

Chapter 6

Agroforestry innovations for soil fertility management in sub-Saharan Africa: Prospects and challenges ahead

Bashir Jama, *World Agroforestry Centre, Kenya*; Freddie Kwesiga, *World Agroforestry Centre, Zimbabwe* and Amadou Niang, *World Agroforestry Centre, Mali*

Abstract

Improving soil fertility is a key entry point for achieving food security, reducing poverty and preserving the environment for smallholder farms in sub-Saharan Africa. Given the high cost of inorganic fertilizers, an integrated approach that combines promising agroforestry technologies – particularly improved fallows and biomass transfer – with locally available and reactive phosphate rock – such as the Minjingu of northern Tanzania – is described in this chapter. Leguminous tree fallows of several species can accumulate significant amounts of nitrogen in their leaves in the short duration (from 6 months to 2 years). Incorporating these leaves into the soil before planting can increase crop yields several-fold. Improved fallows can also contribute to the control of weeds (including *Striga hermontheca*) and provide wood for energy and for staking climbing crops. Some of the species also have fodder value that can improve manure quantity and quality. For biomass transfer, use of *Tithonia diversifolia* is the most promising because of its high nutrient content and rapid rates of decomposition. This plant is now being used more widely for high-value crops such as vegetables. To facilitate the scaling up of these fertility options, future research and development needs to address recommended application rates, impacts at both farm and landscape levels, and the method by which high-value trees, crops and livestock can be intensively farmed to provide a natural progression out of poverty.

Background

Land degradation and declining soil fertility are increasingly being viewed as critical problems affecting agricultural productivity and human welfare in tropical Africa. It is estimated that an average of 660 kg of nitrogen (N) ha⁻¹, 75 kg of phosphorus (P) ha⁻¹ and 450 kg of potassium (K) ha⁻¹ have been lost during the last 30 years from around 200 million ha of cultivated land in 37 countries in sub-Saharan Africa (SSA) (Stroorvogel et al. 1993). The estimated value of such losses averages about US\$4 billion per year (Drechsel and Gyiele

1999). This figure is probably higher than the annual official development assistance given to the agricultural sector in Africa during the last three decades.

The underlying socioeconomic causes of nutrient depletion, their consequences and the various strategies for tackling this constraint are fairly well known (Buresh et al. 1997; Smaling 1993). It is important, however, to underscore that the spatial distribution of nutrient depletion in Africa is not uniform at regional or farm scales. Regions that have not been subject to intensive,

continuous cultivation, or which have a widespread history of fertilizer use, do not exhibit this problem (Scoones and Toulmin 1999). Localized differences in farmer wealth ranking, field-use history and the use of organic additions (typically in fields close to the homestead) generally produce 'islands' of high soil fertility (Shepherd and Soule 1998).

Given the acute poverty and limited access to mineral fertilizers, a promising approach is one that integrates organic and inorganic fertilizers. Organic fertilizers include the use of improved fallows of leguminous trees, shrubs, herbaceous legumes and biomass transfer. The improved fallows system is the product of more than 10 years' of agroforestry research and development efforts by the World Agroforestry Centre (ICRAF) and its many partners in SSA. Both research and development dimensions are discussed in this chapter. We do this by drawing particular reference to the Centre's collaborative work in three regions of Africa – East and Central Africa, southern Africa and the Sahel. Declining soil fertility is a major concern faced by smallholder farmers in all these regions (Franzel 1999; Sanchez and Jama 2002).

