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# Contributions of Agroforestry Research to Livelihood of Smallholder Farmers in Southern Africa: 1. Taking Stock of the Adaptation, Adoption and Impact of Fertilizer Tree Options

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**Abstract:** Agroforestry practies involving fertilizer trees managed in sequential and simultaneous tree-crop systems are key to achieving sustainable food production in Southern Africa as they offer a wider scope for resource-stressed farmers to produce sufficient food for consumption and markets, even where land scarcity and soil fertility are major constraints. In these systems, maize yields have generally increased from less than a tonne per hectare to two or more tonnes, in Malawi, Tanzania, Zambia and Zimbabwe and they have been shown to be comparable to fertilized fields. Application of micro doses of inorganic fertilizers (especially N) in tree-crop systems has generally increased the synergy in nutrient availability thereby producing higher maize yields than unfertilized maize. Fertilizer tree systems are more productive and economically more profitable than unfertilized maize system and the economic impact is high, estimated at US$ 2 million in 2005 for Zambia alone. Fertilizer tree systems practiced on a 0.20 ha area increased maize consumption for a family of five by extra 57-143 days. Training of trainers, farmer-to-farmer extension and support to existing initiatives were the most effective pathways of disseminating proven technologies. Impact assessment studies in Malawi, Mozambique and Zambia indicate that 66-83% of farmers are aware of the contribution of fertilizer tree systems to food production, cash income, fuelwood and their overall livelihoods. However, the slow rate of adoption of fertilizer tree options under farmer's resource-poor conditions underscores the magnitude of the challenge for stimulating long-term investment. There is need to create enabling policy support that would make quality germplasm available in the right amount and time and provide awareness and training to farmers on such knowledge-intensive technologies.

**Key words:** Fertilizer trees, fallows, intercropping, biomass transfer, crop performance, adoption, scaling up

## INTRODUCTION

The attainment of livelihood security in Sub-Saharan Africa (SSA) is intrinsically linked with reversing the decline in agricultural productivity and conserving the natural resource base. Declining soil fertility is a fundamental impediment to agricultural growth and a major reason for slow growth in food production in SSA (Vanlauwe and Giller, 2006; Sanchez, 2002). Compared to parts of North America, Europe and of Asia, most SSA soils are naturally low in fertility, with widespread deficiency especially in nitrogen, phosphorus, sulphur, magnesium and zinc. This can be attributed to the breakdown of traditional fallow systems, deforestation and continuous cultivation without external inputs. Low amounts of Soil Organic Matter (SOM) combined with poor land cover have resulted in poor soil structure, limited rooting depth and susceptibility to accelerated erosion and low nutrient retention capacity.

Beside the primary effects of soil fertility depletion on declining per-capita food production in small-holder farms, the situation also triggers other side effects on-farm such as lack of fodder, fuelwood and construction wood and reduced amounts of farm residues and animal manure

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for food production. Total annual deforestation has been estimated at 55,000 ha for Malawi, 323,000 ha for Tanzania, 264,000 ha for Zambia 50,000 ha for Zimbabwe (Geist, 1999) representing annual deforestation rates of 1.6% for Malawi and 1% for Zambia with Tanzania and Zimbabwe ranging between 0.6 and 0.8%. In Malawi, US$ 6.6 to 19 million worth of nutrients have been estimated to be lost each year through soil erosion, representing 18% of the agricultural GDP (Bojo, 1996). In the same report, Zimbabwe loses US$ 100 million worth of nutrients due to soil erosion. Obviously, any land use practice that might reduce soil erosion and loss of water, needs to be given serious consideration.

Devanon and Casey (1998) asserted that there are two main approaches to improved soil fertility management. One is to attempt to meet plant requirements with purchased mineral fertilizers. The second relies on biological processes to optimize nutrient recycling, with little reliance on external chemical fertilizers, but maximizing the efficiency of their use. The more sustainable middle path is referred to as Integrated Nutrition Management (INM). INM combines mineral fertilizers with organic resources, thus increasing fertilizer use efficiency, reducing the risks of acidification and providing a more balanced supply of nutrients.

The conventional use of chemical fertilizers as a soil fertility management option has proven elusive in most of southern Africa. The landlocked nature of many countries in the region, coupled with poor infrastructure hinders access to fertilizers at affordable prices to small holder farmers. In many of these countries, fertilizers cost two to six times as much as in Europe, North America or Asia. For instance, cost of inorganic fertilizers in the USA is about US$90/ton. By the time it reaches Beira in Mozambique it costs US$120/ton and costs more than US$500/ton when it reaches farmers in Malawi (Sanchez, 2002). Even if readily available, fertilizers alone cannot solve the problem. In fact, studies from other parts of the world have shown considerable decrease in cereal yield with continuous application (up to 25 years) of N, or N and P fertilizers (Sharma and Subehia, 2003). Therefore, short-term solutions such as free fertilizer handouts are not sustainable as a means of eliminating the recurrent hunger and malnutrition in the region. Alternative and complementary approaches are needed to help smallholder farmers and their families move beyond annual dependency on food and fertilizer assistance (Kwesiga *et al.*, 2003; Sanchez, 2002).

Investing in soil fertility is a win-win effort that can generate significant and lasting returns with a high probability of success because all agricultural enterprises depend directly or indirectly on soil quality. Developing and implementing sustainable natural resources management practices with a balanced portfolio of ecosystem services to increase resilience of managed agricultural lands will require an integrated land management approach. Also, the substantial gap between the outcomes under research and under farmer conditions has been another reason for non-adoption of soil fertility enhancing innovations. Under virtually any scenario, the issue comes down to achieving a fit between the farmer's circumstances, the incentives offered for adoption and the factors constraining their capacity to do so.

Considering the huge body of results on process-oriented and adoption research from farmers' fields that have been accumulating since early 1990s to date, this review will focus on soil fertility replenishing agroforestry-based technologies in southern Africa region. The objective of this review is to: Synthesize the development, scaling up and impact of fertilizer tree systems in southern Africa in the last two decades and identify knowledge gaps and research needs for the third millennium. Such review is especially important as it will facilitate improved understanding scaling up proven technologies.

## AGROFORESTRY-BASED SOIL FERTILITY MANAGEMENT OPTIONS

**Traditional tree-crop and parkland systems:** For centuries farmers have retained a low density of trees in the parkland in the tropics, especially in the semi-arid areas in order to improve the yield of understorey crops (Kang and Akinnifesi, 2000; Phombeya, 1999). In southern Africa, traditionally farmers grow crops under scattered trees. In this review we will focus on *Faidherbia albida* A Chevalier (Fabaceae) as this is one of the widely researched legume and its potentials for soil fertility improvement have been documented (Phombeya, 1999; Rhoades, 1995). Specific examples include coffee/ *F. albida* system in Tanzania and the *F. albida*/maize system in southern and central Malawi. *F. albida* has a unique characteristic of shedding most of its leaves during the wet season and resuming leaf growth during the dry season. This makes it possible to cultivate under its canopy with minimum shading effect on the companion crop. Substantial benefits are realized from these practices as resource-use by trees and associated crop components rarely overlap (Weil and Mughogho, 1993). The cultivation of crops under canopies of *F. albida* is the most notable of such traditional agroforestry practices in southern Africa.

The deciduousness of *F. albida* is a unique attribute that farmers exploit for increasing crop yields under canopy area. The albida-effect, known as greater growth of crop under canopy of the tree than in the open field has been widely described as islands of high fertility and organic matter (Kang and Akinnifesi, 2000). Rhoades (1995) reviewed several results in Africa and reported yield increases of 37% for groundnut and 200% for sorghum in the north-central Senegal and 115% for Sorghum in Burkina Faso, while Saka *et al.* (1994) reported 100-400% increase for maize yield in the Lakeshore plain of Malawi.

The improved crop growth under tree canopies can be explained in terms of a combination of factors:

- Increased nutrient inputs including biological N fixation, excreta manure and urine from livestock grazing, resting or camping under the tree and birds that take shelter under or perch in search for food (Kang and Akinnifesi, 2000).
- Increased nutrient availability through enhanced soil biological activity and rates of nutrient turnover.
- Improved micro-climate and soil physico-chemical properties (Buresh and Tian, 1997).

