chain from international buyers to farmers. During the reconnaissance surveys, informal interviews were conducted with farmers, extension agents, rural traders, NGO representatives, crop assemblers, transporters, and government officials. Trader, farmer and key informant interviews were combined with an analysis of quantity and price data, relative price relationships, and gross marketing margins. Quantity and price data were collected from secondary sources, including ministries of agriculture, national statistical offices, the Food and Agriculture Organization (FAO) database, and published and unpublished reports.

Overview of the Pigeonpea Sub-sector in Malawi and Tanzania

Pigeonpea is widely grown in the semi-arid areas of Malawi and Tanzania, mostly as an intercrop with maize, sorghum and pearl millet; but also in hedges around fields and on soil conservation barriers along contours. This makes it difficult to obtain accurate estimates of planted area, yield and production. National statistics indicate that in Malawi, pigeonpea is planted on 180,000 ha, yields are about 600 kg per hectare and annual production is about 100,000 t (Ministry of Agriculture and Irrigation, 2001). In Tanzania about 815,000 ha are planted to pulses, including pigeonpea, yields average 800 kg per hectare, and production is about 635,500 t (Ministry of Agriculture and Food Security, 2002). But the FAO estimates are considerably lower (Table 1). Plantings in Malawi are concentrated in Blantyre, Machinga, and Shire Valley regions. In Tanzania, pigeonpea is mostly grown in Mtwara and Lindi in the southern coastal areas, Babati in the north, and Kondoa in the central region.

Table 1. Pigeonpea area and production in Kenya, Malawi and Tanzania, 1980 to 2001

	Area ('000 ha)		Production ('000 t)	
	1980-82 mean	1999-01 mean	1980-82 mean	1999-01 mean
Kenya	66	147a	29	45a
Malawi	127	123	85	79
Tanzania	37	65	23	47

Source: FAOSTAT, a. 1996-98 average

Management practices vary widely within and between regions. Wide differences exist in choice of variety, tillage, planting methods, intercropping, spacing, soil water and fertility management, weeding, pest and disease control, harvesting, and post-harvest management. For example within the same agroecological zone in Kondoa, better resource-endowed farmers grow as much as 5 ha of pigeonpea intercropped with maize for export markets, using improved varieties and science-based management practices. Poor households grow a few plants in homestead gardens for home consumption using local varieties and traditional practices. Because farmers cultivate small plots, they often plant crop mixtures in the same field to maximize returns to land and labor. In the main pigeonpea producing areas, 58 percent of the maize area is a maize-pigeonpea intercrop, particularly in areas where pigeonpea is a cash crop.

In the major pigeonpea growing regions, 90 percent of farmers grow the crop and 70 percent of farmers are "commercial", selling over half their production (Orr, Jere, and Koloko, 1997). There is a long marketing chain, with many intermediaries. Households sell to vendors who buy from door to door, or transport the grain to village markets for sale to intermediaries. All transactions are in cash, and by volume (bucket), not weight. The intermediaries sell to other intermediaries who then sell to traders for transport to the major towns and sale to large exporters by weight. Traders do not pursue grades and quality standards. They believe the market is not mature enough for trading in graded form, and that farmers may not produce a marketable surplus if grades and standards are introduced. Exporters clean, grade, pack, and ship it to international buyers. In Tanzania there is no milling of pigeonpea; the grain is exported 'raw'. Traders estimated that annual exports currently average 30,000 to 35,000 t, almost double the official estimates (Table 2). Some exports are shipped through Kenya. Likewise in Malawi, traders estimated that about 30,000 t are exported annually, although official estimates are lower (Table 3). Traders estimated that as much as 35 percent of Malawi's exports is grown in Mozambique, although this share has been declining begin-

Table 2. Pigeonpea production and exports (t) in Tanzania, 1993-97

	1993	1994	1995	1996	1997
Production	38,000	34,000	42,000	55,000	41,000
Exports	6934	17,633	3594	17,430	15,489

Source: TCFB for exports; FAO for production data

Table 3. Pigeonpea production and exports, Malawi

		1994	1995	1996	1997	1998	1999
Production		43,311	52,601	87,880	72,672	18,400[b]	80,000[b]
	Whole	1209	13852	1506	7877	-	-
	Processed	6394	7709	6552	9704	-	-
Total Exports	Whole equivalent[a]	10343	24865	10866	21740	18400[b]	19600[b]

[a] Whole equivalent calculated assuming a recovery yield of 70% for *dhal*

[b] Only aggregate data available

Sources: FEWS and FAO

1994-97: Bvumbwe Research Station; Patel, 1998

1998-1999: Malawi National Statistical Office

ning in 1999/2000 because of traders buying directly in that country. The bulk of Malawi's exports are milled into *tur dhal,* thus adding value, and shipped to India.

Trader interviews revealed that both domestic and international markets are very volatile because there is negligible consumption of dry pigeonpea in domestic markets; pigeonpea is mostly exported. The international market is highly globalized and dominated by India, the major producer and consumer. Tables 4 and 5). Export demand depends largely on production in India -- demand and prices for African pigeonpea are high when there is a poor crop in India and Myanmar. Trader interviews also show that there is a marketing window for exports from Tanzania and Malawi, which opens around August to September and closes in October or November. Subsequently prices drop because the crops in India and Myanmar are harvested. This is an opportunistic market. Tanzanian and Malawian traders need to discover prices, obtain confirmed orders with specified prices before they start buying from farmers, and then buy the crop, transport grain to export centers, clean, pack, and export it before prices in India start to fall. Before declaring prices to farmers, traders take into account bagging costs, transportation, handling, cleaning, port charges, freight, local levies, corporate tax, corruption and harassment charges, and financial costs. An increase in any of these cost elements is passed down to smallholder farmers because the farm level-derived supply is highly inelastic in the short run. Exporters are reluctant to hold inventory stocks because of the high price uncertainty of the Indian market. Because Indian traders have monopolistic market power and can drive prices down, forward contracting with farmers is difficult since exporters cannot assure farmers the contracted prices.