Improved fallows

The concept and practice

Although neither the idea nor the research on improved fallows is new (Nye and Greenland 1960), critical examination of the practice, and the wide-scale evaluation of suitable species, is relatively recent (Sanchez 1995). Planted fallows of leguminous trees or shrubs can biologically fix considerable amounts of N – for example, between 60–80 kg ha⁻¹ – in above-ground biomass (Gathumbi 2000). The rest of the recycled N in such leguminous trees or

shrubs is accessed from sub-soil N – Oxisols and Oxic Alfisols – which is unavailable to crops (Mekonnen et al. 1997). Under conditions such as those in western Kenya, where the soils possess substantial anion exchange capacity, net N mineralization exceeds N uptake by crops and high rainfall carries nutrients to the sub-soil, resulting in a build-up of sub-soil N that ranges from 70 to 315 kg ha⁻¹ (Hartemink et al. 1996). Nitrogen that accumulates in the above-ground biomass of planted tree fallows is returned to the soil upon clearing; the fallow biomass is incorporated into the soil for subsequent cropping. Additionally, fallows increase the amount of labile fractions of organic soil matter, which supply nutrients to crops following fallows (Barrios et al. 1997). They can also contribute to improving soil structure, build up of soil organic matter and its carbon (C) stocks, thus contributing to C sequestration.

The choice of which species to plant in the fallow period is influenced by both biophysical and socioeconomic conditions. The ideal tree species is typically fast-growing, N-fixing and efficient at nutrient capture and cycling. Examples of promising species include *Crotalaria grahamiana*, *Tephrosia vogelii*, *Cajanus cajan* (pigeonpea) and *Sesbania sesban* (sesbania). Coppicing species can also be used, and *Gliricidia sepium* (gliricidia) and *Calliandra calothyrsus* (calliandra) are becoming increasingly popular with farmers in Kenya, Malawi and Zambia because they are perennial and, unlike the non-coppicing species, there are no costs involved in replanting them once they are cut back.

Agronomic and economic benefits

Several agronomic studies demonstrate that improved fallows of 1–3 seasons (8–21 months) can increase soil fertility and improve yields considerably. For instance,

Kwesiga and Coe (1994) in premier field studies demonstrated that 2- and 3-year sesbania fallows can increase maize yield, compared to unfertilized maize monoculture, for at least three cropping seasons after harvest of the fallows on an N-deficient soil in Zambia. This was confirmed later in multilocational trials in eastern Zambia (Kwesiga et al. 2003). In western Kenya, similar observations have also been made with use of several species and fallow durations (Jama et al. 1998a; Niang et al. 1996a; Rao et al. 1998). Recent trials in the Sahel that were conducted within the sub-humid region of Mali also demonstrate the ability of several species to improve soil fertility and crop yields considerably (Figure 1). These studies have led to the general conclusion that total farm production can be greater with improved fallow–crop rotations than with continuous cropping, even though crop production is skipped for one or more seasons with improved fallows (Sanchez et al. 1997).

In areas such as southern Malawi with low rainfall and sandy soils, gliricidia fallows that coppice when cut back perform better than those of sesbania, which does not coppice well. This has been demonstrated through long-term trials that also show that the highest yields are obtained when improved fallows are used in conjunction with repeated application of the recommended rates of inorganic fertilizers (Figure 2).

In soils that are severely depleted of nutrients, the addition of inorganic fertilizers increases the productivity of improved fallows. In western Kenya, for instance, there is increasing evidence that 1–2 season-long fallows do not overcome N deficiency in highly degraded soils, especially when deficiencies of other nutrients are overcome and when high-yielding crop varieties are used. Fertilizer use is, however, limited by

