This chapter presents a case study of an improved fallow using trees to replenish soil fertility – a natural resource management (NRM) technology, the development of which was led by the World Agroforestry Centre (formerly the International Centre for Research in Agroforestry, ICRAF). The work synthesizes different studies that were carried out in Zambia to describe the technology, provide historical information on its development, discuss patterns of its adoption, evaluate its impact to improve the lives of resource-poor smallholder farmers and identify the positive effects of the technology on the environment.

Research Leading to the Technological Innovation

Constraints addressed by improved tree fallows in Zambia

One of the greatest biophysical constraints to increasing agricultural productivity in Africa is the low fertility of the soils (Sanchez, 1999) as soils in sub-Saharan Africa are being depleted at annual rates of 22 kg/ha for nitrogen, 2.5 kg/ha for phosphorus and 15 kg/ha for potassium (Smaling et al., 1997). The need to improve soil fertility management in the continent has become a very important issue in the development policy agenda (Scoones and Toulmin, 1999) because of the strong linkage between soil fertility and food insecurity. To mitigate declining soil fertility, farmers in many areas had traditionally left their land under fallow for significant lengths of time. However, given the relative fixed quantity of available cultivable land, as the population increased fallow periods became shorter and were unable to restore soil fertility. Mineral fertilizers could
be used to substitute fallow periods, but due to limited access to credit and high market prices of fertilizer, most African farmers purchase and use limited amounts of mineral fertilizer.

This assessment took place in the Eastern Province of Zambia where the main soil types are loamy-sand or sand Alfisols, interspersed with clay and loam Luvisols. The agricultural economy is mainly dominated by maize, which covers up to 70% of the planted area.

After the country’s political independence in 1964, the agricultural strategy in Zambia as in many other southern African countries focused on increasing maize production through broad interventions in input and output markets. These included generous subsidies on fertilizer, easy access to agricultural credit to purchase fertilizers, and a range of government-supported institutions and fertilizer depots located in rural areas to supply farm inputs and assure the purchase of maize output from farmers. Following the collapse of these support systems in the late 1980s, the ratio of prices of fertilizers and the major crop (maize) increased fourfold leading to a 70% decline in fertilizer use (Howard and Mungoma, 1996). While the government has continued to be involved in distributing fertilizer to smallholders and encouraged private traders to do the same, only 20% of smallholder farmers use fertilizer in Zambia (Govereh et al., 2002). In response to the challenges enumerated above, the World Agroforestry Centre initiated research on sustainable soil fertility management options that are suitable for resource-poor farmers to replenish soil fertility within a short time. Improved tree fallows allow farmers to produce nutrients through land and labour rather than cash, which they lack.

**Description of improved tree fallows and identification of technology intervention**

Improved tree fallows were not practised by farmers in Zambia until after the arrival of ICRAF in southern Africa.¹ The development of improved tree fallows in southern Africa began with diagnostic and design surveys (Ngugi, 1988) and ethno-botanical surveys in the late 1980s which revealed a breakdown of traditional strategies, such as long fallow periods, in sustaining food production. Nitrogen was identified as a key missing nutrient in the soils. At the beginning, ICRAF contemplated and carried out initial research on alley cropping and biomass transfer systems, but these technologies were discontinued because they were too labour-intensive and did not perform well technically (Ong, 1994). The quest for a new approach to respond to soil fertility problems led to research on improved tree fallows. Based on nutrient recycling princi-

¹There was very little practice of improved fallows in the region. The maize–pigeon pea intercropping system had been practised by some farming communities in Malawi for years prior to ICRAF’s arrival in the region, however.
ples, the technology involves planting fast-growing tree species that are (usually) nitrogen-fixing and produce easily decomposable biomass, to provide nitrogen for the subsequent food crop, increase soil organic matter and improve soil physical conditions (Kwesiga and Coe, 1994).

It must be noted that the improved fallow trees do not provide all the major nutrients, as they are capable of fixing only nitrogen, which is the most limiting. The two other macronutrients which are required by crops, phosphorus and potassium, can be recycled by the tree fallows, but the two nutrients must be sourced externally if they are depleted from the soil. Technical details on improved tree fallows have been described elsewhere (Kwesiga and Coe, 1994; Kwesiga et al., 1999; Mafongoya et al., 2003, 2005). In addition to improving soil fertility, tree fallows intervene in several other constraints presented in Table 8.1. As seen from the table, the impact of improved fallows is multidimensional and some of these intervene beyond individual farmers who adopted the technology. The details of some of the main impacts are discussed in section four.

**ICRAF’s contribution to the development and dissemination of the technology**

ICRAF’s contributions to the technology can be summarized into two main phases. The first was the research phase spanning from 1988 to around 1996, initially focusing on scientist-managed research and then expanding into farmer-managed research. Since the technology was new to the region, research was required on the methods to establish tree fallows, screening suitable species and provenances, identifying the most appropriate rotation periods and configurations of trees and crops, cutting, and incorporation of tree biomass. In the mid-1990s, ICRAF coordinated a multi-country trial to test the biophysical limits of promising fallow systems and species. Although some of this research continued, the emphasis of ICRAF’s efforts shifted after 1996 following the conclusion that the improved tree fallow system was beneficial both biologically and financially. The success of the improved tree fallow crucially depends on the suitability to local conditions that was realized by the participation of farmers in technology development and adaptation. As a result, a constructivist approach was adopted in the development of the technology, i.e. farmers assessed the technology and made several modifications and adaptations based on their experiences. The continuous modification and adaptation of the technology were actively encouraged by researchers (Kwesiga et al., 2005). The second phase consisted of efforts to improve the effectiveness and reach of seed and nursery systems, on institutional mechanisms for managing potential conflicts between tree growing and free grazing, and how to manage second-generation issues (e.g. pests) that may be associated with wider adoption of improved fallow species.