Table 4. World pigeonpea production ('000 t), 1980-98

	1980-82	1990-92	1996-98	1996-98 (% share)
India	1983	2432	2420	83.8
Myanmar	29	47	159	5.5
Africa	165	254	250	8.7
Rest of the world	56	72	58	2.0
Total	2805.4	2805	2887	100

Source: FAOSTAT, 2001

Table 5. World dry pea imports ('000 t), 1995-99

	1995	1996	1997	1998	1999
European Union	2522	3838	1530	1882	1890
India	173	155	282	257	366
Total	3603	4743	2538	2845	3016

Source: FAO, 2001

Market Participants' Assessment of Opportunities and Constraints to Increasing Competitiveness

Trader interviews, analysis of volumes traded, and international prices indicate mixed prospects for increasing the long-term competitiveness of African pigeonpea exports. Historically there has been a strong export market demand, but this market is shrinking due to increased competition from other exporters (notably Myanmar) and substitution of pigeonpea with yellow pea (exported by Canada). In the past five years, Myanmar has more than quadrupled exports to India, driving down wholesale prices (Table 6). There also has been a sharp increase of competing yellow pea exports from Canada (Table 7). Because yellow peas have been used in the past as animal feed, they are being exported to India, the Middle East, and North Africa at extremely low prices. Because of increasing price competition, the prospects for producing pigeonpea as a cash crop for the export market are diminishing (Table 8). Indeed, Tanzania and Malawi have lost market share and farm gate prices have declined compared to three years ago, when exports were increasing, production in India was poor, and Myanmar was still not competitive (Table 9). Traders reported that opportunities exist for exporting to niche markets in Europe. But the volumes are small, about 1000 to 1500 t annually, and markets get

Table 6. Myanmar pigeonpea (t) exports to India, 1999-2001

1999	73,430
2000	185,964
2001	293,934

Source: Directorate of Economics and Statistics, Ministry of Agriculture, India

Table 7. Annual exports of dry peas from Canada ('000 t), 1997-2001

	Canada to Asia
1997-98	395
1998-99	700
1999-00	638
2000-01	850

Source: Agriculture and Agri-Food Canada, FAO

Table 8. Pigeonpea import prices, US $ per tonne c.i.f. Mumbai 1995-2001

	September	October	November
1995	375	415	400
1996	315	320	295
1997	n.a.	n.a.	445
1998	450	410	395
1999	325	300	310
2000	300	n.a.	n.a.
2001	295	275	250

Source: The Pulse Importers Association

Table 9. Average pigeonpea prices (US$/t) paid by marketing agents at the first assembly stage, Malawi and Tanzania, 1998-2002

	Malawi	Tanzania
1998	483	478
1999	431	288
2000	336	248
2001	139	136
2002		154

quickly saturated. Another possibility is to supply pigeonpea as green vegetables to Europe. The companies surveyed did not have experience with these niche markets. To expand exports, there is a need to target particular niches and develop ways of reducing prices.

Trader interviews revealed that the major determinants of competitiveness in international markets are consistent quality and quantity, price, and timeliness of delivery, especially for the August-November window. Buyers look for grain color, size and milling characteristics, including ease of dehulling, shape, cleanness, and uniformity. White grains are preferred and fetch premium prices. Babati White from northern Tanzania and white pigeonpea varieties from Malawi have a unique taste that Asian and European customers like; and this explains why exporting firms are still surviving. In terms of grain size, market requirements vary. Indian millers prefer small to medium-grained varieties such as Babati White, while European millers require large-sized grains. Moreover, size requirements can change rapidly from large to small from one year to the next because of shifts in milling technology. Compared to Myanmar and India, Malawi and northern Tanzania produce better quality pigeonpea (Table 10). However, pigeonpea from central and southern Tanzania is mostly red color and poor quality because of insect damage. Infestation begins in the field, during the flowering stage. Insects are carried over into storage, and cause high losses. Quality standards are largely determined by traders who buy, grade, and sort grain for specific markets. For farmers to obtain a high-quality crop, various issues need to be addressed, including correct choice of variety, seed delivery systems for getting pure seed to farmers, crop management, pest and disease management, harvesting methods, post-harvest management and handling during the various stages from farm gate through assembly, transportation, cleaning, grading and packing for export.

Table 10. Grain quality traits relevant for the milling industry

	Africa	Myanmar	Yellow pea
Grain size	Medium to large	Small to medium	Large
Grain shape	Round	Round	Round
Ease of dehulling	Low	Fair	Very high
Cleanness	High	Low	High
Weeviled grains	Fair	High	Low
Homogeneity	High	Low	High
Average yields %	65-70	65-75	90

Traders cited several major constraints affecting the pigeonpea sub sector in Malawi and Tanzania:

- Low yield
- Poor quality
- Low farm gate prices
- High transport costs
- Lack of information
- Attitudes towards traders
- Lack of domestic markets
- Inconsistent government policies

Yield

Because yields are low, grain cannot be delivered at competitive prices. This is partly because farmers use recycled seed of traditional varieties (low-yielding, and susceptible to *Fusarium* wilt) and use poor crop management practices. Also farm gate prices are not high enough to attract investment from other competing activities -- farmers often view pigeonpea as a "wild" crop and focus their investments on other cash crops.

Quality

Pigeonpea from central and southern Tanzania is of poor quality. The varieties are not white-seeded, crop management (especially pest and disease control) is poor, harvesting and post-harvest management are poor. Weevil infestation is a major problem.

Farm gate price

Farmers receive a much lower price than the prices offered by exporters at the factory gate. This is because of the large number of intermediaries and inefficient trading mechanisms. For example, exporters believe that they offer prices as competitive as anywhere in the world. Farmers believe that the prices they receive are too low for pigeonpea to compete with alternative activities. During the 2000/01 marketing season, exporters in Malawi were offering MK 10/kg at the factory gate, while farmers received not more than MK 5/kg at the farm gate. The first middleman was making MK 1/kg and the other intermediaries were earning at least MK 2/kg. Traders interviewed for this study indicated that farmers are justified when they complain that farm gate prices are low.

Transport costs

Competitiveness is eroded by high transport costs and the short time available to buy the crop, move it to export centers, clean, pack, and ship grain to the markets before the export window closes. Because of poor infrastructure and short timing there is a need to ship large quantities of pigeonpea to export centers at the same time that other commodities such as cashew nuts and tobacco are being transported. Transport costs are high because roads are bad (high vehicle depreciation and operational costs) and because few transporters operate, and set monopolistic prices. For example, transporting pigeonpea from Babati to Dar es Salaam cost 42,000 TSh/t, the same as shipping costs from Dar es Salaam to Mumbai. Transport from Tunduru to Mtwara takes 24 hours to travel 265 km and is more expensive than sending goods from Dar es Salaam to Durban. It costs US$ 95/t to transport pigeonpea by road to South Africa from Malawi for transshipment to international markets. If Nacala port in Mozambique worked, transport costs would be only US$23/t. Traders reported that failure to deliver products in time results in renegotiation of contracts and heavy financial losses.

Lack of information

Industry, exporters and farmers often lack information on production and quantity available for sale in different areas, prices offered and quality standards demanded by different buyers, and transport options. Because of the lack of a market information system, there is high price uncertainty, which makes it difficult for exporters to procure pigeonpea and discourages farmers from investing in pigeonpea production as they do not what prices they will get. Because of lack of information, farmers, middlemen and large traders engage in strategic bargaining, further increasing transaction costs.

Attitudes towards traders

There are negative attitudes towards intermediaries and political rhetoric against traders, many of whom are ethnic minorities.