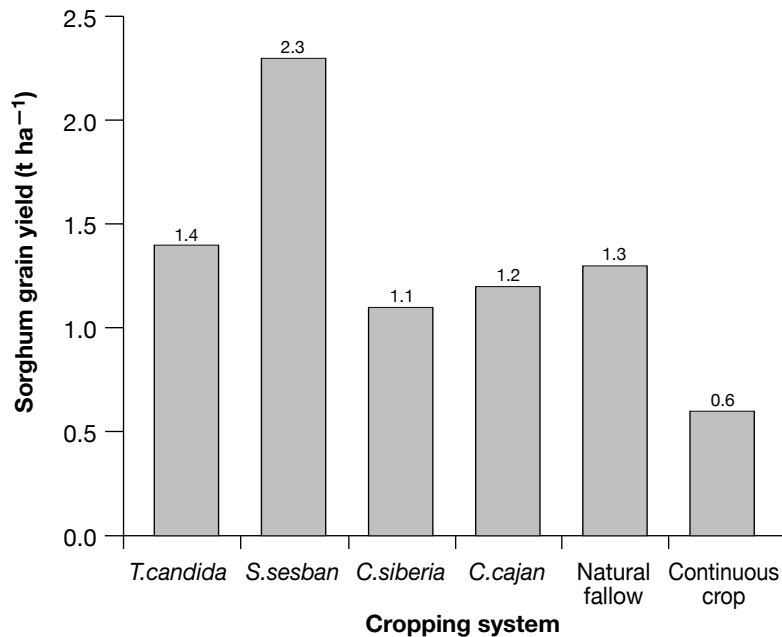


Figure 1. Effect of improved fallows using different species on the grain yield of sorghum at Bamako, Mali.

Source: Niang (unpublished data).

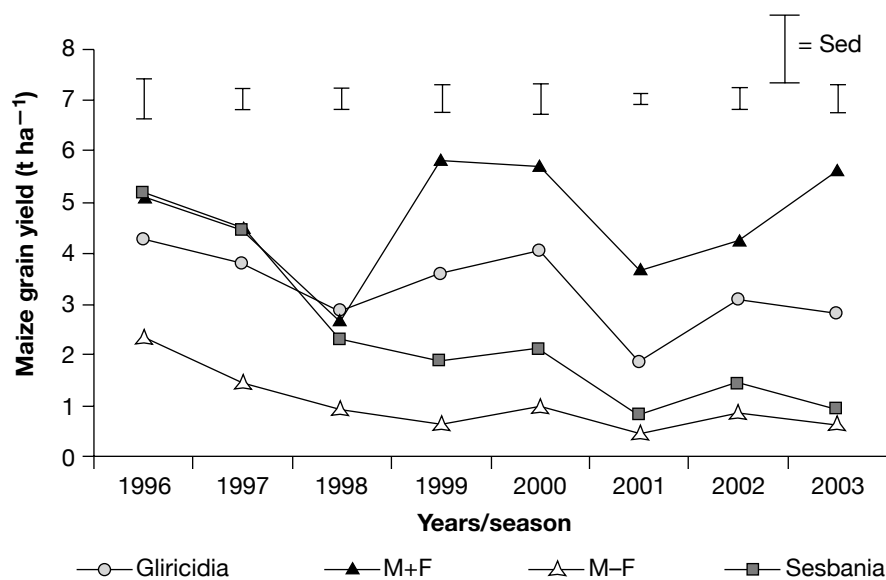


Figure 2. Maize grain yield for eight seasons using *Sesbania sesban* and *Gliricidia sepium* fallows. Sed = Standard error of difference of means. M+F = Maize that was fertilized with 200 kg ha⁻¹ of a compound fertilizer (N = 100 g kg⁻¹, P = 90 g kg⁻¹ and K = 80 g kg⁻¹) at sowing, and 92 g N ha⁻¹ as urea 4 weeks after emergence; M-F is maize not fertilized.

Source: Kwesiga (unpublished data).

its high cost. In SSA, fertilizers cost around 3–4 times the international price largely because of poor roads and the associated high transport costs in many countries. However, fertilizers are needed for the integrated nutrient management approach proposed for replenishing soil fertility in Africa, and hence should be made affordable to farmers.

Economic analysis indicates that improved fallows are generally attractive (Franzel et al. 1999; Swinkels et al. 1997). According to sensitivity studies conducted by Place et al. (2000) in eastern Zambia, which is prone to droughts, this is the case even under drought conditions. In western Kenya, however, economic benefits are marginal. Even though the soils in this region are P-deficient and require application of P-rich fertilizers, that are prohibitively expensive (costing more than US\$500 t⁻¹).

Other benefits

Control of *Striga hermontheica*, a parasitic weed of many cereal crops, is an added benefit of the repeated use of improved fallows (Barrios et al. 1998; Gacheru and Rao 2001). *Striga* causes large yield losses in the Lake Victoria area of the East and Central Africa basin. Although the processes are not well understood, it is suspected that the fallow species excrete substances that cause suicidal early germination of *Striga*.