Further efforts to modify the technology and generate diverse options
of improved tree fallows included experiments conducted to evaluate the interaction between chemical fertilizers and improved tree fallows. Results show that there is a synergistic effect between low doses of mineral fertilizer and tree fallows, producing a higher yield increase especially in later years following a fallow (Kwesiga and Coe, 1994; Ayuk and Mafongoya, 2002). In addition to these efforts, ICRAF facilitated development through: (i) writing extension materials for distribution; (ii) hosting visiting farmers and others at the station or nearby farms to view the performance of the fallows; (iii) provision of training to farmers, extension and project staff on the management of improved fallows; (iv) training to entrepreneurs on seed collection and nursery development; (v) establishment of a network within which organizations involved in improved

Table 8.1. Private and social costs and benefits of improved tree fallows. (After Ajayi and Matakala, 2005.)

<table>
<thead>
<tr>
<th>Private Costs</th>
<th>Social Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Loss of land</td>
<td>• Incidence of <em>Mesoplats</em> beetle pest (restricted to specific species only)</td>
</tr>
<tr>
<td>• Additional labour</td>
<td>• Reduction of free grazing area during dry season</td>
</tr>
<tr>
<td>• Tree seeds and nursery establishment</td>
<td>• Risk of uncontrolled fire outbreak</td>
</tr>
<tr>
<td>• Pest control (some tree fallow species only)</td>
<td></td>
</tr>
<tr>
<td>• Working equipments</td>
<td></td>
</tr>
<tr>
<td>• Risk of uncontrolled fire outbreak</td>
<td></td>
</tr>
<tr>
<td>• Tree seeds and nursery establishment</td>
<td>• Yield increase of subsequent crops</td>
</tr>
<tr>
<td>• Pest control (some tree fallow species only)</td>
<td>• Carbon sequestration</td>
</tr>
<tr>
<td>• Working equipments</td>
<td>• Suppression of weeds</td>
</tr>
<tr>
<td>• Risk of uncontrolled fire outbreak</td>
<td>• Opportunity for farm diversification (e.g. compatible with fish farming and growing of high-value vegetables)</td>
</tr>
<tr>
<td>• Tree seeds and nursery establishment</td>
<td>• Improved soil infiltration and reduced runoff</td>
</tr>
<tr>
<td>• Pest control (some tree fallow species only)</td>
<td>• Enhanced biodiversity</td>
</tr>
<tr>
<td>• Working equipments</td>
<td>• Use of tree leaves</td>
</tr>
<tr>
<td>• Risk of uncontrolled fire outbreak</td>
<td>• Serves as wind breaks</td>
</tr>
<tr>
<td>• Tree seeds and nursery establishment</td>
<td>• Suppresses the growth of weeds</td>
</tr>
<tr>
<td>• Pest control (some tree fallow species only)</td>
<td>• More fuel wood available to reduce deforestation</td>
</tr>
<tr>
<td>• Working equipments</td>
<td></td>
</tr>
<tr>
<td>• Risk of uncontrolled fire outbreak</td>
<td></td>
</tr>
</tbody>
</table>
Adoption of Improved Tree Fallows

Level of adoption

Improved tree fallows are a new technology, and dissemination to farmers on a larger scale took place only recently. Consequently, few farmers have implemented more than one cycle to date. Agroforestry adoption decisions are more complicated than those for annual crops and modern agricultural development packages based on chemical inputs (Scherr and Müller, 1991; Mercer, 2004) due to the multiple components and the multiple years through which testing, modification and eventual ‘adoption’ takes place. As a result, the literature has a less precise definition of ‘adoption’ of agroforestry. Farmers who have planted improved fallow trees for a second cycle (on a reasonable size of land) are most appropriately labelled as ‘adopters’ while those still in the first cycle of tree fallows could be described as ‘users’ as it is not known whether they will continue to grow the trees. Some socio-economic research took place before there were any farmers who had planted at least two cycles, while other studies on which this work is based have lumped together first-time planters and those who have repeatedly planted the fallow trees. To avoid confusion, we have referred to farmers who have established one or more plots of improved fallow trees simply as ‘planters’. The scaling up of the technology to different parts of Zambia was coordinated by the Adaptive Research and Development Network (ARDN) – comprising ICRAF, government research and extension services, farmer organizations and non-governmental organizations (NGOs). The ARDN framework enhances collaboration and exchange of germplasm and information among the different organizations. From less than a hundred planters in the early 1990s, the number of farmers who have planted improved fallow trees has been steadily increasing each year, and especially from 2000 onwards, to tens of thousands of farmers (see Fig. 8.2 below). The data are obtained from regular assessments conducted by agroforestry partners in Zambia through the ARDN framework, with some spot checking by ICRAF. Further information on the number of farmers planting improved tree fallows and the economic impact is presented in section 4.