It has been estimated that about 20 to 30 mature trees are needed to completely cover one hectare of land (Weil and Mughogho, 1993). Okorio and Maghembe (1991) found that in Morogoro Tanzania, intercropping maize with beans under *F. albida* did not improve yields at 4×4, 5×5 and 6×6 m spacings and maize yields were generally low ranging from 300 to 900 kg/ha for maize and 200 to 400 kg/ha for beans. This may be due to the fact that trees are slow growing requiring 15 to 20 years to reach mature age when impact on crops can be substantial.

The *F. albida* was widely promoted in Malawi for almost 15 years where the total number of farmers planting it in a six-year period reached 96,236 (Bunderson *et al.*, 2004). However, the outcome was disappointing with low germination of *F. albida* (<20%) in the community nurseries (Bunderson, pers. comm.) and less than 5% survival in the fields (Carr, 2004). Most of the trees that survived had very slow growth and farmer's enthusiasm faded considerably (Carr, 2004; Bunderson *et al.*, 2004). The reason for this failure was clearly due to lack of research backup. If tree establishment and slow growth could be addressed by research *F. albida* could add to the few species and options available for smallholder farmers for long-term soil fertility restoration in the region.

**Improved fertilizer tree systems:** Traditionally, the presentation of agroforestry practices in reviews has generally followed description of technologies *per se*. Our description of the agroforestry practices in this paper is structured to follow functional (Huang *et al.*, 2002) rather than technological characteristics. Our aim in doing so is to highlight the impact of the various soil fertility improvement practices on key ecological functions and livelihoods. First, we will describe agroforestry practices with similar impacts on ecosystem processes such as nitrogen fixation, soil fertility improvement and soil conservation. This is because agroforestry practices based on fertilizer tree system where fuel wood tree species are also produced may relieve the pressure on forests and threats posed by deforestation due to land expansion for agriculture, excessive fuel wood harvesting, building materials and timber. These will have a significant contribution to reducing deforestation and conserving biodiversity. We will describe practices with similar impacts on biodiversity conservation and production of indigenous fruits, medicines of fuel wood and fodder under although the same tree species may be used for instance for soil fertility improvement.

It has long been recognized that trees have potential to improve soil fertility through nutrients contributed from decomposition of biomass or leaf residues, nutrient flow, atmospheric nitrogen fixation (legumes only), root turnover and nutrient cycling processes and influence on soil microclimate and associated faunal activities (Akinnifesi *et al.*, 1997, 1999, 2002). Traditionally, farmers in Zimbabwe have been known to collect plant litters from miombo woodland and plantations to mulch their crops (Nyadthi and Campbell, 1993). Such practice was probably informed by the potential nutrient acquisition by trees. One of the conceptual foundations upon which agroforestry was based is that nitrogen fixing trees are able to replenish soil fertility and improve the growth and production of associated crops. This concept has been tested widely and such efforts have formed the basis for process-oriented research, farmer testing, adaptation, adoption and up-scaling of *fertilizer trees* in southern Africa.

Fertilizer tree is a new terminology for describing proven soil fertility replenishment options based on managing $N_2$-fixing trees in temporal and spatial arrangements that are compatible with and improve the yield of the associated annual crops (Mafongoya *et al.*, 2006). Essentially, these practices are modifications of the natural fallow and traditional shifting cultivation systems, which have become unsustainable in southern Africa.

Our discussion of *improved fallows* in this study will be restricted to planted tree or shrub fallows (Sanchez, 1995). Improved fallow is a practice whereby a piece of land is dedicated to fallowing with fast-growing nitrogen-fixing trees or shrubs. Improved fallows are improvement over natural fallows, with capability to attain the objective for using natural or traditional fallow systems more quickly, through careful choice of species, management of tree density, spatial arrangement and pruning. From ecosystem perspective, the main function of fallow is the transfer of mineral nutrients from the soil back to the woody biomass, which is then made available through burning, decomposition and nutrient turnover from the organic biomass. Improved fallows can be either short-duration using herbaceous legumes, shrub or non-coppicing tree legumes primarily planted for soil fertility replenishment to support crop production and medium to long-duration fallows involving mainly coppicing tree species for soil amelioration in degraded soils and abandoned lands, as well as for utilization of tree products (Rao *et al*., 1997; Mafongoya *et al*., 2006).

Tree fallows have distinct advantage over herbaceous fallows, particularly in seasonally dry climates, because they have ability to tap nutrients from deeper soil layers and are capable of accumulating large quantities of biomass through which nutrients are recycled back for crop use (Sanchez, 1995). Nitrogen fixing trees have also been found to add large quantities of N through Biological Nitrogen Fixation (BNF) and improve crop yield (Table 1). Research on improved fallows was intensified in southern Africa in the late 1980s. In the last decade improved fallows have been widely tested on farmer's field (Kwesiga *et al*., 1999, 2003).

**Alley cropping or hedgerow intercropping:** Alley cropping is synonymous with the hedgerow intercropping and was widely promoted in the 1990s by both the International Institute for Tropical Agriculture (IITA) and the World Agroforestry Centre (ICRAF, respectively. Alley cropping involves growing crops in alleys formed between planted hedgerows of widely spaced woody species and regularly coppiced at about 0.75 m above ground to reduce shading and below ground competition with companion crops and to provide green manure and mulch (Kang *et al*., 1999). It integrates, on a continuous basis, the restorative attributes of the fallow through simultaneous hedgerows of planted perennial trees or shrubs. *Leucaena leucocephala* De Wit and *Gliricidia sepium* H B and K (Fabaceae) were the major species recommended (Kang *et al*., 1990).

The interactions and the potentials of alley cropping have been reviewed by many authors and have generated much debate (Cooper *et al*., 1996; Kang *et al*., 1990; Kang and Akinnifesi, 2000; Rao *et al*., 1997). The literature on the effect of alley cropping on crop yields in southern Africa is generally contradictory. In northern Zambia, alley cropping with *L. leucocephala* increased yield by 90% compared to limed control after six years while *G. sepium* had no effect in the same trial (Matthews *et al*., 1992). An economic analysis showed that alley cropping in this highly acidic soil is only profitable with *L. leucocephala* when fertilizer costs are high (Matthews *et al*., 1992). Mhando and Mkangwa (1991) also reported increase in maize yield averaging 69 and 79% with unfertilized 4 and 6 m wide alley cropping with *L. leucocephala*. Further application of half recommended N rate increased yield to by an extra 10%. Alley cropping with *L. leucocephala* improved yield by 90% in trials in Kasama, Zambia, although Matthew *et al*. (1992) did not find significant benefit in Kasama, Zambia, especially in the early years of the trial.

In Malawi, the application of *L. leucocephala* leaf prunings in an alley cropping system raised maize grain yield and increased soil pH; organic C; total N; S and exchangeable Ca, Mg and K (Jones *et al*., 1996; Wendt *et al*., 1996). Maize yield also increased from 0.49 t/ha in control to 2.73 t/ha in alley cropping with several species in Malawi (Kwapata, 1991). In multi-location trials, maize yield ranged from 0.2 to 1.71 t/ha in control (averaging 1.18 t/ha), to 1.19 to 5.27 in *G. sepium* (averaging 2.53 t/ha) (Chilimba *et al*., 2004). *G. sepium* increased maize yield by 114% in all the ten harvest cases data calculated from Chilimba *et al*. (2004).

While *L. leucocephala* was location-specific, *Senna spectabilis* (DC) Irwin and Barneby, a non N-fixing legume was shown to be inferior in the trials. A number of cases with use of inappropriate tree species have been noted in the past, e.g. non-coppicing species such as *Sesbania sesban* Merrill, *Cajanus cajan* Druce, *Tephrosia vogelii* Hook f. (Fabaceae) and non-N fixing species such as *S. spectabilis* (Chilimba *et al*., 2004).

In general, alley cropping was more promising in the humid tropics than in the drier areas, mainly due to below- and above-ground interactions between tree and the companion crops and climatic conditions. Economic studies indicated that alley cropping is more profitable than conventional farming (Ehui *et al*., 1990; Ngambeki, 1985). Recent farmer surveys indicate that some farmers are still using the alley-cropping in West Africa, after a decade of withdrawal of research interests (Adesina *et al*., 2000). In western Kenya, Heineman *et al*. (1991) reported a positive increase of 53% for Leucaena and 41% for *G. sepium* alley cropping, after discounting for 25% hedge-effect.