The provision of fuelwood is another benefit of improved fallows. Depending on the species and fallow duration, considerable amounts of wood can be obtained from improved fallows. For instance, in western Kenya, calliandra, which produces wood with good fuelwood properties, can generate more than 10 t ha⁻¹ of wood from as early as the third year of establishment. This is enough to meet the fuelwood needs of a typical rural household with 6–7 members

for 6–8 months. The wood can also be used to support climbing beans and other climbing crops.

Limitations

Two important factors that need to be considered with short-term improved fallow systems are: how much leaf biomass the fallow species produces and the quantity of nutrients recycled with it. Several factors influence biomass production. In degraded sites (nutrient-depleted and eroded), most fallow species grow poorly and produce little biomass. This is also the case in dry areas and those with Vertisols (heavy clays) that drain poorly during the wet season. Such conditions prevail around the Lake Victoria basin where leaf biomass yields are typically less than 1 t ha⁻¹. This will give less than the 80–100 kg N ha⁻¹ required to produce a 2 t ha⁻¹ maize grain yield (Palm 1995). There are options that can be explored to increase biomass yield without necessarily increasing the fallow period. These include the use of coppicing species, and under-sowing the tree fallow with herbaceous green manure legumes such as mucuna (*Mucuna puriens*) and macroptilium (*Macroptilium atropurpureum*). In P-depleted soils, trees respond to P application and can benefit from having P applied to crops planted within them (Jama et al. 1998b).

The incidence of pests and diseases is another important limitation and there are two aspects to this problem. Firstly, there are pests and diseases that affect the trees themselves and limit their productivity. For example, sesbania is damaged, sometimes severely, by the defoliating beetle *Mesoplatys ochroptera*. *Crotalaria grahamiana*, until now a promising species for improved fallows in western Kenya, is attacked and defoliated severely by lepidopterous *Amphicallia pactolicus* caterpillars. Con-

trolling these pests is vital to ensure that the productivity of species used and promoted for improved fallows is maintained. Secondly, there is need to understand and control the effects of these pests on the crops that succeed the fallows. A case in point are the root-knot nematodes associated with sesbania that also affect beans and tomatoes (Desaeger and Rao 2000).

There is also the potential for some of the species used in fallows to become invasive weeds – although no such occurrence has been reported so far. Prolific seeders like *crotalaria* and *leucaena* species are examples of the types of fallow plants most likely to become problematic. Other species may start to seed prolifically when taken out of their ecological range. Thus control mechanisms, including prevention, early detection and rapid response, need to be developed. This requires cross-regional collaborative efforts.

Biomass (green manure) transfer

Apart from improved fallows, existing hedges on farm borders are another source of organic nutrients for biomass transfer. More than 10 species with potential for this purpose have been screened in western Kenya (Niang et al. 1996b), and the most promising of all is *Tithonia diversifolia* of the family Asteraceae (tithonia). Although it is not a legume, the fresh leaf biomass of tithonia has levels of N as high as those found in many N-fixing legumes. This common shrub is also rich in P and K: the fresh leaves contain 3.5% N, 0.3% P and 3.8% K. The leaf biomass decomposes rapidly with a half-life of about one week especially during the rainy season (Gachengo 1996).

Many field studies report that the application of tithonia biomass results in higher

crop yields than application of inorganic fertilizers, and it has longer residual effects (Gachengo 1996; Jama et al. 2000). Part of the yield benefits associated with tithonia could be due to increased availability of nutrients. Phosphorus release from tithonia fresh-leaf biomass is rapid, and the supply of plant-available P from tithonia can be at least as effective as an equivalent amount of soluble fertilizer. Nziguheba et al. (1998) reported that incorporation of green tithonia biomass equivalent to 5 t dry matter ha⁻¹ to an acid soil in western Kenya increased P in soil microbial biomass and reduced P sorption by soil (Table 1). In this study, the plots were kept free of weeds and not cropped in order to eliminate plant uptake of P as a factor affecting soil P fractions and processes. Increased P in soil microbial biomass 2 weeks after tithonia incorporation presumably indicates enhanced biological cycling and turnover of P in labile pools of soil P. Enhanced microbial biomass P following integration of tithonia with triple superphosphate, and not with sole application of triple superphosphate, supports the hypothesis that tithonia increases soil labile P. Soil microbial P before maize planting has been shown by Buresh and Tian (1997) to be directly correlated to maize yield on a P-deficient soil in western Kenya.