Policy and institutional factors affecting the planting of improved fallow trees

The degree to which improved tree fallows are used by farmers is influenced by several factors (Place and DeWees, 1999; Ajayi et al., 2003). Such factors include access to information and management of the technology, incentives for farmer investment, active promotion of the tech-

fallows could exchange information; and (vi) collaboration with development organizations to help them raise funds for development activities.
nology by research partners in ARDN, government extension services and several major (NGO) projects. Also, mechanisms for the introduction of germplasm and technical support for managing tree fallows are vitally important. Another important factor in the adoption decision is the increased cost of fertilizer due to currency devaluation and the withdrawal of subsidies and government-sponsored credit programmes. This situation prevailed throughout the 1990s and certainly increased farmers’ interests in seeking alternatives to the purchase of mineral fertilizer (Peterson et al., 1999). Lastly, several local institutions have implications for the adoption of improved tree fallows. In particular, bushfires and free grazing present threats to the spread of tree fallows but, through the enactment of local by-laws, local leaders have found ways to integrate the fallows into local resource management systems and to protect farmers’ investments in them (Ajayi and Kwesiga, 2003). A study of land tenure institutions found that almost all land is acquired by inheritance or allocation by the chief and is held in perpetuity by households, with little fear of losing land (Place, 1995) (the special case of land ownership by women is discussed in section 3.3). Thus there were no serious tenure impediments to tree planting by households in Zambia. The absence of tenure impediments in Zambia is also partly due to the small size of land area (average of 0.20 ha only) grown to improved fallows. With a higher level of adoption and or an increase in the area devoted to the technology, the influence of land tenure may become more important than it is presently, especially in locations where land is more limiting.

**Household and farm variables affecting the planting of improved tree fallows**

Many studies have been conducted over the past few years to better understand which types of households are using or expanding area under improved fallows. Many of the studies used descriptive statistics while two applied multivariate econometrics. The results from selected adoption studies on this topic have been synthesized in Ajayi et al. (2003). The summary of the synthesis is presented in Table 8.2 and discussed below.

- **Farmer training and awareness.** Given that improved tree fallows are relatively more knowledge-intensive, access to information about the management of the technology is one of the important driving factors for its adoption. Farmers who plant improved tree species have been formally trained by organizations that support agroforestry or have benefited from informal knowledge-sharing by fellow farmers who have adopted earlier and through farmer exchange visits.

- **Wealth status.** Wealthier farmers were more likely to test the technology. This is most probably because their wealth confers on them a lower risk aversion as it a measure of insurance against innovation risks. However, the wealthy were less likely to continue with improved fallows than other social groups (Kiel et al., 2005). The fact that the
Table 8.2. Summary of factors affecting farmers’ decisions to plant improved tree fallows in eastern Zambia. (From Ajayi et al., 2003.)

<table>
<thead>
<tr>
<th>Study</th>
<th>Wealth</th>
<th>Age</th>
<th>Sex</th>
<th>Education</th>
<th>Labour/</th>
<th>Uncultivated</th>
<th>Use of</th>
<th>Off-farm</th>
<th>Oxen</th>
<th>Village exposure to improved fallows</th>
</tr>
</thead>
<tbody>
<tr>
<td>(no. of households in sample)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>household size</td>
<td>Farm size</td>
<td>land</td>
<td>fertilizer</td>
<td>income</td>
<td>ownership</td>
</tr>
<tr>
<td>Factors affecting decision to plant improved tree fallows for the first time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Franzel et al. (1999) [157]</td>
<td>N</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phiri et al. (2004) [218]</td>
<td>+</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Kuntashula et al. (2002) [218]</td>
<td>+</td>
<td>N</td>
<td>N</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td>N</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Ajayi et al. (2001) [305]</td>
<td>N</td>
<td></td>
<td>+, N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peterson et al. (1999) [320]</td>
<td>+</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Factors affecting decision to continue to plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keil et al. (2005) [100]; Tobit analysis]</td>
<td>+/-</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Place et al. (2002) [101]; Logit analysis]</td>
<td>+</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
</tbody>
</table>

+, enhances planting of fallow trees; –, decreases planting of fallow trees; N, no effect on tree planting; +/-, can increase or decrease tree planting; blank means the variable was not included in the specific study.
poor had no means with which to purchase fertilizer was a contributing factor. Whether this pattern continues now that fertilizer prices are partly subsidized has not yet been studied.

- **Gender.** Several studies (Franzel *et al.*, 1999; Gladwin *et al.*, 2002; Phiri *et al.*, 2004; Keil *et al.*, 2005; Ajayi *et al.*, 2006a, 2006b) found no significant differences between the proportions of female- and male-headed households planting improved tree fallows. However, women may be disadvantaged in benefiting from improved fallows because of the traditional power structure between men and women and the difference in decision making and ability to control benefits from productive resources, as sales activities involving cash transfers are dominated by men. The existing power structure, which has both economic and social consequences, may also affect the area that a woman can allocate to the technology.

- **Size of land owned.** Availability of land and size of landholding are positively associated with the establishment of improved tree fallow plots. This is because farmers who have larger uncultivated land could afford more easily to keep some part of their fields under fallow (Place *et al.*, 2002). This limitation led to the introduction of a permanent tree intercrop system, which does not require that cropping phases be interrupted.