Despite the mixed conclusions on the alley cropping system in the past, there has been lack of sound meta-analysis that could properly isolate the effects of

Table 1: Crop yield (Mg $ha^{-1}$) and % yield increase over the unfertilized sole crop in various fertilizer tree options under various biophysical condition in southern Africa

| Field site | Technology | Planted fallow species | Length of cropping (years) | Control Type | Maize yield and (% yield increase) | Annual rainfall (mm) | Soil type | References |
|---|---|---|---|---|---|---|---|---|
| Chipata, Zambia | Non-coppicing fallow | *S. sesban* | 1 | USM | 2.34 (214) | 950 | Alfisols | Kwesiga *et al.* (1999) |
| Chipata | Non-coppicing fallow | *S. sesban* | 1 | USM | 3.30 (59) ‡‡ | 950 | Alfisols | Kwesiga *et al.* (1999) |
| Chipata | Non-coppicing fallow | *S. sesban* | 2 | USM | 5.20 (69) ‡‡ | 950 | Alfisols | Kwesiga *et al.* (1999) |
| Chipata, Zambia | Non-coppicing fallow | *S. sesban* | 2 | USM | 3.80 (317) | 950 | Alfisols | Kwesiga *et al.* (2003) |
| Chipata, Zambia | Non-coppicing fallow | *T. vogelii* | 2 | USM | 2.10 (191) | 950 | Alfisols | Kwesiga *et al.* (2003) |
| Chipata, Zambia | Non-coppicing fallow | *C. cajan* | 2 | USM | 1.71 (155) | 950 | Alfisols | Kwesiga *et al.* (2003) |
| Chipata, Zambia | Non-coppicing fallow | *S. sesban* | 2 | USM | 1.93 (410) | 950 | Alfisols | Ayuk and Mafongoya (2002) |
| Chipata, Zambia | Non-coppicing fallow | *S. sesban* | 1 | USM | 1.93 (42)‡ | 950 | Alfisols | Kwesiga and Coe (1994) |
| Chipata, Zambia | Non-coppicing fallow | *S. sesban* | 2 | USM | 1.97 (125) ‡ | 950 | Alfisols | Kwesiga and Coe (1994) |
| Chipata, Zambia | Non-coppicing fallow | *S. sesban* | 3 | USM | 0.43 (27) ‡ | 950 | Alfisols | Kwesiga and Coe (1994) |
| Chipata, Zambia | Non-coppicing fallow | *T. vogelii* | 2 | USM | 1.80 (382) | 950 | Alfisols | Ayuk and Mafongoya (2002) |
| Chipata, Zambia | Coppicing fallow | *G. sepium* | 3 | USM | 1.75 (700) | 950 | Alfisols | Sileshi and Mafongoya (2006) |
| Chipata, Zambia | Coppicing fallow | *G. sepium* | 3 | USM | 2.05 (273) | 950 | Alfisols | Sileshi and Mafongoya (2006) |
| Chipata, Zambia | Coppicing fallow | *G. sepium* | 8-10 | USM | 1.72 (817) | 950 | Alfisols | Sileshi *et al.* (2005) |
| Chipata, Zambia | Non-coppicing fallow | *S. sesban* | 2 | USM | 1.60 (200) | 950 | Alfisols | Mafongoya *et al.* (2006) |
| Chipata, Zambia | Non-coppicing fallow | *S. sesban* | 2 | USM | 177(253) | 950 | Alfisols | Mafongoya *et al.* (2006) |
| Kagoro, Zambia | Non-coppicing fallow | *S. sesban* | 3[††] | USM | 1.00 (500) | 850 | Acrisol | Chirwa *et al.* (2003a) |
| Kagoro, Zambia | Coppicing fallow | *G. sepium* | 3[††] | USM | 0.80 (500) | 850 | Acrisol | Chirwa *et al.* (2003a) |
| Kagoro, Zambia | Coppicing fallow | *G. sepium* | 3[††] | USM | 1.55 (775) | 850 | Acrisol | Chirwa *et al.* (2003a) |
| Makoka, Malawi | Annual relay fallow | *S. sesban* | 5 | USM | 2.80 (255) | 1024 | Alfisols | IC ICRAF MW (1994)[‡] |
| Makoka, Malawi | Annual relay fallow | *S. sesban* | 5 | USM | 1.00 (109) | 1024 | Alfisols | ICRAF MW (1994) |
| Makoka, Malawi | Annual relay fallow | *S. sesban* | 2 | USM | 0.94 (80) | 1024 | Alfisols | Ikerra *et al.* (2001) |
| Makoka, Malawi | Annual relay fallow | *S. sesban* | 3[††] | USM | 0.85 (73) | 950 | Alfisols | Bohringer *et al.* (1999) |
| Makoka, Malawi | Annual relay fallow | *T. vogelii* | 3[††] | USM | 0.91 (79) | 950 | Alfisols | Bohringer *et al.* (1999) |
| Makoka, Malawi | Annual relay fallow | *S. sesban* | 3 | USM | 1.05 (65) | 1024 | Alfisols | Makumba *et al.* (2001) |
| Makoka, Malawi | Annual relay fallow | *G. sepium* | 3[††] | USM | 0.68 (55) | 1000 | Alfisol | Phiri and Akinnifesi (2001) |
| Makoka, Malawi | Annual relay fallow | *C. cajan* | 3 | USM | 1.20 (126) | 1024 | Alfisols | Makumba (2003) |
| Makoka, Malawi | Permanent Tree Intercropping | *G. sepium* | 10 | USM | 3.15 (315) | 1024 | Alfisols | Akinnifesi *et al.* (2006) |
| Five sites, Malawi | Annual relay fallow | *T. vogelii* | - | USM | 2.44 (617) | - | - | Kumwenda *et al.* (2001) |
| Domasi, Malawi | Permanent Tree Intercropping | *G. sepium* | 4 [††] | USM | 0.65 (108) | 980 | Vertisol | Harawa *et al.* (2006) |
| Makoka, Malawi | Permanent Tree Intercropping | *G. sepium* | 6 | USM | 2.10 (221) | 1024 | Alfisols | Makumba (2003) |
| Malawi | Permanent Tree Intercropping | *G. sepium*[††] | 4 | USM | 0.68 (55) | 1000 | Alfisol | Phiri and Akinnifesi (2001) |
| Kasungu, Malawi | Non-coppicing fallow | *S. sesban* | 2[††] | USM | 2.64 (415) | 1250 | Alfisols | Haule (2003) |
| Domboshawa, Zimbabwe | Non-coppicing fallow | *S. sesban* | 2 | Grass fallow | 3.00 (188) | 750 | Alfisols | Mafongoya and Dzowela, (1998) |
| Domboshawa, Zimbabwe | Non-coppicing fallow | *C. cajan* | 2 | Grass fallow | 1.80 (113) | 750 | Alfisols | Mafongoya and Dzowela (1998);ICRAF ZW(1995) |
| Tabora, Tanzania | Non-coppicing fallow‡ | *S. sesban* | 2 | USM | 1.00 (120) | 700 | Ultisols | ICRAF TZ (1995) |
| Tabora, Tanzania | Non-coppicing fallow | *C. cajan* | 2 | USM | 0.50 (50) | 700 | Ultisols | ICRAF TZ (1995) |
| Shinyanga | Non-coppicing fallow | *S. sesban* | 2 | USM | 0.50 (40) | 800 | Vertisol | ICRAF TZ (1995) |
| Chipata, Zambia | Biomass transfer | *G. sepium* | 1[††] | C Cabbage | 51.1 (135) | 980 | Greysols | Kuntashula *et al.* (2006) |
| Chipata, Zambia | Biomass transfer | *G. sepium* | 1[††] | Onion | 40.8 (122) | 980 | Greysols | Kuntashula *et al.* (2006) |
| Six sites, Malawi | Biomass transfer | *T. diversifolia* | 1 | USM | 2.16 (216) | - | - | Ganuange and Kabambe (1996) |
| Naminjiwa RTC | Biomass transfer | *G. sepium* | 1 | USM | 1.91 (113) | - | - | Chilimba *et al.* (2004) |

[‡] ICRAF MW = ICRAF Malawi, TZ = Tanzania; ZM = Zambia, ZW = Zimbabwe); USM = unfertilized sole maize; *Maize yield in the sole maize averaged 0.15 t/ha compared to 1.90 t/ha in the Gliricidia-maize intercropping; [†] Well degraded soil; [††]On farm type II trial. ‡Three years yield average, discounted for including uncropped years

boundary conditions and determine the niches where the technology works best. These results suggest that the myth surrounding why researchers had abandoned alley cropping is yet inconclusive. Although one of the key reasons alluded to mixed results in alley cropping was root competition for water and nutrients, several reviews of rooting behaviours of trees and crops, indicate that they vary with site, climate and management conditions and more roots may not always mean competition (Akinnifesi *et al.*, 1999, 2004).

