The potential of improved fallows on smallholder maize productivity and food security in Malawi

I.M. HAYES[1], W.T. BUNDERSON[2], S. MINAE[3], F. BODNAR[2] AND D. NGUGI[3]

Key words: biophysical and socio-economic constraints, farmer adaptations, undersown fallows, agroforestry options, dynamic linear programming model

[1] Rockefeller Foundation, Malawi

[2] Malawi Agroforestry Extension Project

[3] International Centre for Research in Agroforestry, Malawi

Abstract

Using preliminary biomass and maize yield results of improved fallows in Malawi, a linear programming model was constructed to evaluate potential adoption of this technology, and its impact on food security at the household and national levels over a twenty year time period. The model demonstrates the use of a flexible integrated approach for evaluating new technology developments in relation to existing practices and other improved alternatives. Gaps and limitations that demand further research are also identified, focusing on technology testing and adaptation with farmers, before promoting broadbased extension efforts. Model results indicate that the standard 2-year fallow has little potential for adoption due to land constraints in Malawi. Farmer adaptations of this practice show more promise. One involves undersowing tree legumes with maize in the first season to reduce the fallow period. Household food security results generated indicate that small farmers will not be able meet minimum nutritional requirements even following adoption without access to off-farm and/or food-for-work opportunities. Additionally, food requirements at the national level cannot be met without reductions in population growth or promoting commercial maize production by the estate sector.

Introduction

The macro situation

Malawi's high and rapidly growing population is eroding the productivity of agriculture and natural resources [Bunderson and Hayes, 1995]. With shrinking land and capital resources, practices that preserved the integrity of the natural resource base are dying out. Marginal areas are being brought under cultivation, and fallowing is almost non-existent. Continuous cropping is now the norm with few inputs or options to diversify. Land degradation in Malawi has reached alarming proportions. Soil erosion currently averages 20 - 30 tons ha^{-1} per annum [World Bank, 1992], with rates more than 50 tons ha^{-1} in some areas. Total forest cover declined by an appalling 41% between 1972 and 1990, averaging a loss of 2.3% annually [MFNR, 1993]. The drop in real income limits opportunities to reverse this situation. By 2015, demands for food and other resources will double as the population grows to 20 million. In their struggle to survive, farmers are unable to make the critical trade-off between sustained resource use and immediate short-term needs.

The maize story

During the 1960s and 70s, Malawi maintained self-sufficiency in food, primarily from smallholder production of maize, the country's staple food. As the population increased, food security became a growing concern. Efforts to raise smallholder maize productivity relied heavily on the government's strategy to promote hybrid maize and inorganic fertilizer. Although successful in terms of an expansion in sales of fertilizer to smallholders, and the expanded area under hybrid maize[1] (Table 1), fertiliser use in the smallholder was still low. Less than 30% of smallholder farmers used fertiliser in the 1987/88 season (Malawi Government, 1993), although this had risen to about 35% by 1990/91 (Conroy, 1993). The result has been stagnant maize yields during the 1980's and 1990's (Table 1), even under the prevailing favorable price, credit and subsidy conditions. With the on-farm results of the MOALD/UNDP/FAO Fertilizer Program, Blackie and Conroy (1993) concluded that smallholders could attain yields of 4000 kg/ha with refined recommendations for seed and fertilizer. This prospect now seems remote with the escalating costs of inputs following the devaluation of the Kwacha and removal of fertilizer subsidies in 1994.

The upshot of this situation is that few farmers currently produce enough maize to meet household food needs [Blackie and Conroy, 1993]. At the national level, Malawi has failed to meet the nutritional needs of its population over the last decade[2] (Table 2), with the exception of the good rainfall season of 1992/93 when free hybrid maize seed and fertilizer was given to smallholders to offset the effects of several drought years.

One of the few factors having a positive impact on soil fertility is the surge in burley tobacco cultivation by smallholders[3] from recent liberalization efforts. With unprecedented cash and credit opportunities, smallholder burley growers are purchasing fertilizers, even in the face of increasing prices. Residual fertilizer effects on burley plots benefit subsequent crops of maize, which commonly follow tobacco. This spin-off effect may partially explain the improved yields of maize after the 1993/94 season, but many smallholders cannot grow sufficient burley tobacco to rotate with maize.