### Economic Impact of Improved Tree Fallows

**Inventory of costs and benefits**

*Benefits from improved tree fallows*

The main benefit from improved tree fallows is increased yields of crops that follow the fallows. The very first trials were conducted from 1988 to 1993 and many others have been conducted on different soils and with different management treatments (for a synthesis see Kwesiga *et al.*, 2003). One example of the results of maize yield obtained during the three seasons after fallow is given in Table 8.3. In summary, the trials show that maize yields from improved tree fallows consistently reached two or more times the yields from farmers’ practice of continuous maize production without application of fertilizer. In addition to increasing crop yields, improved tree fallows provide other benefits to farmers in terms of reduced risk from drought, other by-products such as insecticides made from *Tephrosia vogelii* leaves, and increased availability of fuel wood. A study carried out in Zambia shows that 10, 15 and 21 t of fuel wood per hectare were harvested after 1, 2 and 3 years of *Sesbania sesban* fallow, respectively (Kwesiga and Coe, 1994). Financial analysis showed that improved tree fallow systems were profitable and had positive net benefits (Place *et al.*, 2002; Franzel, 2004; Ajayi *et al.*, 2006a, 2006b).

The main environmental benefits are improved soil physical properties, such as better infiltration and aggregate soil stability, which reduce
soil erosion and enhance the ability of the soil to store water (see section 5.0). *Sesbania* fallows were also found to greatly reduce the occurrence of *Striga* weeds, which generally thrive under conditions of low soil fertility (Kwesiga *et al.*, 1999). Tree fallows may also help to reduce the pressure on woodlands by providing an alternative source for fuel wood. However, rigorous field studies are needed to test this hypothesized linkage between planting trees on farms and reduced deforestation.

The positive productivity effects on smallholders and their yields will have the effect of shifting the supply curve for maize (see Fig. 8.1). The shape of the supply curve has not been empirically estimated, but there is likely to be an inelastic portion reflecting the fact that maize is the main staple food and much of it is grown for subsistence purposes. The equilibrium under the farmers’ practice where mineral fertilizer is not used is point A. The adoption of improved fallows will shift the supply curve and move the equilibrium from A to C. Such a shift is predicted to bring about a fall in the price of maize, yielding consumer surplus. However, there is no evidence to suggest this has happened in eastern Zambia. That may be because demand is highly elastic: there have been almost annual food distribution programmes (distribution of ‘relief maize’ to food-deficit households) somewhere in the region.2 Thus, from the supply shift, we have increased private benefits accruing to farmers (mainly for self-consumption), but we do not have an indication of consumer surplus resulting from lower prices.

The contribution of improved tree fallows to environmental services such as carbon sequestration and others (listed in Table 8.1) may one day increase the demand for the maize production system that includes a carbon-storing improved fallow system. In such a scenario, society would articulate its demand through environmental service payments. This

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**Table 8.3.** Maize grain yield after two-year *Sesbania sesban* fallow with and without recommended fertilizer in eastern Zambia during 1998–2000 (*n*=48). (From Kwesiga *et al.*, 2003.)

<table>
<thead>
<tr>
<th>Type of land-use system</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Sesbania</em> fallow + no fertilizer</td>
<td>3.6</td>
<td>2.0</td>
<td>1.6</td>
</tr>
<tr>
<td><em>Sesbania</em> fallow + 50% recommended fertilizer⁴</td>
<td>3.6</td>
<td>4.4</td>
<td>2.7</td>
</tr>
<tr>
<td><em>Sesbania</em> fallow + 25% recommended fertilizer⁴</td>
<td>3.6</td>
<td>3.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Continuous maize + 100% recommended fertilizer⁴</td>
<td>4.0</td>
<td>4.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Continuous maize + no fertilizer</td>
<td>1.0</td>
<td>1.2</td>
<td>0.4</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.7</td>
<td>0.6</td>
<td>1.1</td>
</tr>
</tbody>
</table>

⁴Recommended fertilizer rate is 112 kg N, 20 kg P and 16 kg K per ha.

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2On the other hand, there is evidence that cabbages grown under improved fallow systems fetch a higher market price as they are perceived as being sweeter than the normal marketed cabbage.
would result in a shift in the equilibrium from C to D and boost the price received by farmers. This has not yet occurred partly because food security attracts much more emphasis than environmental quality at present.

**Costs of improved tree fallows**

The main costs of improved fallows to farmers are the cost of taking land out of cultivation and the cost of labour for planting and managing the trees. The opportunity cost of land is relatively low because maize yields without inputs are low and land scarcity is not acute. Labour use over the entire fallow rotation is not much higher than that under continuous maize production, but farmers still perceive labour investments in the establishment and cutting of fallows, as well as the nursery labour time, as additional burden. In a 5-year cycle, the total labour inputs for a continuously cultivated maize field (without fertilizer) is 462 person-day equivalents per hectare, 532 person-days in maize production (with fertilizer), 434 person-days for *Gliricidia* fallows,\(^3\) 521 person-days for

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\(^3\)Some of the *Gliricidia sepium* fields monitored during the study were burnt by bushfires. The farmers spent little to no labour inputs to weed the plots. As a result, the overall labour inputs and the maize yields recorded in such fields were low.
Sesbania fallows and 493 person-days for Tephrosia fallows (see details on labour inputs in section 4.2).