Many researchers agree that alley cropping was successful under certain biophysical and socioeconomic boundary conditions (Kang *et al.*, 1990; Cooper *et al.*, 1999; Rao *et al.*, 1997; Adesina *et al.*, 2000). The potential constraints to adoption of alley cropping, include some socioeconomic factors such as availability of labour at the right time for pruning trees, secured land tenure for individual smallholder farmers (Adesina *et al.*, 2000), confinement of livestock to avoid browsing of trees, farm revenue as major source of income, infrastructure arrangements which promote extension-farmer and farmer-farmer linkages and a clear perception by farmers that they are substantially benefiting from the technology (Cooper *et al*., 1999). Other biophysical factors include tree management, choice of species, lack of adequate planting material (Kwesiga *et al*., 2003) and below and above ground competition between trees and crops (Rao *et al*., 1997), as well as the area of land lost to trees. The weediness of some species such as *L. leucocephala* may be disincentive to adoption. Use of less self-weeding species was generally suggested (Kang *et al*., 1990). In addition, alley cropping is known to work well under the following boundary conditions:

- Moderate pH (>5.5) with high base saturation.
- Where declining soil fertility is recognized as serious problems by farmers.
- Where trees are scarce in the landscape or have value.
- Adequate rainfall, i.e., >1000 mm.
- Cropping systems dominated by maize (maize responds better to N than most other crops).
- Appropriate species and provenance choice, for fast-growing, high biomass leaf production and yet reduced root growth and penetration (competition).
- Efficient management (frequency and synchrony of pruning).
- Good tree establishment and lack of threatening pest problems.

Most of these identified conditions may also apply to adoption of any other soil fertility replenishment agroforestry technology. A proper targeting of alley cropping to niches where it works and refining of the design and management may be what is needed. The experience with alley cropping has been very useful in developing a better understanding of tree-crop interactions and the biophysical performance provides crucial foundation on which socioeconomic decisions can be built Van Noordwijk, for other improved-fallow based systems.

**Non-coppicing (Rotational) tree fallows:** Non-coppicing tree fallows, variously referred to as improved fallows or sequential fallows, or rotational fallows involve species that do not re-grow when cut at the end of the fallow period, typically after two years of growth. Research on rotational fallows was started with *S. sesban* in Zambia (Kwesiga and Coe, 1994; Kwesiga *et al*., 1999) and was diversified to other species, now including *T. vogelii*, *Tephrosia candida* DC, *C. cajan* and *Crotalaria* sp. (Fabaceae). Mafongoya *et al.* (2003) have identified a *T. candida* provenance from Madagascar (02972) as the most promising for short duration improved fallows as well as for relay cropping as it produces 100% more biomass than *T. vogelii*. Crops utilize the nutrients gained during the fallow period and a gradual depletion begins through crop harvests. Usually, fallows are replanted after the second or third cropping seasons following fallow clearing. Hence, they constitute sequential tree-crop rotation.

Rotational fallows involving non-coppicing legume species have been widely tested and reported to increase crop yields in various parts of Africa. In Zambia, Kwesiga and Coe (1994) reported that maize grain without fertilizer in planted fallows of *S. sesban* had increased with fallow length, with 2.3, 5.6 and 6.0 t/ha after one, two and three-year fallows, respectively. This increased maize yield by 42, 366 and 234%, respectively, compared to unfertilized continuous maize cropping (Table 1). In the same experiment, monoculture maize receiving the recommended fertilizer rate (112 kg N) showed a decreasing trend from 6.1 to 4.9 and 4.3 t/ha after one, two and three years, respectively. Whereas, amending the soil with the same rate of fertilizers following the *S. sesban* fallows recorded increase in yield from 6.8 to 7.2 and 7.6 t/ha following one, two and three-year fallows (Kwesiga and Coe, 1994).

Kwesiga and Coe (1994) have shown that two-year fallows of *S. sesban* and *T. vogelii* are capable of replenishing soil fertility N to levels sufficient to grow subsequent high-yielding maize crops in N-depleted, but P-sufficient soils in southern Africa. For example in Zambia, one-year *S. sesban* fallows increased subsequent maize yields by 50 to 80% and two-year fallows by 150 to 270% over the continuous maize cropping or grass fallow (Kwesiga and Coe, 1994).

In on-farm trials with *S. sesban*, *T. vogelii* and *C. cajan*, Kwesiga *et al.* (1999) reported yield increases of maize ranging from 91 to 214% and 155 to 301% for one and two year fallows, respectively (Table 1). These results agree with those from other studies reported by Mafongoya *et al.* (2006) and Ayuk and Mafongoya (2002). For instance, a yield increase of 1.8 t/ha or 382% was reported in Chipata, Zambia (Table 1). In a degraded soil in Kagoro in Zambia, Chirwa *et al.* (2003a) found that *S. sesban* increased maize yield by 500%. The rotational coppicing fallow tested on-station in eastern Zambia was later scaled up in different parts of eastern Zambia through on-farm research (Kwesiga *et al*., 1999). It has now spread to other parts of Zambia as well as other countries in southern Africa.

In Tabora, Tanzania, Gama *et al.* (2004) showed that improved fallows with *T. vogelii* and *S. sesban* gave yield increases of 40 and 68%, respectively. In Malawi, maize yield following a three-year old pigeon pea (*C. cajan*) fallow was reported to be 55% higher than yield after a natural fallow (Prinz, 1986). Also, in a three-year old improved fallow experiment in Makoka, the first maize crop had grain yield in the following order of magnitude: *T. vogelii* (4.98 t/ha) > *S. sesban* (4.70 t/ha) > *T. diversifolia* (1.29 t/ha) > control without tree (1.0 t/ha). In an on-farm improved fallow trial with 20 farmers in Kasungu where land holding averages 1.75 ha and annual rainfall is 1250 mm, Haule *et al.* (2003) reported yield increase of 2.64 t/ha (415%) (Table 1). The effect of non-coppicing fallows on soil fertility lasts usually for 2-3 cropping seasons, after which they need to be re-established, ideally using different tree species.

Furthermore, fertilizer tree systems generally reduce insect pests such as termites (Sileshi and Mafongoya, 2003; Sileshi *et al.*, 2005) and weed problems including witch weed (*Striga* sp.) (Sileshi *et al.*, 2006). Some species such as *T. vogelii* are also used as natural pesticides. Despite these great advantages in yield and capability of improved fallow to restore degraded lands, the main requirements of improved fallows are availability of enough land, high demand for labour during establishment, availability of water for successfully establishing the trees and the need to protect the improved fallows during the dry season from fires and free-ranging livestock (Ajayi and Kwesiga, 2003; Ajayi and Katanga, 2005). Improved fallows are not appropriate where land holding is small, such as Malawi where average holding is 0.4 ha or less. The 2 to 3 years waiting period may also be a disincentive in land pressured areas and farmers may be unable to allocate a separate field for fallows for such long periods. A well designed simultaneous intercropping or a relay fallow cropping system is ideal for such situations. In some cases, the biomass produced by fallows could be constrained by low soil fertility and a supplement with micro dozes of inorganic fertilizers, especially P is worthwhile. The use of P fertilizers from inorganic fertilizer or rock phosphate has been recommended for poor P-deficient soils (Sanchez, 2002).

