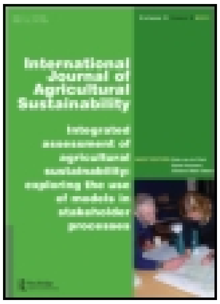

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Agricultural success from Africa: the case of fertilizer tree systems in southern Africa (Malawi, Tanzania, Mozambique, Zambia and Zimbabwe)

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Agricultural success from Africa: the case of fertilizer tree systems in southern Africa (Malawi, Tanzania, Mozambique, Zambia and Zimbabwe)

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In response to the declining soil fertility in southern Africa and the negative effects that this leads to, such as food insecurity besides other developmental challenges, fertilizer tree systems (FTS) were developed as technological innovation to help smallholder farmers to build soil organic matter and fertility in a sustainable manner. In this paper, we trace the historical background and highlight the developmental phases and outcomes of the technology. The synthesis shows that FTS are inexpensive technologies that significantly raise crop yields, reduce food insecurity and enhance environmental services and resilience of agro-ecologies. Many of the achievements recorded with FTS can be traced to some key factors: the availability of a suite of technological options that are appropriate in a range of different household and ecological circumstances, partnership between multiple institutions and disciplines in the development of the technology, active encouragement of farmer innovations in the adaptation process and proactive engagement of several consortia of partner institutions to scale up the technology in farming communities. It is recommended that smallholder farmers would benefit if rural development planners emphasize the merits of different fertility replenishment approaches and taking advantage of the synergy between FTS and mineral fertilizers rather than focusing on ‘organic vs. inorganic’ debates.

Keywords: agricultural innovation; agroforestry; development partnership; research for development; soil fertility; southern Africa

Introduction

Background of the problem addressed by technological innovation

Low soil fertility is widely recognized as a major obstacle to improving agricultural productivity in sub-Saharan Africa (Sanchez, 2002). In most regions of Africa, soil fertility degradation is caused by three interlinked factors: (i) the breakdown of the traditional fallow system as a result of an increase in human population and decreasing per-capita land availability, which forced farmers to crop continuously and encroach on marginal lands in search of more fertile lands; (ii) inadequate adoption of soil management investments such as conservation or crop residue incorporation; and (iii) sub-optimal use of fertilizers by a majority of smallholder farmers due to high cost and constraints to access them. The situation became more challenging after the removal of farm input subsidies and the collapse of para-state agricultural input marketing agencies beginning in the 1980s. For example, after the removal of fertilizer subsidies in Zambia, the price ratio of nitrogen and maize went up by 400 per cent, resulting in a 70 per cent decline in fertilizer use by smallholder farmers (Howard and Mungoma, 1996).

Given the strong linkage between soil fertility and food insecurity, addressing the decline in soil fertility remains an important challenge for those faced with formulating Africa’s development policy agenda

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(NEPAD, 2003). There is a need for technological options that replenish soil fertility as quickly as possible for a range of ecologies and agricultural systems and that are suitable for different types of farm households. Fertilizer tree systems (FTS) are one option that has been developed to meet such challenges.

Description of the technological innovation

FTS [The term 'fertilizer tree system' does not imply that the trees provide all the major nutrients: they are capable of fixing only N, which is the most limiting major soil nutrient. The trees can recycle the soil's phosphorus (P), calcium (Ca), magnesium (Mg) and potassium (K), but these macronutrients must be sourced externally when they are highly depleted from the soil.] involve the planting or regeneration of fast-growing nitrogen-fixing trees or woody shrubs that produce high-quality leaf biomass, and are adapted to the local climatic and soil conditions (Kwesiga and Coe, 1994; Akinnifesi *et al*., 2008). The principle underlining the concept of FTS comes from the fact that although nitrogen is the most limiting macronutrient in the soil, it is highly abundant in the atmosphere. Through biological nitrogen fixation, trees replenish the soil fertility by transforming atmospheric nitrogen and making it available in the soil. Depending on the species, trees grow for one or more years, after which they are cut down and the biomass gets incorporated into the soil. When the tree biomass decomposes, it releases nitrogen for crops' use, thus replenishing the soil fertility and improving crop productivity. FTS help farmers to produce the needed plant nutrients by using land and labour instead of cash, which most farmers lack.