In addition to these investment costs, the development and promotion of improved tree fallows resulted in some unexpected problems resulting in additional costs. These costs include the increased incidence of pests such as Mesoplatys beetles and nematodes. Thus far, damage from these pests has occurred only on the fallow trees and not on other plants. Other social and institutional problems are due to reduced grazing areas and lower tolerance to bushfires as farmers protect their fallow fields. In some cases, these incidents caused unintended social problems resulting from a conflict of economic interests among different sections of the community (details of an in-depth study on this issue have been documented in Ajayi and Kwesiga, 2003). Collaborative efforts by traditional chiefs, village headmen, farmers and R&D organizations, and policy dialogues among the different stakeholders, have resulted in various approaches to successfully deal with the problem of livestock browsing and fire.

Profitability of improved tree fallows

The technical effectiveness of improved fallow species to replenish soil fertility has been well established. Questions have however been asked regarding the labour input requirements for tree fallow management. Given the HIV/AIDS pandemic and its potential impact on the quantity (and quality) of household labour supply, labour input implications of agricultural technologies are essential to consider, especially in the relatively land-abundant areas of eastern Zambia where labour is a much more limiting resource compared with land. The profitability of improved tree fallows compared with other land-use and production systems is also addressed. Using primary data collected from 193 farmers’ maize fields that were monitored on a weekly basis throughout the 2002/03 agricultural season, the profitability and returns to the following five different land-use systems were evaluated: (i) S. sesban fallow; (ii) G. sepium fallow; (iii) T. vogelii fallow; (iv) continuous cropping with fertilizer; and (v) continuous cropping without fertilizer. For improved tree fallows, farmers were selected so as to represent different phases of the 5-year cycle, i.e. 2 years of fallow establishment and 3 years of cropping. The analysis factored in opportunity costs of taking land out of production by valuing all five seasons of maize production from the non-fallow options and comparing them to just three seasons of maize production in the fallow systems. Also, the increased maize under the fallow options occurs starting in the third year and is therefore appropriately discounted. A rather high discount rate of 30% is used (based on banks’ base lending rate in Zambia at the time of the study), which makes the discounted returns from the fallow systems all the more conservative.

The results show that improved fallow options are more profitable
than current farmers’ practices but less profitable than full fertilizer application (Table 8.4). One of the reasons is the government subsidy of chemical fertilizer that is as high as 50% of the market price in Zambia. Using non-subsidized fertilizer prices, the fertilizer option becomes much less profitable (reduced by 30%) and its net present value (NPV) is very close to that of the fallow options (NPV of US$349 compared with US$309). The higher profitability recorded for the mineral fertilizer option was achieved through a higher investment cost and hence its benefit:cost ratio (BCR) is lower compared with the fallow systems. Farmers obtain US$2.65 benefit per dollar invested in fertilizer fields compared with BCR ranging between 2.77 and 3.13 for the different fallow options. In terms of returns to labour, the differences between fully fertilized maize and the improved tree fallow systems are small, even if fertilizer is subsidized. The return to a labour day is US$3.20 for fertilized maize and US$2.50, US$2.40 and US$1.90 for the three fallow species tested. Return to labour for the unfertilized maize system was US$1.10, while the daily agricultural wage is around US$0.50. Thus, while the recommended dose of fertilizer option is the highest performer at subsidized rates, the tree fallow options are only slightly less economically attractive when non-subsidized price is used. In rural areas where road infrastructure is poor and transport costs of fertilizer are high, the profitability of tree fallow options will be competitive with the fertilizer option.

**Table 8.4.** Profitability\(^a\) of maize production per hectare using tree fallows and subsidized fertilizer options over a 5-year cycle in Zambia (\(n=193\)). (From Ajayi *et al*., 2006a, 2006b.)

<table>
<thead>
<tr>
<th>Description of land-use system</th>
<th>NPV (ZMK)</th>
<th>NPV (US$)</th>
<th>BCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous maize for five years + no fertilizer</td>
<td>584,755</td>
<td>130</td>
<td>2.01</td>
</tr>
<tr>
<td>Continuous maize for five years + fertilizer (subsidized at 50%)</td>
<td>2,243,341</td>
<td>499</td>
<td>2.65</td>
</tr>
<tr>
<td>Continuous maize for five years + fertilizer (non-subsidized price)</td>
<td>1,570,500</td>
<td>349</td>
<td>1.77</td>
</tr>
<tr>
<td>Two years of <em>Gliricidia</em> fallow followed by 3 years of crop</td>
<td>1,211,416</td>
<td>269</td>
<td>2.91</td>
</tr>
<tr>
<td>Two years of <em>Sesbania</em> fallow followed by 3 years of crop</td>
<td>1,390,535</td>
<td>309</td>
<td>3.13</td>
</tr>
<tr>
<td>Two years of <em>Tephrosia</em> fallow followed by 3 years of crop</td>
<td>1,048,901</td>
<td>233</td>
<td>2.77</td>
</tr>
</tbody>
</table>

NPV, net present value; ZMK, Zambian Kwacha; BCR, benefit:cost ratio.
\(^a\)Figures are based on input and output prices and an annual discount rate of 30%.