Lack of domestic markets

Few local companies manufacture pigeonpea food products for the domestic market and there is little domestic consumption of processed pigeonpea food products. If exporters are unable to sell the crop in export markets, they incur heavy losses.

Government policies

Pigeonpea production and trade are hampered by inconsistent government policies, including licensing requirements for traders, road haulage, district local government levies and cess. The regulations create opportunities for corruption and harassment and increase transaction costs. For example, the Tanzanian government declared that levies and cess should not exceed 5 percent of the farm gate price but today district rural councils charge levies of more than 25 percent. This directly results in farmers being paid less. Farm gate prices are indirectly reduced because traders are required to have several licenses. For example, a trader requires 6 to 7 licenses to deal in cashew nuts. Traders often need to visit district by district to obtain licenses because of excessive bureaucratic controls and regulations.

Despite these constraints, traders argued that there are high payoffs to investments in the pigeonpea sub-sector. For example, in Malawi, 15 years ago there were only two firms processing pigeonpea. Today over 10 firms process and export pigeonpea, and at least 15 firms export raw pigeonpea.

Farm-level Opportunities and Constraints

Farmer interviews revealed that opportunities exist for expanding the production of pigeonpea both as a food security crop and as a cash crop, targeting niche export markets. But increasing production for the market requires greater use of quality seed of the right varieties (i.e., varieties with traits in demand in specific markets), and better crop management in order to achieve grades and standards required by international buyers. ICRISAT and NARS scientists have developed improved, short- and medium-duration varieties, with white bold grain. These varieties are suitable for cultivation by small-scale farmers aiming to service the August-to-November export market to India. Both on-station and on-farm agronomic trials show that the yield gains from the improved pigeonpea varieties vary from 27 to 190 percent (Figure 1). The marginal rate of return from adoption of the varieties ranges from 500 to 1000 percent, which far exceeds the 100 percent hurdle rate of return that is required for widespread adoption by smallholders. But the perform-

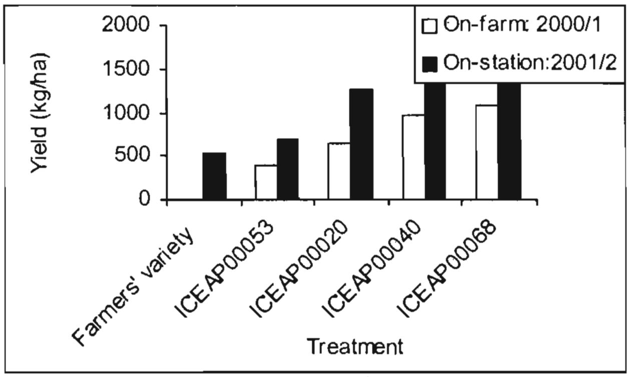

Figure 1. Performance of new pigeonpea varieties in on-station and on-farm trials, Dodoma, Tanzania, 2000/01-2001/02.

ance of sorghum-pigeonpea intercropping technology is highly variable depending on varieties, soil type, rainfall, and crop management practices including methods of land preparation, crop residues management, manure application, planting time and methods weed, pest control, harvesting and post-harvest handling. Productivity gains from short-season varieties under farmers' conditions have been limited, largely because of high insect damage as these cultivars flower during the rainy season, when pest populations are high. In addition, short-season varieties are unsuited to the traditional practice of intercropping. Medium-duration varieties have given much higher gains because they flower during the dry period when pest incidence is low and therefore escape insect damage.

In collaboration with TechnoServe, a US-based NGO, grain samples of the new varieties have been sent for test marketing in Europe and India. Several varieties have been identified that are high yielding, have characteristics demanded in international markets, and offer productivity gains even when planted late and grown without intensive weeding.

NARS scientists have also developed a range of crop management options, (intercropping, planting date, spacing and plant arrangement) designed to fit the different resource endowments, investment strategies, and risk management practices of different smallholders. Use of these management options along with the new varieties will enable farmers to produce grain that fetches a premium in international markets.

Farmers identified opportunities to expand pigeonpea cultivation in semi-arid areas, including maize-pigeon intercrops in areas with less rainfall risk, and sorghum-pigeonpea intercrops in areas of higher risk. Gross margin analysis reveals that pigeonpea-maize and pigeonpea sorghum intercrops are the most profitable among the major competing cropping activities in Tanzania and third most profitable in Malawi (Tables 11 and 12). This explains why in Kondoa district in Tanzania, pigeonpea is now the major cash crop, following an expansion of research and extension over the last five years. Farmers used to grow pigeonpea on a small scale; production expanded when they adopted the *Kombowa* variety, developed at Ilonga Research Station, and intercropping and spacing technologies developed by the Selian Agricultural Research Institute. Because of increased availability of white-seeded medium-size *Kombowa* grain, traders came in from the neighboring Babati district, where pigeonpea was already highly commercialized. Farmers found they could earn high cash income from pigeonpea, and expanded production, attracting even more traders. Farmers have become much more receptive to new technology, adopting crop management practices such as rotating the maize-pigeonpea intercrop with lablab, using mucuna as a cover crop, and adopting the Magoye ripper to incorporate crop residues into the soil to increase fertility.

Farmers interviewed for this study also believe that significant opportunities exist to increase household food security by expanding pigeonpea cultivation. Legumes are commonly eaten as relish, along with cereals. Cowpea and beans are the traditional legume crops but in most semi-arid areas, farmers cannot produce beans successfully because of drought. Pigeonpea is a better alternative, but most households do not plant pigeonpea because they are unfamiliar with the crop and do not know how to utilize it. Some varieties are bitter when dry and difficult to cook.

Farmers reported several constraints to expanded pigeonpea production, including poor farming implements which results in inadequate land preparation and late planting, poor access to seed of improved varieties, non-availability of chemicals for spraying, poor farming knowledge, lack of extension agents, pests and diseases, and lack of reliable organized markets.

Technological, Institutional and Policy Innovations with Potential to Increase Competitiveness

Traders suggested that to increase competitiveness on the international market, constraints must be resolved, and available opportunities exploited. This will require innovative approaches.

Table 11. Profitability of principal crops in Kondoa District, Tanzania, 2001/02 (Tanzania Shilling)

	Maize + Pig'npea	Finger millet	Sesame	Sun-flower	Sorg-hum	Pearl millet	Maize
Gross margin (Sh/ha)	123,731	53,672	48,626	16,519	7,289	6,948	6,379
Breakeven price (Sh/kg)	32	66	82	47	83	53	51
Breakeven yield (kg/ha)	133	541	224	960	907	873	635

Table 12. Profitability of principal crops in Chisepo Extension Planning Area, Malawi, 2000/01

	Tobacco	Ground-nut	Maize + Pig'npea	Soybean	Bambara	Maize
Gross margin (Kwacha/ha)	34,906	10,771	6,495	4,769	4,337	(626)
Breakeven price (Kwacha/kg)	21	15	5	11	18	11
Breakeven yield (kg/ha)	198	249	330	155	340	1,144

Traders suggest that the most important intervention would be to promote the use of improved, high-yielding varieties with traits demanded in target markets. This can be achieved by expanding investments in breeder, foundation and certified seed production. They also recommend targeting investments to improve productivity by providing advice on crop management, harvesting and post-harvest sorting through village-level demonstrations and farmer training. Traders argued that if farmers increase productivity and production, unit costs of grain assembly and transportation will fall.