Over the years, different types of FTS have been developed including sequential fallows, semi-permanent tree/crop intercropping, annual relay cropping and biomass transfer. To ensure substantial contribution in terms of amount of nitrogen fixed and biomass production, the choice of FTS promoted in a given area takes cognisance of agro-ecology and soil conditions. Technical details of FTS have been documented elsewhere (Mafongoya *et al*., 2006; Akinnifesi *et al*., 2010).

Processes

Who developed the technological or institutional innovation?

Diagnostic research identified the key obstacles to agricultural production and farming systems in the region. In particular, nitrogen was identified as the most important missing nutrient and this lack of nitrogen is responsible for low yields of maize, the staple and politically strategic food crop in the region. Given that farmers in the region do not traditionally plant trees to improve soil fertility, an ethno-botanical survey was carried out to establish an inventory of indigenous tree species that grow quickly to amass sufficient biomass, tolerate periodic droughts or waterlogging and survive under nitrogen-limiting conditions. The initial attempts to fertilize soils using trees through the alley cropping technique were discontinued because the technology did not technically fit in parts of the region (Ong, 1994). Efforts were then directed to research on improved tree fallows and modification of the alley cropping concept to improve the performance of nitrogen-fixing trees in a semi-permanent intercropping system. Research on FTS was initiated in the late 1980s through the collaboration of researchers from the World Agroforestry Centre (ICRAF) and national agricultural and forestry institutions in four southern African countries: Malawi, Tanzania, Zambia and Zimbabwe. Improved (sequential) fallows were developed and first tested in Zambia (Kwesiga and Coe, 1994). Annual relay fallows and *Gliricidia*–maize intercropping were both developed and were first tested on-station and on-farm in southern Malawi (Akinnifesi *et al*., 2008).

FTS on-station experiments conducted in the early 1990s showed promising results of increasing crop yield through *Sesbania sesban* with or without the application of mineral fertilizers (Kwesiga and Coe, 1994). To avoid the potential genetic risk associated with using only one plant species and to diversify options to meet the preference of different typologies of households, other plant species and provenances were evaluated alongside *Sesbania*. These include *Cajanus cajan*, *Tephrosia vogelii* and *Tephrosia candida*, which are directly sown and hence save labour inputs on nursery establishment and transplanting. The others are *Gliricidia sepium*, *Leucaena* spp., *Calliandra calothyrsus* and *Acacia* spp. The work on a tree–crop intercrop system using *G. sepium* was developed by ICRAF in southern Malawi to address small landholding size (Akinnifesi *et al*., 2010). It is a modification to address key shortcomings that affected crop performance, including eliminating the 'hedge competition effect'. It allows concurrent cultivation of trees with crops during farm seasons and fallow during off-season up to 20 years without replanting (Akinnifesi *et al*., 2008). It is currently the fertilizer tree species most preferred by smallholder farmers in Malawi.

What partnerships helped?

The development of FTS was based on multi-institutional and cross-disciplinary partnership and collaboration between researchers and farmers. Over time, researchers placed increasing emphasis on testing FTS under the realities of farmers' fields and increasing the involvement of farmers as key partners to refine and develop the technology further. Researchers began to test the technologies on-farm and involve farmers as partners in the process in southern Africa in the late 1980s. The first set of on-farm testing was designed and wholly managed by researchers (Type 1 trials). The second stage of on-farm testing of FTS was designed by researchers but managed by farmers (Type 2 trials). In the third stage, on-farm testing was wholly designed and fully managed by farmers (Type 3 trials).