Availability of sufficient quantities of tithonia biomass and the labour required to harvest and transport it to cropped fields are likely to be two major constraints to the wide-scale adoption of this technology by farmers. Recognizing these limitations, most farmers in western Kenya are using tithonia on small parcels of land and on high-value crops such as tomato and kale (*Brassica oleraceae* var *acephala*; ICRAF 1997). They are also experimenting with tithonia in maize–bean (*Phaseolus vulgaris*) intercrops, where it could be more financially attractive than in sole maize because

Table 1. Effects of 15 kg P ha⁻¹ as either green tithonia biomass or triple superphosphate (TSP) on increase in microbial biomass P and decrease in sorbed P at 0.2 mg P L⁻¹ solution.

Weeks after application	Increase in microbial biomass P (mg P kg ⁻¹)			Reduction in sorbed P (mg P kg ⁻¹)		
	Tithonia	TSP	Tithonia + TSP	Tithonia	TSP	Tithonia + TSP
2	4.3 **	1.8	7.8 **	49 **	41 **	30 *
16	1.6	0	3.7 **	27 *	10 *	20

* indicates significance at $P = 0.05$ and ** at $P = 0.01$. All values are relative to a control with no added TSP or tithonia.

Source: Nziguheba et al. (1998)

beans are of higher value than maize. In Zambia, farmers are doing the same in the 'dambos' (wetlands) during the dry season (Kuntashula et al. 2004). In Mali, it is increasingly being used for vegetable farming in urban and peri-urban agriculture. Indeed, economic analyses indicate positive returns from the use of tithonia on high-value vegetables but not for low-priced maize (ICRAF 1997).

Based on feedback from farmers, research on tithonia is now focused on several issues of practical importance: i) identifying ways of increasing its production on-farm by growing it in small niches such as around farm boundaries and in soil conservation structures; ii) integrating it with inorganic fertilizers to reduce the required quantities of each material; iii) using it to complement low-quality organic materials such as crop residues and farmyard manure that are used as fertilizers; iv) identifying the minimum acceptable quantities of tithonia for application to vegetables and cereals; and v) optimizing its use efficiency through timely application and appropriate placement.

Livestock manure

For smallholder farms, farmyard manure is a major source of nutrients. However,

quality is poor and quantities available are often low, especially in densely populated regions like western Kenya where farmers keep few animals (Kihanda and Gichuru 1999). Quality can be improved through better management, including feeding nutrient-rich tree fodder to cattle. Manure from livestock fed with calliandra fodder can be especially high in P, for example, as demonstrated through studies in western Kenya (Jama et al. 1997). Application of this manure at rates typically used by farmers in the area more than doubled maize yields in P-deficient soils, and effects were even greater when it was spot applied (placed in the planting hole) instead of broadcast. However, much more assessment is needed on improvements in tree fodder and manure quality, including a better understanding of their interaction with inorganic fertilizers and how they affect overall household economic conditions.

Need for phosphorus inputs

Phosphorus deficiency is widespread in SSA. This is particularly pronounced in western Kenya where, for instance, more than 80 percent of the farms are severely deficient in P, with less than three parts per million of available P when analysed by the Olsen procedures. As a consequence, crop yields remain low. Under these conditions, P input

is a must if crop yields are to be improved. Although trees can add some P to the soil, this is mostly by recycling what is already there and not through new additions. The exception is biomass transfer. Even then, the amounts that can be added through the biomass of trees are often low.