Agroforestry alternatives to promote smallholder maize productivity

With one of the highest population densities and rates of growth on the continent [Conroy, 1995], Malawi needs practical alternatives to improve soil fertility and maize productivity in the smallholder sector. The inadequacy of the hybrid maize-fertilizer approach demonstrates the urgency to identify low-cost organic means of restoring soil fertility. Failure to tackle this opportunity has ramifications on food security and the environment that become more serious each season.

Agroforestry is gaining support as a prime organic alternative to improve soil fertility and crop yields in Malawi. This derives from the greater potential of trees relative to herbaceous plants to restore fertility. Technology development and testing include short and long-term practices to address problems of soil fertility, erosion, runoff, and wood shortages. Key institutions comprise the Department of Agriculture Research (DAR) in the Ministry of Agriculture and Livestock Development (MOALD), Bunda College of Agriculture, the Forestry Research Institute of Malawi (FRIM) and the International Centre for Research in Agroforestry (ICRAF).

Technical and financial support have come from the United States Agency for International Development (USAID), the Overseas Development Agency (ODA) and the Rockefeller Foundation. Two donor-funded projects dominate efforts to test, adapt and extend agroforestry and soil conservation practices at the farm level: USAID’s Malawi Agroforestry Extension Project (MAFEP) and the European Union’s (EU) Poverty Alleviation Program Pilot Project Agroforestry (PAPPPA). Both projects fall under the Land Resources and Conservation Branch of the MOALD, and work closely with the departments of research and extension. MAFEP is also providing training, germplasm and technical support to the growing number of Non-Governmental Organizations (NGOs) who are interested in promoting agroforestry at the farm community level. ICRAF plans to participate in these efforts in the near future.

This paper discusses the potential of improved fallows relative to other organic and inorganic options to improve soil fertility and maize yields in Malawi’s smallholder sector. The first section focuses on the biophysical characteristics of improved fallows, which is followed by an evaluation of the socio-economic conditions affecting adoption.

Biophysical characteristics of improved fallows

Improved fallows aim to restore soil fertility in a short time span with fast-growing, soil-enhancing plants that produce high quantities of biomass. At the same time, the vegetative cover protects the soil from erosion and weed growth. Certain fallow plants can also reduce the incidence of pests, such as *Striga*. Cumulative fertility effects can ensue with each rotation cycle. Improved fallows have relatively low labour costs, and with no companion crop, are simple to manage. Other significant benefits include wood production, while prolific seed production increases self-sufficiency in germplasm to meet growing demands.

ICRAF's trials on improved fallows have produced impressive yield responses from maize in Eastern Zambia [Kwesiga et al., 1994; Kwesiga et al., 1995]. Similarities in the environment suggest their potential in Malawi’s mid altitude plains Although improved fallows might be regarded as inappropriate for Malawi due to land constraints, recent land-use surveys indicate more fallow or idle land under customary tenure than originally thought (Hayes, 1996a; K. Berger, pers. comm., 1996). Much of this land is either exhausted from over-cultivation, or households are unable to cultivate all their land due to labour and/or seed constraints. Improved fallows offer unique opportunities to restore the integrity of smallholder households by improving the productivity of degraded or under-utilised farmland.

Information presented below highlights the biophysical characteristics of 2-year fallows in Malawi. Recent on-farm adaptations suggest modifications in design to improve compatibility with Malawi's smallholder farmers.

Biophysical Limits Trial of 2-Year Improved Fallows

This trial falls under a regional initiative by AFRENA to assess the biophysical limits of 2-year fallows in southern Africa. ICRAF is the implementing agency in Malawi with collaboration from

Chitedze Research Station and MAFEP. The species under study are *Sesbania sesban* and *Tephrosia vogelii*, which are fast growing, but short-lived nitrogen-fixing shrubs. Control plots include grass/weed fallows, and continuous maize with and without fertilizer. Trial sites were selected in different ecologies in the 1993/94 season and the 1994/95 season (Figure 1). All sites have unreplicated plots of each treatment 20 x 20 m in size.