At national and sub-national levels, two major partnerships were formed in the course of development of the technology. One was the 'adaptive participatory trial', which focused primarily on ensuring collaboration with farmers in on-farm trials of FTS. The other partnership was a network of key stakeholders involved in FTS drawn from government and non-government institutions. These were christened as 'Consultative Forum on Agroforestry' in Zambia, 'National Agroforestry Research and Development Forum' in Malawi and 'National Agroforestry Steering Committee' in Tanzania and Zimbabwe. Members of the network met once a year to review activities from the preceding year, share research results and experiences regarding field performances of FTS, and plan for the coming year.

More recently, through the Agroforestry Food Security Programme (AFSP) currently being implemented in Malawi, ICRAF has been scaling up the testing and dissemination of fertilizer trees with more than 20 Research for Development stakeholders in Malawi since 2007. In this scaling-up approach, stakeholders undertake annual joint planning and budgeting and implementation in 13 agricultural districts. ICRAF provides research and science backstopping, training and information, and ensures quality germplasm provision.

To what extent was social capital development a part of the project?

Following one cycle of researcher-managed experimentation, a constructivist approach was adopted, that is, farmers were encouraged to experiment and share their experiences with the technology. Much of the training and planning took place through farmer groups, which were important for collaborative nursery management. From research and farmer findings, it became apparent that efforts must be focused on shortening fallow period, identifying cheaper methods of plant establishment and encouraging wider farmer participation in technology development and adaptation. As a result, farmers made several modifications and adaptations based on their experiences (Kwesiga *et al*., 2003; Akinnifesi *et al*., 2008), including

- intercropping maize with trees during the first year of tree establishment to reduce the waiting period before trees start to impact on soil fertility;
- using bare-rooted seedlings instead of the recommended potted seedlings, to reduce labour inputs; and
- pruning *Gliricidia* simultaneously with weeding rather than performing these two operations separately.

The details of these innovations have been documented elsewhere (Katanga *et al*., 2007). In addition, in recent years, studies have been carried out to obtain systematic feedback about FTS through a better understanding of farmers' knowledge, attitude and practices on soil fertility FTS (Ajayi, 2007).

Outcomes

The number of farmers adopting

The early years of the development of FTS were devoted to technology generation, while adoption and scaling up of the technology among farmers were increasingly emphasized in recent years. In a continent-wide survey carried out among a panel of science and development experts in Africa, FTS were cited as an example of 'successes in African agriculture' (Gabre-Madhin and Haggblade, 2004).

The end of the project report of Zambezi Basin Agroforestry Project revealed that about two-thirds of the roughly 400,000 smallholder farmers had adopted FTS in the five countries Malawi, Tanzania, Mozambique, Zambia and Zimbabwe. The Zambia data are presented below as a case study as it disaggregated agroforestry adoption by gender and the extension approach used (Table 1). From only 12 farmers who participated in the initial on-farm testing in the early 1990s, the number of planters of FTS increased steadily, especially from 2000 onwards, to about 66,000 farmers in Zambia as at 2006. (The initial research and development of FTS

Table 1 | **Approach for reaching farmers with agroforestry technologies in Zambia**

Training methods used to disseminate agroforestry	Male	Female	Total
Prong 1: Direct training of farmer trainers and local change teams	7,373	8,773	16,146
Prong 2: Training of collaborating partner institutions' staff, that is, training of trainers	23,532	16,190	39,722
Prong 4: Support to the national extension system to promote agroforestry	7,446	3,165	10,611
Total	38,351	28,128	66,479

Note: The figure for farmers reached through Prong 3 (which involved farmer-to-farmer exchange) was not assessed.
Source: Zambia ICRAF Agroforestry Project report for 2005, Chipata, Zambia.

were supported mainly by funding from the Canadian International Development Agency, Rockefeller Foundation and Swedish International Development Agency.)