The benefit of fertilizer tree systems is largely due to nutrient cycling capability of trees and other soil improvement processes such as: increased soil organic matter accumulation and related nutrients; reduced soil erosion and run-off; reduced soil bulk density; increased soil aeration and water retention and increased microbial and soil fauna activities of trees and shrubs that are used during short rotation fallows. Significant additional benefits are derived from harvest of fuel wood, amounting in the case of two-year sesbania fallows, to over 10 t/ha (Kwesiga *et al.*, 1999, 2003).

**Coppicing fallows:** Coppicing fallows consist of leguminous trees that are able to re-sprout when cut back. In coppicing fallows practice, trees are planted at close density (1×1 m spacing), just as non- coppicing fallows. The trees are left to grow in the first two to three years. Trees are pruned back to 30 cm at several stages during crop growth to minimize below and above ground competition and also managed during the dry season (after maize harvest) to maximize the quantity and quality of biomass produced. The re-sprouted biomass is cut twice to three times during cropping and incorporated by splitting the ridges, stuffing the biomass and building it up again. This soil fertility option has been mainly evaluated in Zambia.

The species evaluated for coppicing fallows in Zambia include *G. Leucaena* sp., *Calliandra calothyrsus* Meissner, *Senna siamea* (Lam) Erwin and Barneby, *Flemingia macrophylla* (Wild) Kuntze and *Acacia* sp. (Kwesiga *et al.*, 2003; Mafongoya *et al.*, 2006). The species significantly differ in their coppicing ability and biomass production, with *L. leucocephalla*, *G. sepium* and *S. siamea* having the greatest coppicing ability and biomass production, while *C. calothyrsus* and *F. macrophylla* performed poorly (Mafongoya *et al.*, 2006). In contrast to a non-coppicing species, coppicing species shows increases in residual soil fertility beyond 2-3 years because of the additional organic inputs that are derived each year from coppice re-growth that is cut and applied to the soil (Mafongoya *et al.*, 2006). Coppicing fallows have consistently increased maize yield over unfertilized monoculture maize and maize grown after traditional grass fallows (Chintu *et al.*, 2004; Mafongoya *et al.*, 2006; Sileshi *et al.*, 2005). For brevity, we will only highlight the magnitude of increase (Table 1 and 2).

Mixing species with compatible and complementary rooting or shoot-growth patterns in fallow systems were proposed to diversify the systems and maximize growth and resource utilization above and below-ground. For example, mixing a coppicing fallow species such as *G. sepium* with a non-coppicing species like *S. sesban* has significantly increased maize yields compared to single-species fallows, reduced the level of subsoil nitrate and also reduce beetle damage to *S. sesban* (Chirwa *et al.*, 2003a; Mafongoya *et al.*, 2006).

In the coppicing fallows in Zambia, long term nutrient budget suggests that while N maintains positive balance after 10 years of continuous maize cropping, K shows a sign of decline after a 10 years period in Zambia (Mafongoya *et al.*, 2006) and P after 9 years in Malawi (Akinnifesi *et al.*, 2006). Both non-coppicing and coppicing fallows have been shown to have potential to alleviate N and K deficiency (Kwesiga *et al.*, 1999, 2003).

Table 2: N-fixed by various legumes under smallholder farm in southern Africa (adapted from Mafongoya *et al.*, 2006)

| Legume species | Amount of $N_2$-fixed (kg N/ha) | Location | Source |
|---|---|---|---|
| Cowpea | 28-47 | Zimbabwe | Rowe and Giller (2003), Chikowo *et al.* (2004) |
| Groundnut | 33 | Zimbabwe | Rowe and Giller (2003) |
| *Cajanus cajan* | 3-97 | Zimbabwe | Mapfumo *et al.* (2004), Rowe and Giller (2003) |
| *Sesbania sesban* | 84 | Zimbabwe | Chikowo *et al.* (2004) |
| *Gliricidia sepium* | 212 | Zambia | Mafongoya *et al.* (2006) |
| *Tephrosia candida* | 280 | Zambia | Mafongoya *et al.* (2006) |
| *Tephrosia vogelii* | 157 | Zambia | Mafongoya *et al.* (2006) |
| *Leucaena collensii* | 300 | Zambia | Mafongoya *et al.* (2006) |

One of the major shortcoming of the coppicing fallow is the spacing of 1×1 m which has been found not to be compatible with ox ploughing done by the smallholder farmer in parts of Zambia. The trees also tend to grow sideways and make passage and cultivation difficult. Therefore, a wider spacing of 1×2 m is recommended (Mafongoya *et al.*, 2006).

**Gliricidia/maize intercropping:** The semi-permanent tree/crop intercropping of *G. sepium* with crop is an improved version combining the characteristics and advantages of alley cropping and coppicing fallows. It has been variously named as mixed intercropping (Cooper *et al.*, 1999; Chirwa *et al.*, 2003b), simultaneous intercropping (Makumba *et al.*, 2005), or simply as Gliricidia-maize intercropping (Akinnifesi *et al.*, 2006), since *G. sepium* is the suitable promising species so far (Ngulube, 1994). Unlike the tree arrangement in alley cropping or coppicing fallows described above, this practice involves strip intercropping between tree rows (not hedgerow). The typical practice involves establishing *G. sepium* at a density similar to hedgerow intercropping, but arranged at a regularly dispersed spacing of 0.9×1.5 m rather than as hedgerows, thereby enabling planting of maize crop at same population as the sole maize (Akinnifesi *et al.*, 2006). Unlike the coppicing fallows, the spacing between tree rows is wider allowing two rows of maize to be grown between the tree rows. However, the coppice management is similar to the coppicing fallows. Unlike the coppicing fallows, trees are planted in the furrows and crops (e.g., maize) planted on the ridges in regular double-rows at 25×75 or 25×90 cm apart. Hence it is not appropriate to refer to this practice as mixed intercropping, because the trees are regularly dispersed and not mixed or random.

Gliricidia-maize intercropping has formed an important part of on-station and on-farm research in Malawi since the early 1990s. Gliricidia-maize intercropping works well on smallholder farms in Malawi's densely populated areas. The main advantage of this technology is that once farmers plant the trees, they can continue to be pruned and managed to continuously supply green fertilizer for 15 years without drastic reduction in biomass production (Akinnifesi *et al.*, 2006; Kwesiga *et al.*, 2003). This system fits to the southern Malawi environment, where many farmers have small land holding (<0.2ha) because of high population pressure (Akinnifesi *et al.*, 2006). The socioeconomic and biophysical conditions in southern Malawi seem to meet most of the broadly defined criteria for success of simultaneous intercropping of crop with trees (Akinnifesi *et al.*, 2006). The fact that land is scarce, labour is relatively cheap, fertilizer is costly in Malawi and the country is highly nitrogen deficient, coupled with the fact that maize, a high nitrogen-demander, is the major staple food creates prospect for wide adoption of gliricidia/maize intercropping in southern Malawi.

A ten-year long-term trial at Makoka has demonstrated the potential of intercropping *G. sepium* with maize in southern Malawi (Akinnifesi *et al.*, 2006). Maize yield increases ranged from 100 to 500%, averaging 315% over the ten year-period (Table 1). In the first two years, there was no significant effect and maize yield even reduced by 17%, because trees were not yet pruned. Application of a quarter doze of recommended N (23 kg N/ha) resulted into a synergy of 30% in maize yield. Many workers have reported yield increases when gliricidia was combined with fertilizers (Ikerra *et al.*, 1999; Akinnifesi *et al.*, 2006). Figure 1 shows the long-term performance of *G. sepium*/maize intercropping in Makoka, Malawi. Plots with *G. sepium* were superior to control throughout the study, expect for the first year. Combination of inorganic N and *G. sepium* gave the best result.