Farmers recommended farm level training on pigeonpea production (how to improve yields and quality), sale of inputs in retail outlets within walking distance, loan of small seed packs, more government extension agents, farmer to farmer extension, and direct participation by smallholders in marketing.

Other recommendations included: improve market efficiency by establishing a market information system. This will lead to price premiums for quality, reduce transportation and transaction costs, and improve technical and operational efficiency of buying in the villages and transporting to export centers.

Because of the decline in cash-cropping opportunities (in turn due to declining export markets), respondents argued for promoting pigeonpea for food security by familiarizing and encouraging people to eat it. To increase domestic consumption they recommended training of farmers in better cooking methods using, for example, the radio to reach more households. Respondents also recommended that local industries be encouraged to expand collateral investments in new product and market development such as using pigeonpea for livestock feed.

Finally, recommendations were made for more enlightened taxing and licensing policies, removal of legislative and administrative barriers to trading, and measures to correct market imperfections.

Summary and Conclusions

The prospects for pigeonpea in international markets are mixed. Historically pigeonpea cultivation expanded because of export-led growth. Pigeonpea markets are highly globalized and dominated by India. The export window for Tanzanian and Malawian pigeonpea is shrinking because of competing exports from Myanmar, and substitution of pigeonpea with yellow peas exported by Canada and France. Farm gate prices are falling, so farmers preferentially invest in other crops (and non-farm activities) rather than pigeonpea. To increase competitiveness, the pigeonpea sub-sectors in Tanzania and Malawi need to reduce prices and look at particular niches. Traders identified several opportunities for increasing competitiveness: including promoting the use of high-yielding varieties with traits demanded in niche markets; extending crop management advice that is linked to producing grain with quality characteristics required by buyers; setting up marketing arrangements to encourage a premium for quality production, and reducing transaction and transport costs. At the farm level, opportunities lie in farmer training to improve yields and quality, sale of inputs at retail outlets within walking distance, loans for small packs of inputs, more government extension agents, farmer to farmer extension, and direct participation by smallholders in marketing. Because of the decline in opportunities for producing for export, respondents argued for promoting pigeonpea for food security by familiarizing and encouraging people to eat it. To increase domestic consumption respondents recommended training of farmers in better cooking methods using, for example, the radio to reach more households. These initiatives, together with improvements in policy, will improve adoption of pigeonpea technologies, and thus help smallholder farmers improve food security, income, and soil fertility.

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Questions and Answers

Promotion, Economics and Adoption of Annual Legumes

To Dorah Mwenye

Q: How much was your project trying to promote a presumably tested and trusted package, and how much were you asking farmers to test technologies?
A: The project tried and tested 1) rotations of cereals/legumes, 2) intercrops of grain legumes and green manures, and 3) evaluated two green manure legumes (sunnhemp + velvet bean). Farmers tested all the technologies and evaluated them, but only those technologies acceptable by them are being promoted.

Q: 1) To what extent are long-term benefits associated with different legume technologies being explained in current promotion efforts?
2) What is the minimum investment required to kick–start legumes on degraded (abandoned) fields?
A: 1) The long benefits in the promotion of soyabean rotations are in the provision of food and reduction in input costs. Green manures will complement the meager rates of fertilizers applied by farmers to their maize crop.
2) The minimum input investment required will be provided, as a result of the soil analysis to assess the initial fertility status of the field. Further research is needed in this area.

Q: There is need to look more at management of green manures, including the time of planting on green manure performance. Late planting would also reduce legume performance rather than attributing poor performance solely to the sandy nature of the soils.
A: Agreed, the general management of green manures is important. All the demonstrations were set up on limed plots.

Q: What are the causes for the non-availability of information on green manures to extension and the farming community and what measures should be put in place to improve the situation?
A: Information generated still lies in the hands of researchers. One of the limiting factors is the weak linkage between research and extension. The measures to be put in place to improve the situation are discussed at the end of the conference.

Q: When you add the element of utilization in your project it will help to increase the adoption rate of the legume crops.
A: Yes I agree. An impact assessment will best reveal the way forward. One of the issues to be considered in the next step is utilization.

To Mulugetta Mekuria and Shephard Siziba

Q: Your comments on macroeconomic policy were all criticisms of governments in southern Africa. What do you think is the effect of agricultural policies in the EU and the USA?
A: Yes agricultural development has been adversely affected by poor policies in Southern Africa. For example, declining investments in extension, agricultural research. It is also true that protection and subsidy policies of the OECD will affect our competitiveness. Hence the debate on free world trade.

Q: Discounting rate came out as having a large effect on NPV. How do you measure discounting rate, for different groups of farmers?
A: The discounting rate used for both farmers is the same. It is the going interest (borrowing) rate used by a public bank.

Q: In the medium term we can forget subsidies. The USA has launched the GOA initiative and regional trade hubs.
A: I think you are right.

Q: The presenters cited the issue of policy being wrong. It is now three or four years since the SFNet Economics and Policy Working Group (EPWG) was constituted. What is the impact of EPWG in terms of making the policy right?
A: Its not easy for researchers to influence policy change – policies are not favorable still.

Q: Looking at sensitivity analysis, what policy instruments would you advocate for concerning green manures, and are there major recommendations from this conference?
A: Profitability of green manure technology is sensitive to prices and input costs. Recommendations are that relatively high output market prices of maize favour adoption of mucuna. A low interest rate will also facilitate adoption of mucuna by farmers.

To Charles Nhemachena, et al.

Q:
1) What target yields (or limits) can be recommended for grain and green manure legumes under the current economic tools of analysis in order to give a positive feedback to research?
2) Most of the economic evaluation seems to be based on data sets that do not represent the optimal practices/experimental designs. Are we sure we are not dismissing or upgrading technologies prematurely?
A:
1) Due to great diversity of the biophysical and socio-economic environments, it is difficult to recommend specific yields for grain and green manure legumes. Depending on the available conditions in an area, yield levels should be high enough to cover the costs of production incurred and give positive net returns to farmers. Generally, from a given grain and green manure legume, yield levels should be high enough to offer positive net returns to factors of production used.
2) Economic evaluations of any undertaking or enterprise make assumptions or goes in the form of an abstraction from reality to understand relationships between certain variables, holding other conditions constant. Like any scientific experiment, it has controls. In addition, provisions are given for possible outcomes if other factors previously held constant come into play, for example in sensitivity analysis, so I don't think we are dismissing or upgrading technologies prematurely.