Being an incipient technology, efforts to enhance the uptake of FTS have focused on some key areas: creating awareness about the technology, the training of farmers about integration and management of trees on farm and the development of sustainable germplasm supply systems. Several scaling-up approaches were tested and a four-pronged scaling-up concept was developed. These dissemination prongs are (i) the direct training of farmer trainers by project staff; (ii) the training of partner staff as farmer trainers; (iii) facilitating direct farmer-to-farmer training and (iv) providing support to national extension programmes. Experiences in Zambia indicate that the most cost-effective way to reach farmers was through the training of staff of development organizations, that is, prong 2. Based on the training of trainers principle, the prong facilitates the provision of appropriate information about the technologies to field staff of development organizations, who in turn proceed to train farmers in their respective project locations. This approach builds on the comparative advantage of the various organizations and enhances synergy among them. Almost two-thirds of the farmers who planted agroforestry trees were reached through this approach (Table 1). With the onset of time, support to national extension systems and sensitizing the policy makers are becoming increasingly important in the dissemination of FTS, as scaling-up efforts move from the local to the national level.

Not all the farmers who tested FTS eventually adopted it. The responses are mixed depending on region. Empirical research in Zambia found that 75 per cent of farmers who initially tested the technology eventually adopted it (Keil *et al*., 2005). But in Western Kenya, where improved fallows were less suited to the small farms, studies showed that many farmers dropped out after withdrawal of a major project (Kiptot *et al*., 2007).

In Malawi, rather than improved fallows, emphasis has been on relay and intercrop FTS due to small farm sizes. The number of farmers who have established FTS plots has increased because of a number of initiatives carried out to promote the technology. It is estimated that currently over 145,000 farmers have established FTS plots in Malawi through the ongoing AFSP (Table 2). With explicit but modest efforts, scaling-up approaches have been used to reach female farmers and assist them to benefit from fertilizer trees in the country.

The number of hectares covered by new technologies or practices

In addition to increases in the number of farmers practising fertilizer trees, the field measurement carried out in 2003 in eastern Zambia showed that the average size of plots has also increased from an average 0.07ha recorded in the mid-1990s to 0.20ha per farmer in 2003 (the field size ranges widely from 0.01 to 0.78ha in 2003). This translates to about 13,300ha in Zambia alone.

Table 2 | **The number of farmers who established ongoing FTS plots through AFSP in Malawi**

Region of Malawi	Male	Female	Total
Northern region	15,206	17,409	32,615
Central region	26,945	27,712	54,657
Southern region	28,628	30,917	59,545
Total	70,779	76,038	146,817

Note: The figures reported in this table are exclusively farmers that were reached under the auspices of the AFSP funded by Irish Aid. Beyond this figure, many more farmers have been reached through other initiatives such as the Malawi Agroforestry Extension Programme, Total Land Care Programme and other organizations.
Source: AFSP annual report, 2010.

Predicted trends for both farmers and hectares into the future

Several factors affect the level of uptake of fertilizer trees. A recent review showed that the adoption of fertilizer trees in southern Africa is affected by a matrix of factors (Ajayi *et al*., 2007a). These factors, which will determine the future trend of hectares under agroforestry, may be classified into four broad categories: (i) the prevailing policy such as the price of nutrients and other farm inputs and outputs; (ii) technology-specific factors such as management regime required to integrate trees and crops in the same field, the period of time trees take to produce a noticeable effect on biomass and crop yield; (iii) household-specific factors such as the effective number of people available for farm work in the household, the trend of landholding size per capita; and (iv) geo-spatial factors such as future trend of climate and soil conditions that support tree establishment.

Effects on food production or productivity (either yields or total production)?