Different price and other policy scenarios affect the financial attractiveness and potential adoption of maize production systems even when agronomic relationships between inputs and outputs remain the same. For example, if the subsidy on fertilizer is removed in the analysis, the
difference in the financial profitability between the mineral fertilizer option and improved tree fallows is greatly reduced as shown in the third row of Table 8.4.

Performance of improved tree fallow systems under drought

Franzel and Scherr (2002) identified three major ways in which improved tree fallows can help mitigate risk for small-scale farmers compared with the use of mineral fertilizers or production without external inputs. First, farmers who plant tree fallows would lose less investment (usually only labour) than those who invested in mineral fertilizer bought by cash or credit. Second, the benefits of improved fallows are spread over multiple years whereas those of mineral fertilizer usually take place in a single year. Third, tree fallows improve the soil structure and organic matter content of the soil, thus enhancing the soil’s ability to retain moisture during drought years.

The findings from our data analysis support these benefits of improved tree fallows. In addition, simulations were made using data from a long-term researcher-managed trial between 1988 and 1993 during which there was a severe drought in 1992. In the researcher-managed trial, a one- or two-season fallow always performed better than the no-input continuous maize system if a drought were to occur in any single year. The 1-year and 2-year fallows performed surprisingly well even if two drought years were to occur. The only case where a 2-year fallow was found to be worse than the no-input continuous cropping case is if drought occurred in consecutive seasons immediately after the fallow phase. The most critical season in the 5-year fallow cycle is the first cropping year just after the fallow has been cut.

Estimate of total benefits to farmers and internal rate of return to research investment in eastern Zambia

Estimated number of farmers planting improved fallows

The number of farmers who have planted improved fallow trees is shown in Fig. 8.2. From less than a hundred planters in the early 1990s, the number of farmers who have planted improved fallow trees has been steadily increasing each year, especially from 2000 onwards. The data are obtained from regular assessments conducted by agroforestry partners in Zambia through the ARDN network, with some spot checking by ICRAF. During the annual planning and review forum of the ARDN, each member institution presents an overview of their activities for the previous season including the number of farmers they work with who have established improved tree fallow plots, the challenges they faced and the plan for the new agricultural season. The forum provides opportunities for other member institutions to ask questions regarding their peers’ activities.
Information on the number of farmers who have planted improved fallow trees is collated and aggregated for all the members of ARDN.

The increase in the number of planters from the late 1990s is due to increased intensity of activities by ARDN members to disseminate the technology to different farming communities. The commencement of operations by several agricultural development organizations that were interested in promoting NRM technologies to farmers in eastern Zambia provided added impetus to enhance the uptake of the technology. Such organizations include the Zambia Integrated Agroforestry Project, the Eastern Province Development Women Association, the US Agency for International Development-supported Accelerating Impact of Agroforestry Technologies on Smallholder Farmer Livelihoods Project, the Soil Conservation and Agroforestry Extension Project supported by the Sindh Irrigation and Drainage Authority, and new interests in agroforestry technology by international NGOs such as Plan International (an international NGO focusing on child nutrition and welfare) and the Service Centre for Development Cooperation (a service centre for Finnish NGOs interested in development work and global issues). In partnership with ICRAF, these institutions reached a nucleus of farmers through direct training and provision of initial seed to farmers. These contributed to ‘kick start’ the spread of the technology mainly through catalysing a farmer-to-farmer exchange process.

In addition, the period also coincided with a time when ICRAF’s operational strategy placed an increased emphasis on the development phase (‘scaling up’) of the technology in Zambia and the southern Africa region. There is also an emerging interest by private sector organizations including tobacco companies and individual entrepreneurs in Zambia in the provision of inputs for improved tree fallows. Another factor for the
increase in number of planters is that tobacco companies train and support their out-grower scheme farmers to use branches of the improved trees to make sheds for curing tobacco to avoid further deforestation in addition to improving the soil. Individual entrepreneurs establish large hectares of seed orchards to meet rising demand for the seeds of improved tree fallows, especially *G. sepium*. In addition to an increase in the number of farmers planting improved tree fallows, the average size of improved tree fallow plots has also increased. From an average field size of 0.07 ha in 1997, the average size of improved tree fallow fields increased to 0.20 ha in 2003\(^4\) (Ajayi *et al*., 2006a, 2006b).

The number of planters fell in 2003 compared with 2002 mainly because of the phasing out of the Zambia Integrated Agroforestry Project, one of the leading agroforestry training and dissemination organizations in eastern Zambia and an important member of the ARDN. Other partners within the ARDN have however continued their normal activities on agroforestry dissemination.

**Total benefits to farmers**

Using the numbers of farmers planting improved tree fallows, it is possible to integrate the information on average size of fallow, average maize yield response as shown above and average wood value (which is about 20% of the value of the increased maize crop) to produce an overall estimate of the economic benefits to farmers using the system. This information is most accurate for Eastern Province in Zambia where the bulk of the analyses have been done. In 2004, the planters of fallows in 2000, 2001 and 2002 will reap some benefits. We estimated the total benefits to be about US$1.32 million accruing to approximately 67,000 planters. In the 2003/04 season, it has been estimated that a cumulative figure of 77,500 farmers had planted a fallow. Thus by 2005/06, the economic impacts may increase to nearly US$2 million.