Biomass and maize results to date are shown in Tables 4 and 5 respectively. Note that maize data are absent for fallow plots established in 1994/95 since these are now in the crop phase. However, crop estimates are given from 4 farms at Mzimba in Table 6. Overall results show that 2-year tree fallows of *Sesbania* and *Tephrosia* double maize yields over the control without fertilizer (from 1.3 to 2.5 t/ha). Non-woody biomass was similar for the two species and the herbaceous fallow, but wood yields from *Sesbania* were substantial higher. A major concern is the tremendous variation between sites from huge differences in soil fertility and tree performance. This indicates need to test the practice with farmers on a larger scale, and to select a wider range of species.

Limitations of 2-Year Improved Fallows

The impressive results on improved fallows in neighbouring Zambia are not directly transferable to Malawi where farmers face more severe resource constraints and a lower soil fertility base. Improved fallow research in Malawi is relatively new, and work has only just moved on-farm. The narrow choice of species is a major concern. We have already witnessed many problems with *Sesbania sesban,* including high costs of establishment from seedlings, difficulties with direct sowing, defoliation by beetles, nematode attack, and poor performance under low fertility and pH conditions. One important problem is that both *Sesbania* and *Tephrosia* are prone to root knot nematodes, which could lead to serious pest problems for tobacco and other susceptible crops if grown on the same land. This risk demands diligent research to assess the potential threat from these tree species since tobacco is Malawi's primary cash crop, and its cultivation is expanding rapidly among smallholders.

A greater diversity of species is needed for adaptability and tolerance to different environments, pests and diseases. A wider selection of species will also generate a greater range of secondary benefits. For example, an extract from an infusion of *Tephrosia* leaves in water is being used to effectively control aphids on beans and cowpeas (Allison, pers. comm., 1997).

Undersown Fallows

Problems of land scarcity preclude extended fallows by many smallholders, particularly in the Southern Region of Malawi. To improve compatibility with local farm conditions, adaptations of the standard 2-year fallow are under evaluation. These involve a 4-year rotation of hybrid maize and fast-growing shrubs such as *Cajanus cajan, Sesbania* spp*.* or *Tephrosia vogelii* (Figure 2). In year one, the shrub is undersown at or shortly after planting maize. In year two, cultivation is abandoned, allowing the tree fallow to mature. At the onset of the 3rd season, the trees are cut down at ground level, leaving the root and leaf biomass to decompose in situ. Woody branches may be removed for firewood or other uses. Cropping is resumed during year 3 and 4 under conditions of improved fertility. Beginning in year 5, the rotation is repeated. With each cycle, crop yields should improve from the cumulative effects on soil fertility. This adaptation has the advantage of a shorter fallow period, while maintaining high levels of biomass production. Although cropland is lost for 1 in 4 years, gains in crop productivity, wood and seed harvests should compensate for this loss. Moreover, the farmer is free to determine how much land to undersow.

On-station and on-farm trials by the Malawi Agroforestry Commodity Team across a wide range of agro-ecologies indicate little or no competition with maize from intercropping *Tephrosia vogelii* and *Sesbania* species during the first year [Saka et al., 1995]. In these trials, *Tephrosia* was easiest to establish and showed the best growth. *S. macrantha* had to be replanted several times. *S. sesban*, which was planted from seedlings, was badly attacked by insects.

On-Farm Trials to Evaluate the Method, Time and Cost of Undersowing Shrubs

In 1995/96, several institutions and individuals began undersowing trials with *Tephrosia vogelii* in different agro-ecologies using different methods and times of establishment. The aim is to produce a high amount of quality biomass to improve soil fertility with low land and labor costs. These efforts included about 50 on-farm trials by MAFEP in low, medium and high altitude areas (Bunderson and Bodnar, unpubl., 1997); 2 on-farm trials on Zomba plateau (Carr, pers. comm., 1996); and observation plots by ICRAF at Makoka (Maghembe, 1997), and by PAPPPA in Lilongwe (Allison, pers. comm., 1997).

Carr, ICRAF and PAPPPA all established *Tephrosia* by broadcasting at second weeding. Carr and ICRAF used seed rates of 275 kg/ha while PAPPPA used a seed rate of 68 kg/ha.. MAFEP used lower seed rates to reduce costs, and farmers were free to determine the method and time of establishment. MAFEP also evaluated the time of planting on biomass yields of *Cajanus cajan* from several on-farm plots at medium and high altitudes. In September 1996, MAFEP made a preliminary assessment of these efforts to document farmer attitudes about these practices, and to evaluate the time and method of undersowing on biomass production and seed costs. Maize responses and farmer adaptations will be monitored during the 1996/97 cropping season. Results to date on biomass and seed costs are summarized in Tables 7 and 8.