Fertilizer trees have been widely documented and known to substantially increase the yield of maize compared with continuous maize production without fertilizer, which is *de facto* farmers' practice. A recent meta-analysis conducted across several regions in Africa found that FTS doubled yields of maize relative to the control (maize without fertilizer) in most cases, especially in sites with low-to-medium potential and under good management (Sileshi *et al*., 2008). The analysis also suggests that organic inputs from legumes have synergetic effects with mineral fertilizer and that legume rotations can play an important role in raising crop productivity without relying fully on expensive mineral fertilizers. One way to assess the impact of the higher yield in terms of food security is by determining the number of additional days of food provided. Using Zambia as an example, with an average tree plot area of 0.20ha, FTS generate between 57 and 114 extra person days of maize consumption per year (Ajayi *et al*., 2007b). A multi-country study conducted among households in Malawi, Mozambique, Tanzania, Zambia and Zimbabwe shows that FTS have positive impacts on household food security among other impacts (Schüller *et al*., 2005). Details are presented in Table 3.

In terms of economic performance, field studies performed in Zambia show that FTS perform much better than continuous maize production without fertilizer (Franzel *et al*., 2002; Franzel, 2004; Ajayi *et al*., 2007, 2009). Over a five-year cycle, the net profit from unfertilized maize was US$130 per hectare compared to US$269 and US$309 for maize grown with *Gliricidia* or *Sesbania*, respectively. With respect to returns per investment, FTS performed better with a benefit-to-cost ratio ranging between 2.77 and 3.13 in contrast to 2.65 in (subsidized) fertilizer fields, 1.77 in (non-subsidized) fertilizer fields and 2.01 in non-fertilized fields (Ajayi *et al*., 2009).

Table 3 | **Qualitative assessment of the impact of agroforestry adoption on livelihoods of farmers in southern Africa**

Impact indicator	Proportion of households interviewed (%)		
	Malawi (*n* = 31)	Zambia (*n* = 184)	Mozambique (*n* = 57)
Increase in area under agroforestry	55	87	65
Increase in maize yield (quarter to double)	70	90	71
Improvement in food security (greater than two months of hunger reduction)	94	84	54
Increase in income	58	68	53
Increase in savings	87	94	71
Increase in wealth	77	84	77
Strong reduction in *Striga* spp.	90	93	88
Soil improvement	84	82	59

Source: Schüller *et al*. (2005).

Effects on environmental services (e.g. standing and soil carbon, biodiversity, water and soils)

Fertilizer trees improve soil physical properties through the addition of litter fall, root biomass, root activity, biological activities, and roots leaving macropores in the soil following their decomposition. The trees also improve soil aggregation, thereby enhancing water filtration (Chirwa *et al*., 2007), which reduces water runoff and soil erosion relative to production systems where maize was continuously cultivated without planting trees (Phiri *et al*., 2003).

Improved tree fallows enhance soil biodiversity by increasing soil invertebrates, which perform important ecosystem functions that can affect plant growth. A long-term study concluded that the technology also has a positive impact on biodiversity, enhances the ecosystem services rendered by soil invertebrates (Sileshi and Mafongoya, 2006), suppresses weeds (Sileshi *et al*., 2006) and sequesters carbon (Makumba *et al*., 2007).

Organic inputs from tree legumes can supply enough nitrogen for crops but may not supply sufficient phosphorus and potassium to support crop yields over time. An eight-year nutrient balance trial conducted showed that unfertilized maize had the lowest N and P balances even though maize grain and stubble yields were very low over time (Mafongoya *et al*., 2005). The tree-based fallows had a positive nitrogen balance due to biological nitrogen fixation and capture of nitrogen from depth, but the nitrogen balance became very small in the second year of cropping. Most of the maize production systems showed a positive phosphorus balance due to low uptake of phosphorus in maize grain yield and stubble (relative to nitrogen), and increased mycorrhizal populations in the soil. Most maize production systems showed a negative balance for potassium. The largest negative potassium balance was obtained in fully fertilized maize fields due to higher maize and stubble yields, which extract a lot of potassium (Table 4). Similarly, soil pH was lower in continuously cropped, fully fertilized maize compared with maize grown in FTS in eastern Zambia (Chintu *et al*., 2004) and Malawi (Akinnifesi *et al*., 2007). This is in agreement with reports from elsewhere that show that application of organic residues can mitigate soil acidity to some extent (Haynes and Mokolobate, 2001), especially due to nutrient recycling from deeper soil layers by tree roots (Akinnifesi *et al*., 2004). Nevertheless, the long-term impact of biological nitrogen fixation and net crop export on the soil resource is an important area that requires further research.