One may also value the impact of improved tree fallows in terms of food security – by determining the number of days of additional food they provide to a household. To do this, we take the mean incremental increase in yields from the results presented and smooth these out into annualized returns. Such a system provides between 425 and 850 extra kg of maize per hectare per year (depending on species and performance). However, the average fallow plot is 0.20 ha (for the year 2002/03) and would generate on average between 85 and 170 kg additional maize per year. Daily maize consumption per adult in Zambia is about 1.5 kg per capita. Thus, the systems generate between 57 and 114 extra person-days of maize consumption.\(^5\)

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\(^4\)The field size varies widely, ranging from 0.01 ha to 0.78 ha.

\(^5\)Another method of valuation of the system is through the substitute value of nitrogen. Nitrogen fixation by improved tree fallows is estimated at 150 kg N/ha per year. The nitrogen level may translate into amounts as high as US$6 million per year for the whole of southern Africa at the estimated adoption level of 180,000 planters and assuming the same average plot size of 0.20 ha.
**Internal rate of return to research and development**

The calculation of the internal rate of return (IRR) was challenging because of the difficulty in separating costs that are unique to the Project and in monitoring benefits of the Project that accrue to farmers in other locations. Thus both costs and benefits may be underestimated. On the benefit side, ICRAF has been collecting data on the number of farmers planting improved fallows in eastern Zambia. However, the spillover effects of adoption of the technology by farmers elsewhere in the region are not as reliably documented, although it is known to be high. For the baseline IRR, we have included only Zambian farmers (within and outside Eastern Province), thus using conservative assumptions of the generated benefits. We have assumed that the number of plantings of fallows each year remains the same as it was in 2002/03 period, i.e. 30,000. Eventually, this declines around 2014, taking note of the rural population in Zambia and because we assume those wishing to adopt the fallows will have done so over the next 10 years. As benefits, we have included the impact on crop yields and production of firewood, assuming constant prices for both. We have not yet factored in any benefits for carbon sequestration because it is unlikely that Kyoto type of carbon projects for smallholder communities will be viable in the near future. On the cost side, it was not possible to obtain clear figures for soil fertility R&D for Zambia alone, so we had to make assumptions on the costs incurred. Some costs such as vehicles were depreciated (straight line method) over time. It was not possible to separate out ICRAF’s investments between research and development facilitation. We thus assumed that all pre-1995 investments were in research and that the share invested in development facilitation increased steadily after that. Over the period 1989–2004, the average annual cost in R&D for soil fertility ranged between US$230,000 and US$350,000. Costs were assumed to increase slightly over time due to inflation, but diminish around 2010. Development costs of two major projects in the late 1990s and early 2000s were included and a figure of around US$70,000 was assumed to persist over time for these two development projects. Because of the long period of research expenditure before benefits were observed on farm, we calculated an IRR for three different time horizons – 20, 25 and 30 years – to reflect the long-term nature of research, each beginning in 1988 (the year of first research costs). The results show that the benefits begin to be larger than R&D costs only from 2001. Cumulative net benefits (non-discounted) become positive only in 2005. The IRR calculated for the 1988–2008 period is very low at 3.2%. However, if the time period is expanded to 25 years, the IRR increases to 15.2% and finally for a 30-year horizon it is 20.8%.
Ecosystem Impacts

Effect on soil physical and biological properties

The ability of trees and biomass from trees to maintain or improve soil physical properties has been well documented (Hullugalle and Kang, 1990). Tree fallows can improve soil physical properties also due to the additional quantities of litter fall, root biomass, root activity, biological activities, and roots leaving macro-pores in the soil following their decomposition (Rao et al., 1998). In addition to improved soil fertility, soil aggregation is higher in tree fallow fields; this enhances water infiltration and water-holding capacity and reduces water runoff and soil erosion compared with maize fields that were continuously cultivated (Phiri et al., 2003). Improved tree fallows enhance soil biodiversity by increasing soil invertebrates, which perform important ecosystem functions that can affect plant growth. A long-term study (Sileshi and Mafongoya, 2006) concluded that the improved tree legume fallows not only increase maize yields, but they also have a positive impact on biodiversity and enhance the ecosystem services rendered by soil invertebrates.

Effect on soil nutrient balances

Organic inputs of tree legumes supply enough nitrogen for crops but these organic inputs do not supply enough phosphorus and potassium to support crop yields over time. The question for sustainability is: Do improved fallows reduce soil stocks of phosphorus and potassium over time, even while maintaining a positive nitrogen balance? To answer this question, an 8-year nutrient balance trial was conducted. For all the improved fallow species, there was a positive nitrogen balance in the two years of cropping after the fallow (Table 8.5). Fertilized maize had the highest nitrogen balance due to the annual application of 112 kg N/ha in each year. Unfertilized maize had lower balances even though maize grain and stubble yields were very low over time. The tree-based fallows had a positive nitrogen balance due to biological nitrogen fixation and capture of nitrogen from depth but the nitrogen balance became very small in the second year of cropping. Most of the land-use systems showed a positive phosphorus balance due to low uptake of phosphorus in maize grain yield and stubble (relative to nitrogen), and increased mycorrhizal populations in the soil. Most land-use systems showed a negative balance for potassium. The highest negative potassium balance was obtained in fully fertilized maize fields due to higher maize and stubble yields which extract a lot of potassium.
Effect on deforestation of miombo woodlands