C: There is need for longer-term rotational trials to have a quantitative idea about longer effects of legumes on soil fertility.

To Joseph Rusike, et al.

Q: Can we learn from what happened in Myanmar where pigeonpea production has increased substantially in a few years time?
A: Agricultural sector growth is being actively promoted by the Myanmar Government.

Q: What is the potential size of the pigeonpea market in India and the world?
A: Total world pigeon pea production from 1980–82 to 1996-98 is as follows: (in 1000 t).

1980–1982	2,805.4
1990–1992	2,805
1996–1998	2,887

Q: Grain yields for pigeonpea from most presentations are around 200 kg/ha. Is the yield potential for pigeonpea any higher than this for Zimbabwe? How do our potential yields compare with yield levels achieved elsewhere in the world, in places such as India?

Q: I too am interested in the pigeonpea yields in ideal conditions. Seeds are also a constraint. There are seeds coming through donations, coming through NGO programs, etc. Maybe the Soil Fert Net can help with pigeonpea in future.
A: Here is the performance of new pigeonpea varieties in on–station trials at Hombolo and Makutupora Research Stations, Tanzania, 2001–2002.

Variety	Days to 50% flowering	100-seed weight	Yield (kg/ha)
Farmer	183	16.2	476
ICEAP00053	165	16.4	604
ICEAP00040	162	20.0	667
ICEAP00020	163	18.8	752
ICEAP00068	85	14.0	1530

Q: The market for pigeonpea in India will be saturated if the whole of SADC grows pigeonpea. We need to diversity markets to include domestic markets.
A: Yes I agree.

Q: How do we promote technologies to farmers? Are the technologies introduced to the farmers one after the other or simultaneously.

C: We can ask, should the technologies be introduced at once or should we choose which technologies to expose to farmers? One of the approaches we are using in Zimbabwe is to cluster technologies in an area. We give each farmer one or two technologies and give other different technologies to other farmers in the area to try. Involve all farmers in the area on implementation, monitoring, evaluation of all the technologies and hold field days. Allow farmers later to choose the technology they want to adopt.

Synthesis and Working Group Reports

Synthesis Reports

Reporters:

Webster Sakala, Steve Twomlow, Aggrey Agumya, Ishmael Pompi, Moses Mwale, Wezi Mhango, Paul Mapfumo, and Joseph Rusike

Introductory Key Papers

The papers in this session were very broad ranging. Important points included:

Targeting and Niches:

- Targeting is useful, through decision trees and whole farm models, into niches on farm. Niches were thought to be important because not all technologies perform best in all environments. For example, mucuna does not grow well in waterlogged conditions. Another example on proper utilization of niches is the use of long duration pigeonpea. These do well in a well-extended rainy season. The system is well adapted to southern parts of Malawi because of the extended *Chiperoni* rains after the main rains.
- From this work we have learned and need to accept that some technologies may not be useful and adaptable, e.g. alley cropping compared with soyabean in some parts of Zimbabwe.
- Process research is to be encouraged so that we can develop a clear understanding on some factors that limit technology adaptation to marginal niches.

Multiple value of green manure:

- The papers also indicated that fast and quick adoption of some green manures and grain legumes is facilitated by their multiple uses including as food, feed, cash and firewood.
- Technologies with higher multiple values are likely to be adopted. Examples were pigeonpea because of its.cash attractiveness, and soyabean (not mainly for soil fertility but) because of the cash incentive.

Socio Economic Factors:

- When new technologies are being tested in new areas there is need to further understand the existing farming household systems in the area.
- Once the systems have been fully studied, some aspects of the cropping systems can be incorporated into the technology, to better fit the technology into the existing system.
- Conduct cost-benefit analysis as a routine.

Scaling Up:

A range of questions emerged during the discussion:

- Who does it and who is best placed to do it?
- When is the best time to measure technology and method adoption?
- What influences adoption?

Synchrony:

- We need to look more at the practicality of matching nutrient release and nutrient demand from combined organics and inorganics.

Seed Issues:

- Who provides the starter seed with annual legumes?
- If seed is of no clear economic value (as with some green manures), how then do we sustain its supply?

Rhizobium, N Fixation and Microbiology

Four papers were presented:

Nitrogen fixation, grain yields and residual N-benefits of promiscuous soyabean to maize under smallholder field conditions. *Kasasa et al.*

Interaction of inoculum and liming on yield and N fixation by soyabean grown on sandy soil: A case study of Murewa District. *Nemasasi et al.*

Response of different cultivars of bean to inoculation and nitrogen fertilizer application. *Sikombe et al.*

Role of phosphorus and mycorrhizal fungi on nodulation and shoot nitrogen content in groundnut, pigeonpea and lablab bean. *Besmer et al.*

Reasons for Quantifying N Fixation:

- There is a need for an understanding of the relative contribution of N-fixing components to the N cycle within ecological conditions.
- To understand the amount of N_2 fixed by legumes for the development of an efficient agricultural production system.
- Evaluation of the symbiotic effectiveness of rhizobial inoculants and success of inoculation, or the N fixing capabilities of legume genotypes in plant breeding programs.

- Assessment of the potential benefits from the input of fixed N_2, residual effects on subsequent crops following the growth of legumes or effects on crops associated with legumes.

Need for a Reference Crop:
—The assumption is that both non-fixing (control) and fixing crops take up N from the soil in the same ratio.

—Wrong choice of a reference crop can either underestimate or overestimate the N_2 fixed.

- Reference crop combinations include wheat (bean), maize (soyabean), and non-promiscuous soyabean variety (soyabean).

Why do legumes fix nitrogen?:

- "Conventional wisdom" has it that legumes fix N for themselves.
- However data here showed that maize yields after soyabean increased even where stover was removed. This appeared due to root exudates and build-up in SOM.

Inoculum Use:
The following aspects are important:

1. Isolate
2. Selection and authentication (Testing)
3. Production for specific locations

The possibility exists that applying exotic strains of rhizobium indiscriminately can suppress indigenous strains.

Effect of N source on Bean grain yield:

- CIAT 899 and the local isolate were comparable in Mbala and Lundazi, Zambia.
- In Pembela, the native rhizobia strains at the trial site were as effective as other strains in increasing grain yields.
- Soil available P determines to a large degree the nodulation in groundnut in semi-arid parts of Zimbabwe.
- Enhancing AMF activity of native fungi promotes nodulation and increases shoot N concentration in lablab bean.
- To enhance N fixation, can we explore combinations of P and Rhizobia?

Screening of Annual Legumes for Adaptation and Use

Presentations covered indigenous herbaceous legumes, timing of legume incorporation, performance of short duration pigeon pea, risk diversification through legumes and simulating maize response to mucuna.

Three of the five papers were directly devoted to screening. The other two dealt with issues relevant to screening. Only the paper on indifallows dealt with bringing on stream a new family of legumes—the indigenous ones.