Increase in yield is more apparent from the third year after tree establishment and onwards (Akinnifesi *et al.*, 2006). This is because trees grow slowly in the early years before accumulating enough vigour and biomass. In an on-farm experiment by Phiri *et al.* (2001), 30% of the 40 on-farm type 2 farmers (farmer managed) experienced increase in yield in the first two years and 90% of these experienced yield increases in the subsequent two years. Yield increases in the third and fourth years averaged 69%. The authors observed that farmers with low yields in these early years were associated with poor management conditions. Similarly, Makumba and Maghembe (2001) reported yield increase in Makoka area of 1.55 t/ha (126%) over 3 years for type 1 farmers

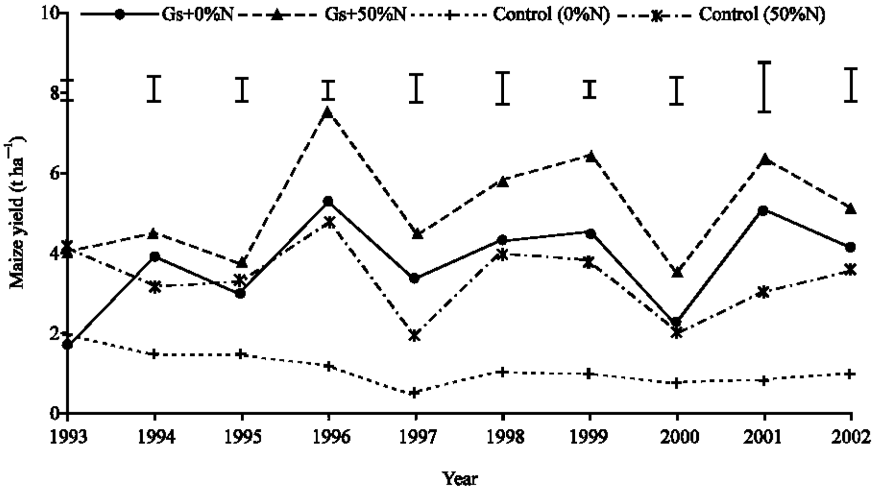

Fig. 1: Maize grain yield in *G. sepium* (Gs) and sole maize (Control) with and without inorganic N fertilizer [0%N, 50N%. recommended fertilizer was 96 kg/ha] (Adapted from Akinnifesi *et al.*, 2006)

fields (researcher managed) and an increase of 0.56 ton (37%) in on-farm type 2 averaged over 5 years. The low response was attributed to erratic rainfall during the period.

The Gliricidia-maize intercropping system has the advantage that crops are produced while organic material is produced for soil replenishment. With appropriate tree management and design tree-crop competition is minimized or eliminated. Gliricidia has very low root concentrations in the upper soil layers (16%) in Malawi (Akinnifesi *et al.*, 2004). Several aspects of the system have been addressed in recent research, such as pruning frequency and timing (Makumba *et al.,* 2005), soil nitrogen dynamics (Ikerra *et al.*, 1999; Chirwa *et al.*, 2006), water dynamics under intercropping with pigeon pea (Chirwa *et al.*, 2007), rooting behaviour (Akinnifesi *et al.*, 2004), long-term performance under fertilizer N and P rates (Akinnifesi *et al.*, 2006) and P-phosphorus adsorption dynamics (Mweta *et al.*, submitted, a, b). When the intercrop plots were amended with 46 kg N/ha and 40 kg $P_2O_5$/ha (representing 50% N and 100% P, respectively) there was a 79% increase in grain yield over the recommended practice, indicating synergy between applied fertilizer and organic inputs from Gliricidia (Akinnifesi *et al.* (2007). Response surface modelling showed that the optimum combination of factors for maximum grain yield (4.2 t/ha) in monoculture maize is 80 kg N/ha, 31 kg P/ha and 917 mm seasonal rainfall. In the gliricidia/maize intercrop, the stationary point had no unique maximum. Ridge analysis revealed that the estimated ridge of maximum grain yield (5.7 t/ha) in the intercrop is when 69 kg N ha$^{-1}$, 37 kg P ha$^{-1}$ is applied and a seasonal rainfall of 977 mm is received (Akinnifesi *et al.*, 2007). Tens of thousands of farmers in Malawi and Zambia have been testing, adapting and adopting the technology since 1994 and have indicated it as their best choice for soil fertility management (Kwesiga *et al.*, 2003). These results confirm the potential of the system as sustainable for small holder farmers.

The amount of labour demanded for tree management can be considerable, but this is not yet a bottleneck as land holdings are less than a hectare and less than a quarter of a hectare is put to Gliricidia-maize intercropping in the southern region; labour is cheap in Malawi and farmers appreciate that coppicing trees need to be established only once and can then be used for many years, despite low initial returns.

**Annual relay fallow intercropping:** In relay fallow intercropping, fast-growing nitrogen-fixing trees or shrubs are inter-planted simultaneously into a field at a time when annual crops, such as maize crop have already been well established (Phiri *et al.*, 1999; Harawa *et al.*, 2006). The shrubs continue to grow after the crop harvest throughout the off-season. Short-duration fallow shrubs such as *Sesbania* sp., *Tephrosia* sp. or *C. cajan* are recommended.

*S. sesban* seedlings are often raised in nurseries and then transplanted into the field. The other species such as *T. vogelii* and *Crotolaria* sp. and *C. cajan* are sown directly under a canopy of established crops. This removes labour or costs for nursery operations. The trees thrive mostly on residual moisture and develop their full canopy only after the crop is harvested. As farmers prepare land for the next season, they clear-cut trees and incorporate the biomass into the soil and then repeat the cycle. Biomass quantities of 1.5-2.5 t/ha can be obtained for *T. vogelii* and 1.8-4.0 t/ha for *S. sesban* for use as green manure, depending on rainfall received and the position of the field in the landscape. The low biomass compared to improved fallows is due to shorter growing period for trees, of only 8 months.

Several results on-station and on-farm have shown that relay cropping has good potential for small farmers in Malawi. Phiri *et al.* (1999) determined the production of relay-cropped maize using *S. sesbania* at three landscape positions (*dambo* valley or bottomland, *dambo* margin with < 12% slope and steep slopes with > 12% slope) on farmers' fields in southern Malawi. The results demonstrate that relay cropping of *S. sesban* with maize increased maize grain yield, as compared to unfertilized sole maize in two of three years. Maize yields tended to be lower on steep slopes than in the dambo valley and dambo margin areas. Biomass production of sesbania and hence the potential benefits of intercropping sesbania with maize appear greater in the dambo valleys and dambo margins than on steep slopes. Boehringer *et al.* (1999) reported annual maize yield increase of 73 and 79% in relay cropping using *S. sesban* and *T. vogelii*, respectively in on-farm trial for 3 years. Research by Kumwenda at 5 sites in Malawi showed that early incorporation of *T. vogelii* (2.85 t/ha) was superior to later incorporation (1.48 t/ha) compared to sole maize (0.40 t/ha). The yield advantages derived from relay cropping reported by various authors is summarized in Table 1 and 2.

The major advantage of this system is that farmers do not have to wait for the fallow phase of 2 years in the sequential fallows, or for the initial period of tree establishment for Gliricidia-maize intercropping. However, the yield levels are usually less than intercropping and fallow systems. It works well on small farms and the benefit of trees can be seen immediately after one season of tree growth. In this case, farmers do not lose any cropping year of maize. The main limitation of the technology is that farmers must depend on late rainfall for good tree establishment. In very dry years, the risk is high that trees will produce little biomass and hence have little effect on crop yield. In addition, the trees need to be replanted every year and yields may not increase as dramatically as in the two options described earlier. In the case of *S. sesban*, additional benefits from fuel wood are derived. This would minimize the dependence of the smallholder farmers on natural forests and woodlands, which are under increasing threat of deforestation (Phiri *et al.*, 1999).

**Biomass transfer:** The biomass transfer is essentially moving green leaves and twigs of fertilizer trees or shrubs from one part of a farm to another to be used as mulch or green manure. Traditionally, resource-poor farmers in parts of southern Africa have collected leaf litter from secondary miombo forest as a source of nutrients for their crops. In the long term, this practice is not sustainable because it mines nutrients from the forest ecosystems in order to enhance soil fertility in croplands. The miombo litter is of low quality and may immobilize N instead of supplying it immediately to the crop (Mafongoya and Nair, 1997). In parts of Zimbabwe, northern Zambia and Tanzania, biomass transfer is a traditional practice, in which farmers gather litter from the miombo woodland and incorporate it in the food production fields (Nyathi and Campbell, 1993; Kwesiga *et al.*, 2003). To improve the system, appropriate nutrient-rich tree species have been selected.