These findings together with farmer assessments reveal the following:

- Farmers found little or no competitive effect on maize in the first season from undersowing shrubs at or soon after planting.
- Farmers consider the technology easy to understand and manage.
- Farmers prefer species that can be direct sown to reduce labor and establishment costs.
- Farmers become discouraged with species that are readily damaged by beetles or other pests.
- Regardless of the establishment method, late planting reduces biomass production so that effects on subsequent crops will likely be low.
- Broadcasting seed at first or second weeding requires low inputs of labor, but effective germination and growth are poor. High seed rates may offset this, but seed costs are high and there is much waste of seed. This was corroborated by farmers, most of whom considered broadcasting to be wasteful of seed, and hence opted to direct sow in lines. These concerns make broadcasting prohibitive for seed that is expensive and short in supply.
- Farmers had no problems direct sowing *Tephrosia* in lines between maize stations as done with crops such as pigeon peas. Planting in this way is practical and cost effective. For example, the seed requirements for *Tephrosia* are less than 1 kg for 1/10 ha at a seed cost of K5.
- Farmers found weeding relatively easy with direct sowing in lines since the plants are in clearly defined stations unlike broadcasting where plants become intermingled with weeds.
- Overall, biomass levels achieved under farmer conditions in one season were judged to be insufficient to improve yields on subsequent crops. This trend was more pronounced with late undersowing, especially at medium and high altitudes.

- Farmers have the option to retain trees for a second season as fallows to improve crop yields in the following season from expectations of increased biomass. Many farmers elected to choose this option due to the low biomass levels after the first season.

Exposure to this technology has generated high farmer demand for this practice. Over 3400 farmers have undersown plots of *Tephrosia vogelii* from seed collections organized by MAFEP and the PAPPPA project. During the 1996/97 season, these two projects have also implemented 200 on-farm trials of this and other agroforestry and soil conservation practices across Malawi. Since seed availability is a major constraint, undersowing efforts are concentrating on *Cajanus cajan* (pigeon peas) and *Tephrosia vogelii.*

In summary, although good progress is being made with this technology at the farm level, more research is needed to identify a wider range of species and their management, focusing work on-farm to ensure relevance to real farm conditions. In this regard, on station and on-farm research has already begun by scientists based at Chitedze Agricultural Research Station looking at species other than *Sesbania* and *Tephrosia*, including *cajanus*, *crotalaria* and *mucuna*.

Using these preliminary results on improved fallows, an economic model was constructed to evaluate relevant socio-economic constraints of adopting this technology by different smallholder households under a range of alternative options.

Socio-economic boundary conditions of improved fallows

For the purposes of examining the primary socio-economic boundary conditions pertaining to improved fallows in Malawi, a flexible integrated economic model was constructed to determine the potential impact of this new technology, in relation to alternative agroforestry and other technologies, on the food security situation, both at the national and household level. The model is based on an assumed progression from the current state of productivity in the smallholder sector to an improved state over a twenty year time horizon. The latter state has been generated by running a profit-maximizing[4] dynamic[5] linear programming (LP) model for three different farm sizes. The LP model results are then linked to a spreadsheet model set up to generate food security estimations over the next twenty years. Several scenarios are considered to evaluate the impact of different options open to policy makers in order to ameliorate the food insecurity in Malawi.

Landholding size, resource base, labor availability and household food security were the primary constraints evaluated in relation to improved fallow uptake by smallholder farmers in Malawi. Other socio-economic concerns including land tenure, livestock issues and management skills are also briefly discussed.