Indifallows:

- These appear to be self-regenerating and well adapted.
- Among the benefits for N_2 fixation and farmer adoption, some indifallow species demonstrated high levels of N_2 fixation, and the "Gwezu smell approach" participatory method for identifying legumes works well.
- There was some concern that these species may not withstand grazing.
- Suggestions for the indifallow work included extending the study to Matebeleland and measuring how the population of species varies with the duration of the fallow. It is likely to change markedly.

Effect of time of legume incorporation on maize yield:

- Yields from early or late incorporation were not statistically different. Late incorporation spreads labour demand. This is consistent with the earlier SoilFertNet study over three seasons.
- Soil moisture content from late incorporation is higher.
- Water use efficiency is an additional benefit to N_2-fixation. Inclusion of water use in the study objectives was commended.
- Mucuna and *C. grahamiana* are recommended as best bets for Zimbabwe communal lands. *C. grahamiana* adapts better to degraded soils due to its strong roots.
- Examine the method of incorporation—it might be a constraint for expansion of plot sizes.

Short duration pigeon pea in Matebeleland:

- The short duration types performed better in clayey than in sandier soils.
- Concern was raised about the low yields and competition by weeds.
- Also there was concern about the need for spraying against pests. Explore the effect of not spraying on performance.
- The recommended time of incorporation is after harvesting the grain.
- We also need to see how to improve access to literature about past work on legumes in the region.

Screening:

- New options identified were "indifallows" and a broadening of the suitability range for pigeon pea in southern Africa.
- All three screening studies reported were started recently in the 2000/01 and 2001/02 seasons, yet benefits usually accrue after 3-5 years. Computer simulation of benefits could augment the experiments.
- There was a general view that we should continue screening but that first we should establish what has already been done by a thorough literature review and employing tools such as the Legume Expert System.
- Biotechnology offers prospects of improving our ability to screen thousands of species.

Risk diversification and computer simulation:

- Adoption of legumes depends on return on investment and risk characteristics.
- Computer simulation is undertaken to explore long-term trends.
- The results (recommendations) from the APSIM simulations are consistent with current farmer practices except for the use of kraal manure in drier areas.
- The extremely low rates of fertilizer application in semi-arid areas (18 kg/ha) reflect farmer aversion to risk in these areas.
- Non-market benefits (remaining in the soil) are captured in the yield through APSIM. Values not captured are considered not relevant to farmers.

Simulating maize yield response:

- Computer simulation is undertaken to overcome the short-term perspective of most experimental trials. The simulations reported covered a 46-year period.
- APSIM, unlike many modeling tools, considers carry-over effects of variables including soil N.
- Long-term simulation of *Mucuna* indicates large potential benefits over the long term. Increases of 100-200% in maize yield were reported. These benefits are not captured in short-term experiments.
- So far, the simulated maize yields are showing satisfactory agreement with field trials, but more needs to be done about legumes. Consultations are underway to validate legume grain yields.

General comments:

We should look at soil fertility more broadly and give greater attention to other benefits from legumes besides N-fixation, e.g. soil physical properties, water use efficiency, weed suppression and tillage effects. For example, pigeon pea's noted contribution to SOM is probably traceable to deep rooting, while chickpea increases the availability of P.

With respect to soil nutrients, whereas P and N are adequately discussed; more consideration should be given to other nutrients such as zinc.

A general question was, where should we start the screening; from the plant side or the *rhizobium* side?

It is important that improved legume varieties be developed. This means that we need to involve/collaborate with breeders in the screening. We also need to be involved in their work so that the soil fertility improvement, water use, weed suppression and other traits that we would like to see enhanced in legumes are given some attention by breeders.

Identification of Best Bet Legumes for On-Farm Performance as Grain Legumes, Intercrops, Rotations, and Green Manures

Eight papers and one poster were presented.

Key findings from the presentations and discussion:

- From the evidence presented in the different papers, it is clear that yield responses were greater when crop residues and manures were ploughed in, i.e. incorporated, compared to when they were left on the surface as a mulch. Consequently, we may begin to see some conflicts between soil fertility and conservation farming which advocates that crop residues be left on the soil surface as a mulch.

- Intercropping vs. rotation issues. Data presented by the authors suggest that in the short term (two or three seasons) a cereal-green manure rotation is less productive than a cereal/grain legume intercrop. This is supported by the fact that many farmers that have participated in trials are more willing to adopt an intercrop approach to soil fertility amendment than a green manure-cereal rotation, particularly when land is scarce.

- We had little information presented on the intercropping characteristics of the different legume and cereal varieties currently available. More work needs to be done on that.

- Although many of the studies reported in this session were conducted on farmers fields, very few studies characterized the household assets of the host farmers. Consequently it is difficult to assess the reasons why some farmers may favour one technology and others another.

- Few papers presented actually showed clear hypotheses for the experiments.
- It is evident from the papers presented that host farmers are beginning to develop their own local taxonomies. These need to be catalogued to enable wider dissemination.

Suggestions arising:

- There is a need to collate information from different trials in the region into GIS databases to look at soil, climate and social interactions.
- *Ex ante* market studies on legumes are required. This will meet a growing need to assess market demands for legumes before they are promoted in an area.
- Need a synthesis study on results we have to date concerning the relative merits and benefits of intercropping and rotations.
- Combinations of inorganics and organics need further attention. More and detailed studies are required on the synergistic effects of organic and inorganic fertility amendments. At the same time, work is required to develop simple and transferable messages.
- Detailed economic analyses of many of the interventions bring into question their appropriateness for smallholder farming systems. If research intends that the smallholder farmer is to benefit from their work, it is essential that research take on a greater participatory emphasis in problem identification, development and evaluation of interventions.

Legume Benefits on Maize Productivity and Soil Properties

Main issues from the three presentations in this session were:

1. Maize response to legumes in rotations and intercrops.
2. N availability/dynamics in soil as affected by green manures and grain legumes in rotations and intercrops.
3. N recovery from legumes (and fertilizer) by subsequent maize crops.

1. Maize response to legumes in rotations and intercrops:

- In two studies, legumes gave very large maize yield increases; by 2-3x the yields without fertilizer.
- BUT one study found only weak responses to legume residues and concluded that fertilizer N applications were necessary for sustained production (based on one abnormal year).

2. N availability/dynamics in soil:

- Mineral-N in soil does not correlate well with N recovery by maize from preceding legumes nor with maize yield response.
- Mineral-N dynamics suggest that mineralized N is flushed through the soil profile before maize roots are present to extract it, leading to poor synchrony of N availability and N uptake by maize.