Options for P inputs are phosphorous fertilizers and phosphate rock (PR), depending on which is cost-effective. There are several PR deposits in Africa that could be of agronomic use (van Straaten 2000), for example the Tilemsi in Mali and the Minjingu in northern Tanzania. The agronomic effectiveness of Minjingu rock phosphate was examined in long-term (5-year) field trials in western Kenya. Two different strategies of phosphorus application were compared – a large one-time application (250 kg P ha⁻¹) that is expected to provide a strong residual effect for at least 5 years, and annual applications of 50 kg P ha⁻¹ applied to the rainy-season maize crop. Over the 5 years of the study, cumulative maize yield was significantly increased by P fertilization, and the cumulative grain yields were almost the same, regardless of which P source or application method was employed (Figure 3). This clearly demonstrates the utility of Minjingu and other reactive PRs in soil fertility management approaches in SSA.

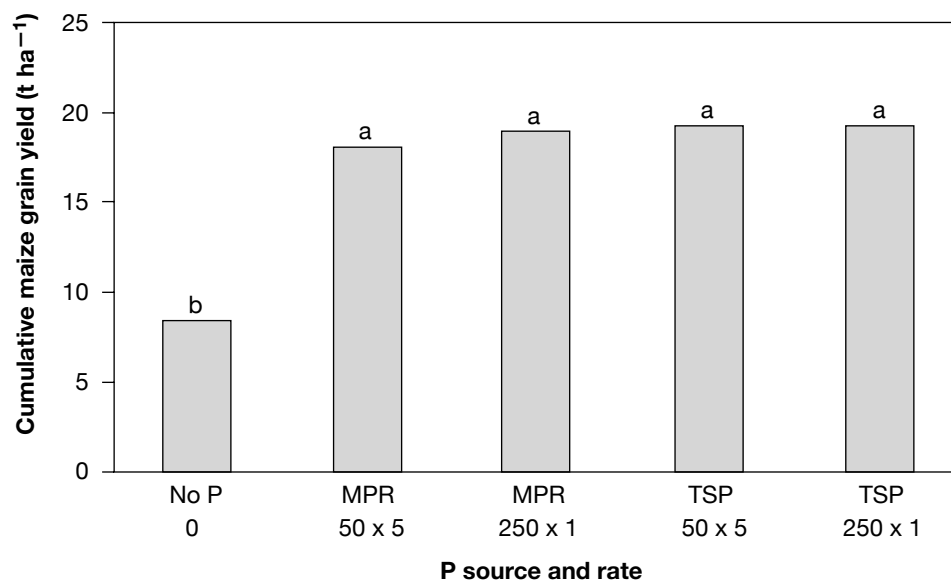


Figure 3. Cumulative maize yields over 5 years (five crops, 'long rains' cropping season only) in western Kenya. Nitrogen (N) and potassium (K) were supplied. Minjingu phosphate rock (MPR) or triple superphosphate (TSP) fertilizer were added, either once at 250 kg P ha⁻¹, or at a rate of 50 kg ha⁻¹ each year for 5 years. There was also a control plot with no added P.

Source: Sanchez and Jama (2002).

Conclusion and way forward

Improved fallows of leguminous species and biomass transfer are both promising agroforestry techniques that can contribute to integrated soil fertility management practices in smallholder farms. They can also provide other benefits such as control of pests and diseases, and in the case of improve fallows, provide fuelwood that is in short supply in many rural settings. To enhance the impact of these technologies, there are a few remaining challenges that need to be addressed. These include:

1. Determining the recommendation domains (geographic areas and household types where the technologies are feasible and profitable), something that is necessary given the large biophysical and socio-economic variability that exists within and between farms.
2. Developing strategies to

- make fertilizers affordable, especially those containing P that organic produce cannot supply adequately.
3. Promoting widely synergistic technologies such as biological soil and water conservation measures.
4. Promoting the keeping of livestock to produce manure, and developing best management practices for its use.
5. Developing strategies for wide-scale dissemination of the options available, particularly those that deal with overcoming the prevailing constraints of germplasm supply and information on their use.
6. Assessing ecological benefits of fallow plant species while mitigating potential problems of them becoming invasive weeds.
7. Determining ways in which high-value trees, crops and livestock can be more intensively farmed, providing a natural progression out of poverty.

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