Farmers who establish improved tree fallow fields satisfy some of their household fuel and other wood requirements from their own fields. This may reduce the exploitation of wood from the communally owned miombo forests and thus reduce deforestation. A study was carried out in eastern Zambia to determine whether this was observed or not (Govere, 2002). Of the total amount of firewood consumed (3.1 t/household), the improved fallows contributed 11% on average. The value to individual farmers varied according to local supply conditions for fuel wood. For the two study sites in Chipata North and South, non-adopters of improved fallow trees collected more fuel wood from the miombo woodlands. However, although the fallows in Chipata South are contributing firewood that ultimately reduces the amount of fuel energy collected from the miombo woodlands, this is not the case in the other district where collection amounts are nearly the same despite the additional wood from the fallows. Thus there are some positive signs that the fallows may be able to reduce the pressure on natural woodlands, but this is not guaranteed; further monitoring will be necessary. We have not yet studied whether the adoption of tree fallows has reduced the demand for clearing of new land, nor whether the dramatic reduction in fertilizer use has increased clearing. Also, we are not aware of such a study.

Effects on carbon sequestration

Agroforestry land-use systems sequester amounts of soil carbon (Montagnini and Nair, 2004). The amount of carbon stored in the biomass and in the soil was measured in long-term trials involving improved fallows and other land uses in Zambia. The results, showing different potentials of various fallow types and rotational woodlots (a rotational woodlot is a longer-term fallow of about 5 years, in which the wood product is a major product sought by farmers) to sequester carbon in the above- and below-ground biomass, are presented in Table 8.6. Although much of the carbon stored in the biomass would be lost if the wood was...
burned for energy, section 5.3 indicates that in at least some cases the fallow wood replaces that of naturally growing trees, resulting in a net storage of carbon on the landscape. Soil carbon under improved tree fallow systems varied according to species and location, with highest amounts being 2.5 to 3.6 t/ha.

Table 8.6. Carbon sequestration in tree fallows and woodlot fields (t/ha).

<table>
<thead>
<tr>
<th></th>
<th>Rotational falls (1–2 seasons)</th>
<th>Permanent intercrops (2–3 seasons)</th>
<th>Woodlots (5 seasons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C fixation in biomass (t/ha)</td>
<td>1.9–7.0</td>
<td>3.0–8.9</td>
<td>32.6–73.9</td>
</tr>
<tr>
<td>Intake of C (t/ha)</td>
<td>1.6–3.2</td>
<td>1.4–4.2</td>
<td>3.5–8.0</td>
</tr>
<tr>
<td>Root C input (t/ha)</td>
<td>0.7–2.5</td>
<td>1.0–3.6</td>
<td>17.6</td>
</tr>
</tbody>
</table>

Current prices of carbon for land managers are between US$3 and US$8 per tonne, so the potential for improved tree fallows to increase the incomes of farmers is limited at this point in time (even if the full carbon stored of 12.7 t/ha over 2 years were to be compensated, for a fallow of 0.2 ha this amounts to about US$7.50 per year).

Summary and Conclusions

This case study focuses on the development, adoption and impact of improved tree fallows on smallholder farmers in Zambia. It shows that in order to make a sustainable impact, agricultural technology innovations should be targeted to the real needs of farmers in relevant locations, with active encouragement of user modification and adaptation of the technology. The adoption of the technology by farmers is not a direct relationship based exclusively on technological characteristics, but is influenced by several broad groups of factors including institutional and policy factors (especially fertilizer subsidies), spatial and geographical factors and household-specific variables. Wealth and gender do not appear to be highly related to the use of rotational tree fallows, but land size was found to be an important determinant. About 77,500 farmers were practising improved tree fallows in Zambia in 2003.

Improved tree fallows generate large increases in subsequent maize yields. A 0.20 ha fallow system can generate between 57 and 143 extra days of maize consumption. The fallow system is much more profitable than the traditional practice of continuous maize cultivation without fertilizer application. However, the tree fallow system is less profitable than fully fertilized plots, especially when fertilizer is subsidized. Still, the tree fallow system is quite competitive most notably in terms of returns to labour. The case study identified different types of costs and benefits of improved tree fallows for the individual adopters and a wide range of
environmental services that accrue to society at large. Some of these have been quantified but a detailed study is required to assign a quantitative value for others. The economic impacts of improved fallow trees in Zambia alone are nearly US$2 million by 2005 with cumulative net benefits (above research costs) reaching US$20 million by 2010. This is a very conservative estimate that underestimates the returns to research since the improved tree fallow technology has been disseminated in many other countries in the region.

In the absence of massive government investment in roads, credit and fertilizer subsidies, there will remain a large proportion of the rural population who will not be able to afford mineral fertilizer. For the many maize farmers who will not benefit from these types of public investments, improved tree fallows provide a productive and profitable option for increasing maize production. Because the system performs well in terms of returns to labour, it is expected to remain a demanded technology even during increased growth of agriculture and the development of better agricultural labour markets. Despite the impacts that tree fallows can have, the ability to alleviate poverty through production of maize or any other cereal on relatively small farms is limited. Thus, the technology is likely to be transitory for some farmers and more lasting for others; in either case, it can provide a needed boost to income and can potentially help to finance a shift into more profitable undertakings. There are very few other available technologies which could provide such a boost for the very poor in rural southern Africa while at the same time not requiring cash investments.

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