3. N recovery from legumes (and fertilizer) by subsequent maize crops:

- Measured using 15N techniques by Chikowo *et al.*
- Net N inputs from legumes were < 10 kg/ha for soybean, pigeonpea and *Crotolaria* but > 80 kg/ha for mucuna.
- N recovery was always < 36%; being least for mucuna (12%) and greater for legumes with small N inputs. Their high percent recovery possibly being due to their low total N input.
- N recovery from fertilizer was 2x N recovery from mucuna, which had similar inputs (95 and 84 kg-N/ha, respectively).

Issues from the questions and discussion:

- Economics of green manures: What marginal increment/ yield gain is necessary for farmers to take up the technology?
- The multiple uses of green manures need to be considered in maize/green manure-grain legume systems; e.g., animals that graze residues.

Improving the Productivity of Grain Legumes and Green Manures

Highlight points from the papers:

1. Agronomic effectiveness of phosphate rock products, mono-ammonium phosphate and lime on grain legume productivity in some Zambian soils (Obed I. Lungu and Kalaluka Munyinda)

- Partially acidulated phosphate rock (PAPR) maintained a high level of soil P than mono ammonium phosphate (MAP)
- Lime increased P effectiveness and legume biomass productivity
- Optimal P application rate for legumes was 80 kg P_2O_5 per ha
- Simply processed PAPR (acidulated with sulphuric acid) was agronomically as effective as

MAP and even more effective than MAP on acid soils
- Was greater soil residual P with PAPR than with MAP.

2. The effect of P and S on biomass productivity of grain legume crops and subsequent maize grain yields in Malawi (AB Mwalwanda, Spider Mughogho and Webster Sakala)
- Dry matter yields ranged from 2 t per ha with no P and S to >6 t per ha with 20-40 kg P per ha and 4-8 kg per ha S
- Yields were Pigeonpea<Tephrosia<Mucuna
- Biomass production increased with increasing P and S rates
- Highest maize grain yield was after mucuna.

3. Contribution of pigeonpea intercropping, inorganic fertilizer management and drought and low nitrogen tolerant varieties in enhancing maize yields in Malawi (R Mkandawire and Vernon Kabambe)
- No yield improvement without mineral fertilizer even following legumes (N use efficiency issue)
- Pigeonpea rotation alone was the same as maize-maize if no fertilizer applied
- There were no variety effects.

4. Management of an acid soil using mine tailings as lime for soybean production (Lackson K Phiri, M Mwale and MI Damaseke)
- Soil pH and Ca increased
- Tailings increased exchangable Mg
- Both lime and tailings did not increase soya yields in the 1st and 2nd seasons
- Results are currently inconclusive with respect to the residual effects.

The key issues discussed included:
- A need to focus more on economic analysis, and for agricultural economists to be more proactive
- Too much emphasis on soil-plant relationships with too little on livestock x crop interactions
- Many people continue working on rock phosphate but its availability for use is questionable (e.g. in Togo and Tanzania).

Overall observations and synthesis:
- Legume yields can be trebled if low to moderate rates of P and S are applied, but should we fertilize the green manures? Is this acceptable to farmers and economic for them?
- Rock phosphate exhibited better residual effects than quick acting sources of P
- Rock phosphate could be used but there are still mixed reactions regarding the economics of its use and its availability to the farmers
- There was often a lack of maize yield improvement after legumes (notably pigeonpea) if no mineral fertilizer was applied. Are we managing the legumes well (since there are widespread reports of responses from elsewhere in Africa). Might the degree of response be a function of the maize varieties tested?
- Mg-rich mine tailings appear to be a viable liming alternative, but do we have mechanisms for their widespread distribution and use (e.g. the experiment itself could not continue after the mine changed hands)?
- There was a consensus that there has been too much emphasis on soil-plant relationships and there now needs to be more on livestock.

Targeting, Promotion, Economics and Adoption of Legumes

- Scaling up technologies identified offer benefits
- Target niches to improve resource use efficiency
- Increase benefits to early adopters.

Methods:
- GIS
- Biophysical
- Data problems
- Weights used as proxies?
- Decision tree/guide
- Biophysical
- Correlations/Ranking Participatory?
- Communication strategies
- FPR, Group, Demonstrations, Field days
- How to assess adoption?

Research Gaps:
- Agro ecological factors, population densities, markets
- Investment trade-offs: prices, returns, risks
- Markets change rapidly
- Rules: Inconsistent policies
- Human factor: politics; extension
- Communication channels and messages
- Self-reinforcement mechanisms because of increasing returns.

1. Financial analysis of green manure:
It is emerging that green manures may be only marginally profitable (and in some cases uneconomic) in Zimbabwe and Malawi. To raise the chances of being economic, we need to:
- Improve the biomass production of green manures, including mucuna
- Identify the best soils on which the green manures will grow

- Conduct more research to measure and value other benefits
- Develop policy instruments (price increases and decrease in interest rates) to support green manures.

2. **To raise the economic potential of Green Manure, we need to address:**

a) Market constraints

- Low yields
- Poor quality
- Gap, factory vs. farm gate
- Lack of information
- Government policies
- Local industrial use.

b) Farm constraints

- Poor fit into cropping system
- Poor input market
- Communication problems (poor marketing).

3. **Learn from socio economic analysis**

- Policy and development planning is vital
- Assess the conditions under which cereal legume rotations and intercropping are most feasible in the smallholder sector

Appreciate that cowpea appears the most attractive of all legumes to Zimbabwe farmers.

Working Group Reports

Biophysical Work

1. Benefits of the Technologies and the Work Completed

- Legumes (grain legumes as well as green manures) increase soil fertility and productivity and therefore the grain yields of subsequent maize crops.
- Green manures tended to give more consistent and substantive effects on subsequent maize yields than did grain legumes. Green manures can increase maize grain yields by as much as 385%, or 2.5 – 3.0 t/ha on farmer's fields in Malawi.
- The yield benefit of N from a legume can be due to an increase in below ground biomass, as appears to be the case with soyabean.
- Improvements in maize productivity have important consequences for diversification and food security.
- Various types of economic benefits accrue, including the reduction in amounts and costs of inorganic fertilizer inputs and extra grain and cash.
- Weed suppression may result (and can be especially beneficial with Striga). There may be important labour savings for weeding, especially in high rainfall areas.
- There is a potential benefit with improved soil physical properties (aggregates, infiltration, porosity, soil loss/surface runoff, water use efficiency).
- Fodder resources may increase also.

2. Gaps and Limits with Existing Work and Knowledge

Reviews and Synthesis:

- The current reviews presented for Malawi and Zimbabwe cover green manures but not the grain legumes.
- A review of Zambian work highlights the need for widespread dissemination of green manures.
- Not all the lessons from the comprehensive work presented from other regions of Africa, particularly West Africa, are directly transferable to Southern Africa. The environments (and socio-economics) are different.