Social outcomes – who are the key beneficiaries? Who are the losers?

Studies from Zambia found that wealthier farmers were more likely to test the technology, but less likely to continue with FTS compared with other social groups (Keil *et al*., 2005) because poorer farmers are less able to purchase fertilizer. Whether this pattern continues now that fertilizer prices are partly subsidized has not yet been studied. Several studies (e.g. Gladwin *et al*., 2002; Keil *et al*., 2005) found no significant differences between the proportions of female- and male-headed households planting improved tree fallows. Other studies found that men in the region control many household decisions including those involving cash transactions and hence, although women may be using the technology as commonly as men, they may not be benefiting from it as much.

Another social outcome of FTS is that with the establishment of trees, fields that hitherto were ‘common property’ on which livestock may freely graze have become more privatized even during the dry season. This sometimes leads to conflicts because it limits fodder availability for livestock or results in extra labour being deployed in herding animals. This has triggered changes in traditional customary practices on livestock rearing and use of bush fires to hunt for mice (local delicacies) during the dry season. Details of these social impacts have been described elsewhere (Ajayi and Kwesiga, 2003).

How could the technology or practice be spread to other agro-ecological zones or countries?

Given the increasing awareness at national and international levels of the need to maintain the agricultural resource base in food production strategies, there are

Table 4 | **Nutrient budgets for different maize production systems in two-year fallows (0–60cm of soil)**

Land-use system	Nitrogen			Phosphorus			Potassium		
	1998	1999	2002	1998	1999	2002	1998	1999	2002
Cajanus fallow	44	17	84	21	8	33	37	9	27
Sesbania fallow	47	19	110	39	24	32	−20	−25	−20
Fertilized maize	70	54	48	14	12	12	−56	−52	−65
Unfertilized maize	−20	−17	−22	−2	−1	−2	−31	−30	−38

Source: Mafongoya *et al*. (2005).

good prospects for spreading fertilizer trees to other zones. FTS do not perform equally well in all eco-regions and different types are more appropriate for different household conditions. Specific fertilizer trees should be targeted to their biophysical niches (to ensure that they perform well in the field) and their socio-cultural niches (to ensure that resources are committed to disseminating technologies that are most relevant to the needs of farmers and can make the greatest impacts in given locations). Due to the important influence of policies on farmers' adoption of the technology, a scaling-up strategy should combine farmer training and dissemination activities at the farm level with active engagement with policy makers. Local and national policy-making processes need to institutionalize sustainable agricultural production (e.g. through specific policy documents and budgetary allocations, and implementation of various governmental declarations on sustainable agricultural production systems).

The well-documented synergy between fertilizer trees and mineral fertilizer should be emphasized rather than focusing on 'organic vs. inorganic' debates. Indeed, there is a need for African farmers to increase the use of a range of soil fertility management practices. There is also a need to expand the use of FTS on high-value crops as most research carried out on the technology to date has focused almost exclusively on maize.

Conclusion

Experiences with FTS in southern Africa demonstrate that inexpensive technologies are available to significantly raise crop yields, reduce food insecurity and enhance environmental services in ways that help ensure the long-term productive capacity of the soils. Hundreds of thousands of poor farmers are currently using the technologies in Malawi and Zambia. The key obstacles to its wider use, which is the same that confronts other agricultural technologies (e.g. improved seed and fertilizer), include policy and institutional changes and the generally low returns on investments in rainfed smallholder agriculture in sub-Saharan Africa.

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