Ganunga and Kabambe (2000) conducted a trial with *Tithonia diversifolia* A Gray (Asteraceae) at five sites in Malawi and reported that the average yield of maize increased by 2.55 t/ha (216%) using 4.5 t/ha of biomass compare to control plot (Table 1 and 2). Transferring biomass of *T. diversifolia*, has also been shown to be a good option in East Africa. Biomass transfer of *T. diversifolia* leaf from roadsides and hedges into cropped fields adds nutrients and doubles maize yields at rates used by farmers, without fertilizer additions. This organic source of nutrients is more effective than urea when applied at the same nitrogen rate because this plant also adds other plant nutrients, particularly potassium and micronutrients (Sanchez, 2002). Because of high labour requirements for cutting and carrying the biomass to fields, the use of *T. diversifolia* as a nutrient source is profitable only with high-value crops such as vegetables but not with relatively low-valued maize (Sanchez, 2002). Planting *T. diversifolia* on farm should be discouraged as this species is invasive species and in some countries such as the Republic of South Africa its planting is prohibited. However, it could be cut from natural wastelands.

Currently, this practice is especially used to fertilize vegetables in the wetlands (*dambos*) in the dry season (Kwesiga *et al.*, 2003; Kuntashula *et al.*, 2004, 2006). Among the legume species tested for biomass transfer, so far *G. sepium* has shown superior performance in southern Africa. Mafongoya *et al.* (2006) reported yield increase of onion by 40 t/ha (183%) and 51 t/ha (143%), respectively when 8 and 12 t/ha biomass of *G. sepium* was applied. Similarly, the yields of cabbage was increased by 9 t/ha (145%) and 6 t/ha (145%) for garlic and 7 t/ha (92%) for green maize when 8 t/ha *G. sepium* biomass was used. Recently, Kuntashula *et al.* (2004, 2006) compared the effect on vegetable yields and economic returns of biomass transfer using *G. sepium*

(8 and 12 t/ha), *L. leucocephala* (12 t/ha) with that of recommended fertilizer and no fertilizer application on farmers fields in eastern Zambia. Using *G. sepium* cabbage, onion and maize yields comparable with those from full fertilizer application can be obtained (Kuntashula *et al*., 2004, 2006). Biomass transfer also recorded higher net incomes than the unfertilized control and required lower cash inputs than the fully fertilized crop. Farmers obtained increases of 135 and 122% for cabbage and onion, respectively (Table 1) in one of the studies (Kuntashula *et al*., 2006), In Malawi, biomass transfer with *G. sepium* and *L. leucocephala* have been shown to be superior, increasing maize yields by 140% and 86%, respectively (Chilimba *et al*., 2004).

Biomass transfer system could be turned into a profitable venture in the region, as it offers huge prospects for increasing cash income and diversifying the number of crops and increasing the number of crops per year. Biomass transfer holds promise for smallholder farmers especially where organically produced vegetables may attract higher premiums (Kuntashula *et al*., 2006). The financial assessment of the system, so far showed it is promising, but wide scale adoption needs to be strategic and based on prior testing in the location. The effects of nutrient mining may become important on the plot where biomass is harvested from, especially if it needs to be cultivated in the same year.

**Biological N Fixation on farm:** Tropical grain legumes can fix substantial amounts of N but the majority of that amount of N is often harvested in the grains (Mafongoya *et al*., 2006) and when residues are returned to the soil there is generally a net removal from the field and they tend to immobilise N due to high lignin content and high C/N ratio. Therefore other means of harnessing N is required for staple crops and N-fixing leguminous trees have shown to be capable of supplying large amounts of biologically fixed N (Table 2). Biological N Fixation (BNF) is the basis for fertilizer tree technologies as alternative or complementary source of N supply to industrially manufactured N fertilizers. The amount of N fixed by fertilizer trees under farmers conditions have been variously estimated at 84 kg N/ha for *Sesbania sesban*, 157-280 kg N/hafor *Tephrosia* sp. and 212 kg N/ha for *Gliricidia sepium* (Table 2).

## LESSONS ON ADOPTION, SCALING UP AND IMPACT

In the preceding discussion, we have established the importance of agroforestry from production, environmental and social perspectives. Several efforts are also being made by several research and development institutions to enhance uptake among farmers (Ajayi *et al*., 2006; Franzel *et al*., 2002; Kwesiga *et al*., 2003), assess farmer's perception of and feedback regarding the technologies (Ajayi, 2007) and by exploring various approaches for disseminating the technologies to farm communities.

**Adoption of fertilizer tree systems:** A number of surveys to investigate the actual and potential adoption of agroforestry technologies have focused primarily on the influence of different household and farm characteristics on the adoption by farmers. Several empirical studies have been carried out to gain insights into the adoption of agroforestry in southern African region. The specific studies investigated the types of farmers who adopt (adopt) agroforestry (Ajayi *et al*., 2003, 2006b; Gladwin *et al*., 2002; Phiri *et al*., 2004). Other studies examined the factors that drive the adoption of agroforestry (Ajayi *et al*., 2003; Place *et al*., 2002; Franzel and Scherr, 2002; Ajayi and Kwesiga, 2003; Keil *et al*., 2005; Thangata and Alavalapati, 2003).

An example of the summary of the adoption studies carried out in Zambia is given by Ajayi *et al*. (2003). The studies reveal that the adoption of agroforestry is not a direct relationship based on technological characteristics of agroforestry alone, but it is a matrix of several factors including household-specific variables (e.g., age, education), technological characteristics of agroforestry, institutional and policy variables (e.g., land tenure system and agricultural policies) and geographical and landscape factors (e.g., spatial adoption-accessibility to markets, climate, soil characteristics). The process of adoption is dynamic and the various factors are likely to influence each other.

The process of technology adoption of agroforestry technologies is more complex because of the multi-years through which testing, modification and eventual adoption of the technologies by farmers takes place (Ajayi *et al*., 2007). During the testing phase, factors such as availability of information, ability to witness the performance of agroforestry in fellow farmers' fields, availability of seeds and training opportunities play important roles in shaping farmers' decision to establish an agroforestry plot. Over time however, institutional constraints (Ajayi and Kwesiga, 2003; Ajayi and Katanga, 2005), land size and tenure arrangement, national policies (Place and Dewees, 1999) and compatibility with other operations in the farming systems become more important. The is the need to distinguish between factors which are

Table 3: Financial profitability of maize production systems using tree fallows, fertilizer and farmers' practices in Zambia†††

| Description of system | Benefit-cost ratio | Net present value (US $/ha) | Increase in net profit over unfertilized maize (%) |
|---|---|---|---|
| Continuous maize-non fertilized | 2.01 | 130 | 0 |
| Continuous maize-subsidized fertilizer† | 2.65 | 499 | 284 |
| Continuous maize-Fertilizer prized at market rate†† | 1.77 | 349 | 168 |
| 2-yr *Gliricidia sepium* fallow | 2.91 | 269 | 107 |
| 2-yr *Sesbania sesban* fallow | 3.13 | 309 | 138 |
| 2-yr *Tephrosia sepium* fallow | 2.77 | 233 | 79 |

†: Fertilizer subsidized by government at 50%; †† Fertilizer at market rates; †††Figures are on one hectare basis, at prevailing costs and prices and annual discount of 30%. Source: Ajayi *et al.* (2004, 2006a)

Table 4: Cumulative number of agroforestry technology adopters in southern Africa

| | Methodological prongs applied to reach farmers | | | | |
|---|---|---|---|---|---|
| Country | Training of farmer-trainers and local change teams | Training of partner institutions | Support to extension and other national initiatives | School-community linkages | Country totals |
| Malawi | 15,476 | 68,248 | 26,982 | - | 110,701 |
| Mozambique | 4,491 | - | - | - | 4,491 |
| Tanzania | 15,000 | 106,228 | 83,000 | 29,500 | 233,728 |
| Zambia | 15,387 | 37,838 | 8,358 | - | 61,583 |
| Zimbabwe | - | - | - | - | 7000* |
| Prong totals | 50,354 | 212,309 | 118,340 | 29,500 | 417,503 |

*The breakdown figure was not available

Table 5: Qualitative assessment of impact of agroforestry adoption on livelihoods of farmers in Malawi, Mozambique and Zambia (ICRAF SA Report, 2005)

| | Malawi (n = 31) | Zambia (n = 184) | Mozambique (n = 57) | Regional range* |
|---|---|---|---|---|
| Impact indicator | (% of respondents) | | | |
| 1. Increase in area under agroforestry | 55 | 87 | 65 | 83-100 |
| 2. Yield increases (>quarter to tripled) | 70 | 90 | 71 | 83-100 |
| 3. Significant food security (>2 months of hunger reduction) | 94 | 84 | 54 | 66-100 |
| 4. Increase in income | 58 | 68 | 53 | 33-83 |
| 5. Firewood availability | 90 | nd† | 59 | nd |
| 5. Increased savings | 87 | 94 | 71 | nd |
| 6. Change in wealth | 77 | 84 | 77 | 77-100 |
| 7. Strong reduction in *Striga spp.* | 90 | 93 | 88 | 71-100 |
| 8. Soil improvement | 84 | 82 | 59 | 71-100 |
| 9. Other benefits | 65†† | nd | 24 | nd |

†† nd, not determined; ††Malawi, seed sale; Mozambique, stakes

associated with the farmers' initial decision to test agroforestry technologies and factors that influence farmers to continue ( adopt) with the technologies on an expanded and long term basis (Ajayi *et al.*, 2006).