Soil Science:

- There is inadequate measurement of soil physical properties and related issues like reduced tillage.
- Non-nitrogen benefits of legumes on below ground biomass, texture, Ca/Mg balance and P, cations, need more attention, as does SOM and C sequestration.
- We need to pin down the fate of N in the system. What goes into the plant and what elsewhere? This also involves nutrient balances and partitioning of N in pools.
- Far more information is needed on mycorhiza/P interactions for us to provide appropriate recommendations.
- The evaluation of long-term benefits and sustainability aspects need attention.

Legume Germplasm:

- The genetic base of species/provenances we have worked with has been too narrow. We need to screen more of these. What approaches should be used and where should screening be done?
- Link up with breeders more often. They need to work on issues that we are already working on and we need to help focus their work onto new useful traits.
- Need to inoculate with rhizobium/mycorhizae (where, which legumes, and with what?).
- Alternative uses of green manures, as seeds and firewood, need to be determined.

Systems and Networks:

There are gaps on:

- ⇒ Sharing of information within the Soil Fert Net and other networks.
- ⇒ Soil-Crops-Livestock integration.
- ⇒ Management of legumes, including time of residue incorporation, method, time of planting in intercrops, and seed maintenance.
- ⇒ Establishing the agro-ecological niches for the species and varieties.

Research Methods and Interpretations:

- People should synthesize their data fully.
- We must avoid generalization with no data or evidence. Do we know where we haven't done enough research?
- There are big gaps on information flows between research-extension-farmers.

3. Strategies and Work for the Future

Research Synthesis:

- Review the literature on existing uses of grain legumes and green manures in different countries, including indigenous and private sector knowledge. Link with other disciplines, e.g. food technology and animal nutritionists.
- Review and synthesize information on the management of legumes. Identify gaps that can then be researched. Develop a database.

Research:

- We need further work to identify the biophysical, socio-economic, and cultural conditions where the legumes perform best.
- There is need to explore ways that may maximize the benefit from green manures as intercrops or in rotations.
- Establish long-term trials to monitor soil physical properties, and evaluate other long-term benefits of green manures and grain legumes.
- Plant breeders need to breed for the farmers using their conditions, e.g. breed in soils with low soil fertility. We need to collect legume materials from the breeders and screen them in different conditions.
- Screening should be done for new species and not endlessly repeated for the same ones already done. More screening of indigenous legumes is needed, as they seem to have a positive role to play in soil fertility improvement.
- Further research is required on nutrients other than N and P, and on C sequestration.
- When screening for BNF, we have to be more systematic and take plant samples from different geographic areas and see if legumes are nodulating in different soils.
- There is a great need for more interdisciplinary Soils-Crops-Livestock interaction research, e.g. on feed quality and manure quality. How serious are the sustainability issues where the cycle is not balanced?
- There is a clear need to re-visit the ideas (widely used during the first few years of Soil Fert Net) of developing common experimental protocols and establish multi-locational trials.
- Management issues should be considered to improve the chances for green manures, e.g. avoid very late planting.
- Negative results should also be reported so that similar experiments are not repeated in future, e.g. it is all right to say "Legumes did not suppress *Striga*".

Technology Promotion:

- Rules of thumb will be useful on the economic yield increase of maize and other cereals following various classes of legumes. Should it be a two fold, three fold or five fold yield increase that we need for it to be economic?
- GIS and modelling should be used more often for scaling up purposes.
- We need to do more on the processing and utilization of legumes, including linkages with food technologists to encourage local utilization.

Networking and Capacity Building:

- Improve network linkages. We need to keep trying to develop an effective network databank for members to know what is happening, what has been done, etc.
- Soil Fert Net and others should look at conducting more training courses on new techniques.
- Networks can help with the setting up of screening experiments.
- Build capacity to undertake our research more effectively, including how to measure and assess the longer-term benefits of legumes.
- Attach graduate students to work on different issues with Government research, not necessarily using network funds.
- Members should link more effectively with other existing networks e.g. ANAFE.

Socio-Economics, Policy and Technology Promotion

Results	Benefits	Research gaps	Research strategies
Application of GIS for targeting and scaling up	Efficiency and speed. It saves resources. Multiple biophysical and economic data can be collected.	Capacity lacking — both human and capital.	Training of research and extension staff on the use or interpretation of GIS data.
Decision guides (Decision support systems, DSS)	Gives flexible options for choice of technologies and their management.	Available guides are incomplete and consider mainly biophysical traits. Inadequate farmer characterization. There is ample data in the region, waiting for synthesis. Priority should be given to gap filling and synthesis of regional knowledge.	The synthesis and development of guides should consider and incorporate socio-economic factors, policy issues and current production trends. DSS and qualitative indicators should be tested, validated, refined and identified to target socio-economic and biophysical niches and over larger areas for the integration of legumes. DSS should be geared not only towards increasing productivity, but also suggest ways that could minimize or distribute risk, decrease opportunity costs, identify niches and respect social values.
Technology promotion approaches	Farmer empowerment. Enhanced linkages between research, extension, farmers and other role players in technology promotion.	There is limited multi-disciplinary integration and initiative for true linkages among the various actors and stakeholders. Limited capacity of extension/ research to extend "best bet" options. Lack of solutions to emergency problem of land degradation.	Identify appropriate technologies that could be scaled up immediately to be effective in the short and long term. Improve researcher-extension-farmer linkages. Increase the capacity of farmers to organize themselves to have bargaining power in markets.
Several promising grain legumes and green manures have been developed and identified,. but adoption is low	Improve soil fertility and increase food production and income.	Seed unavailability is a major constraint. Limited knowledge among extension staff. Poor/limited farmer participation in research and scaling up process. Lack of communication media with farmers (bulletins, pamphlets, that are developed in local languages, and in forms that are easy to understand).	Seed bulking. Enhance extension efforts. Conduct comprehensive adoption and impact studies. Focus on adoption barriers, and give feedback to researchers to modify and improve the technology. Technology adoption could be enhanced if farmers participate in the research and scaling-up processes. To minimize poor adoption, encourage linkage between farmers, scientists, extension. Develop ownership and follow up the problem.
Unfavorable policy environment	None	Concrete and convincing data seems to be absent. Policy makers are unaware or do not believe or understand what is coming out of the research centres. Lack of advocacy, and poor linkages between policy makers and researchers.	Produce and present convincing information to influence the decision making of policy makers. Demonstrate benefits of technology to policy makers under different scenarios. Simplify our findings, create a forum and facilitate opportunities so as to create awareness among policy makers. Invite them to targeted meetings. Create a forum where farmers will have access to policy makers (e.g. invite farmers to meetings and encourage discussion with policy makers).
Need for more economic analysis of grain legumes and green manure technologies	Incentive to produce.	Limited market information. Limited productivity and quality. No organized markets. Financial returns not attractive to farmers.	Proper financial analysis. Undertake empirical studies to demonstrate the profitability and sustainability of technologies across regions, locations and times. Promotion of local utilization. Develop market studies and provide market information on both inputs and outputs. Create farmer groups for marketing purposes.