**Impact and Scaling up of fertilizer trees technologies:** There have been several studies in southern Africa on the adoption of the various technologies (Ajay *et al.*, 2003, 2007; Phiri *et al.*, 2004). Studies that were carried out to assess the impacts of agroforestry in southern Africa region show that they are profitable and have favourable financial ratios compared with conventional scenario where trees are not grown (Franzel, 2004; Ajayi *et al.*, 2006a; Place *et al.*, 2002). Studies on improved tree fallow in Zambia show that improved tree fallow is more profitable than continuous maize production without external inputs but, less profitable than mineral fertilizer application (Ajayi *et al.*, 2006a). Government subsidy on mineral fertilizer particularly enhanced its superior financial performance over agroforestry-based options. However, when valued at its market price, the magnitude of the differences in the profitability of agroforestry option and mineral fertilizer option decreases by 30% and the net present value of fertilizer ($349) is very close to one of the agroforestry options (NPV of $309) (Table 3). The higher net benefits obtained in mineral fertilizer fields were achieved however through a higher investment cost.

A qualitative impact assessment of agroforestry technologies undertaken in five countries in southern Africa showed evidence of adoption and positive impact of agroforestry on farm households across the different sites (Table 3, 4 and 5). Results of the study show that 83 to 100% of respondents indicated increased maize yield due to adoption of agroforestry (Table 5). These, 59-90% of farmers reported more than half yield increase, the yield doubled for 12-45 and 22-44% had experienced a tripling in the yield of maize. In addition, 66 to 100% indicated improved food security, 33 to 88% indicated increased income, savings increased due to agroforestry for 87% respondents in Malawi, 94% in Zambia, 71% for Mozambique (Table 5). Maize yield doubled by 19% and tripled by 29% of farmers interviewed in Malawi. Similarly, 20 to 45% of farmers in Zambia reported double increase in yield and 22 to 44% reported triple increase. In terms of food security, fertilizer trees reduce hunger by providing food for household members for additional number of days. At current average fallow size (0.20 ha) and the per capita maize consumption (fertilizer tree systems generate between 57 and 114 extra person days of maize consumption per year (Ajayi *et al*., 2006a). Agroforestry also helps farmers to improve household income between 33 to 83% and to diversify household income base.

Agroforestry technologies have multiple impacts on both adopters and non-adopters, on food security and the environment as presented in Table 5. The impacts of agroforestry that are most pronounced include improved soil fertility and higher crop yield, improved and diversified income, increased firewood supply and protection of the environment. The increase in land area means that farmers generally persist in using agroforestry and confirms that incentives for increased crop yield, food security, income, soil improvement, fire wood and other benefits are important elements of adoption (Table 3, 4 and 5).

More than 417,000 farmers have been using various agroforestry technologies in the 5 countries during 2001 to 2004 and more than 40% of adopters are women farmers (Table 4). During 2001 to 2005, small-scale farmers in the region have used more than 100 tons of agroforestry tree seeds in the five countries under the Zambezi Basin Agroforestry Programme. Several NGOs had contributed to the scaling up of agroforestry in the region. For instance, in Zambia, the World Vision project indicated that 27% of the 90,000 farmers targeted had planted improved fallow in eastern Zambia (Hooper, unpublished data).

## RESEARCH NEEDS AND WAY FORWARD

In general, the adoption of agroforestry technologies is still low, despite the demonstrated potential (Kwesiga *et al*., 2003; Ajayi *et al*., 2006). A number of technical and biophysical aspects still require investigation in order to increase the robustness of the technologies.

- It is important to identify the constraints, boundaries to adoption and the critical point at which massive adoption will be take place. Undertaking the whole farm analysis, quantitative impact assessment and income flows at household level will be crucial. A meta-analysis is needed to better understand biophysical and socioeconomic gains and limitations of the technologies.
- Amendment of the soil with fertilizer should be encouraged where feasible and when crop yields start to decline, which often takes place 2 years after cropping the tree fallow land. This builds synergies in productivity, especially under suboptimal weather conditions.
- Our experience has shown that initial crop yield in gliricidia intercropping may be slow, or even negative in the first two years when trees have not yet been pruned and incorporated and farmers will start to obtain increases from the third year onward. Care must be exercised in the assessment of early performance so that premature conclusions are not made on the performance of the technology. Research is also needed to boost the initial growth of trees such as gliricidia in order to increase green biomass production earlier than is currently the case.
- Availability of tree seeds is a major limitation for wide-adoption of *G. sepium* based options, as the species is a shy seed producer. Farmers may need to retain at least 10 trees unpruned, as seed source for expansion purpose. Research is needed on ways to speed up seed production in species such as *G. sepium* that produce very little seed under southern Africa conditions.
- There is need for wider testing of species and provenances for various agroforestry options. Most of the species in use are exotic. There is need for more testing of indigenous species.
- Gender is a factor that could limit agroforestry in areas where matrilineal system is practiced, such as in southern Malawi where land right belong to women, or in other patrilineal systems where it is the reverse Land holding size, which may be linked to gender and communal or family hierarchy system, may affect the size of plot that individual farmers can put to agroforestry.
- Several second generation issues may affect the performance of the agroforestry systems in general. This include: quality of seeds used and genetic diversity, pests and diseases, uncontrolled grazing, drought, fires, improper species-site matching including topography (biophysical boundaries), farm size, crop varieties used, planting time and tree-crop-soil management. Deploying GIS-based technologies and remote sensing for targeting the niches where trees and options will work or otherwise, needs to be applied on a wider scale and more objectively. Genetic diversity of trees and crops needs to be increased and use of quality protein maize and hybrids by farmers should be encouraged.

- Policy hindrances to massive scaling up and institutionalizing agroforestry into the national agenda in each country, in the region, efforts of research and development communities should aim at developing effective policies that will support long-term investment, political will and supports to agroforestry.
- Market for excess products from agroforestry needs to be developed. This will include more research on linking farmers to the private sectors and markets; development of new products and value addition and diversifying products.

## CONCLUSIONS

Agroforestry in southern Africa has come out of age and is now benefiting more than 400,000 smallholder farmers in the region. Large quantities of tree seeds are needed to meet the demands of farmers adopting agroforestry. Over 100 tons of tree seeds were distributed in the last five years in five countries. The economic impact of fertilizer trees in terms of yield increase is high, estimated at an aggregate value of US$ 2 million in 2005 for Zambia alone for the over 60,000 farmers who were practicing the technology as at 2005 (Ajayi *et al*., 2004). Fertilizer tree systems practiced on a 0.20 ha increased maize yield by extra 57 to 143 days of maize consumption. Long term investment by governments and the donor community is one of the major factors that will trigger massive adoption to benefit millions of farmers in the region. Appropriate policy framework and changes are needed to support adoption and massive scaling up. Successful scaling up of agroforestry technologies requires a proper design to meet farmer's needs-biophysical needs, socioeconomic and socio-cultural circumstances and expectations. The adoption and scaling up of agroforestry technologies in southern Africa is evidence that research-partner-farmer partnerships could be worthwhile, profitable and lead to improved livelihoods.

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