Landholding size

The most important socio-economic issue concerning the uptake of improved fallows by smallholder farmers in Malawi is that of landholding size given that the standard version of this technology requires that land be left uncropped for a certain period. Malawi has a very high population density averaging 110 people km^{-2}, ranging from 44, 113 and 162 people km^{-2} in the northern, central and southern regions respectively [Bunderson and Hayes, 1995]. This translates into severe land pressure in the smallholder sector with 56% of all smallholders in Malawi cultivating less than one hectare of land, 31% having 1 to 2 hectares, and the remaining 13% more than 2 hectares in 1987/88. Within these categories, average holding sizes were 0.55 ha, 1.40 ha, and 2.91 ha respectively, with an average of 1.11 ha respectively [Malawi Government, 1993]. In light of this concern, the model included a less land-extensive variant of the 2-year fallow option, described above as undersown fallow. The

LP formulation was run for the three average landholding size categories mentioned above within which smallholder farmers have the option of selecting one, all or none of these technologies.

Smallholder resource base

Following structural changes in the smallholder credit system, most farmers have to depend on their own resources to finance external inputs. However, Conroy (1995) suggests that the resource base of the smallholder sector[6] is not adequate, given the high cost of fertilizer in Malawi, to ensure that additional inputs purchased on a cash basis will be sufficient to redress the overall decline in soil fertility and therefore permit a general increase in maize productivity. This suggests a possible role for improved fallow options that can help boost fertility without recourse to expensive inputs. In order to take account of this, cash and credit constraints have been explicitly included in the economic model using survey data from the 1995/96 season.

Labor requirements

Labor requirements are always a factor that farmers take into consideration when assessing whether or not to adopt a new technology [Nair, 1990]. This is of particular relevance to new agroforestry practices in light of the recent concern over the labor requirements of alley cropping [Carter, 1995]. This issue was taken into consideration in the model with the inclusion of a labor constraint which related farmer labor availability to the labor requirements for each crop enterprise. Labor availability has been estimated for the different landholding sizes from 1995/96 survey data[7]. Estimated labor requirements for the two improved fallow options are detailed in Tables 9 and 10. In order to reduce labour requirements, *Tephrosia vogelii* was selected as the species for the improved fallow options as it is possible to direct sow.

Food security

The issue of food security is considered at both the national and household level. The former is defined as the ability of the country to provide adequate levels of food supply to meet demand throughout the year, both through domestic production and imports, whilst the latter is defined as the ability of households to produce, purchase or acquire an adequate amount of food to meet biological requirements (Malawi Government, 1993). In order to evaluate this concern, a minimum food constraint based on average farm family size was included in the model. Although maize is the staple food crop, sorghum and cassava have also been incorporated in the food security constraint due to their drought resistant characteristics (Malawi Government, 1990). In addition, farmers have the option of buying maize and a food-for-work option to meet their minimum nutrition requirements.

Land and tree tenure

Land and tree tenure are additional important socio-economic issues that merit examination in relation to agroforestry adoption [Nair, 1990; Carter, 1995]. With regard to land tenure, results from a 1995/96 adoption survey indicate that the survey farmers feel they have long-term ownership of their fields which their children (principally male) will inherit (Hayes, 1996a). As such security of land tenure does not appear to be a major concern. In addition, the issue of land tenure relates particularly to long-term practices [Nair, 1990], and is less relevant for short-term technologies such as improved fallows. With regard to tree tenure, the survey indicated that farmers feel stronger ownership over planted trees than naturally growing ones. A number of farmers also indicated stronger ownership over planted exotic trees (e.g. *Senna spectabilis*) than with planted indigenous trees (e.g. *Acacia polyacantha*). This has implications for promoting exotic versus indigenous agroforestry species. For example farmer should plant indigenous trees in a regular arrangement so that they are not mistaken for naturally growing trees.

Livestock control

The issue of livestock damage to both tree and crop components systems has been raised previously [MacDicken and Vergara, 1990]. The issue of tree damage is particularly relevant in Malawi due the general practice of unsupervised herding during the dry season, especially prevalent in the central region (Hayes, 1996a). Livestock cause damage through grazing of palatable species and trampling, with goats being the prime culprits. One solution to limit damage is to concentrate on non-palatable species. This is one of the advantages of *Tephrosia vogelii* which has been used in the model. A change is also needed in current livestock grazing practices, though this is beyond the remit of this paper.

Technology management skills

One of the key findings of on-farm alley cropping research has been that a certain level of management skill is required in order for the smallholder farmer to be sure of benefiting from agroforestry adoption. Results from a farmer maize yield survey in the 1995/96 season indicate the timing of pruning vigorous alley hedges is crucial in that incorrect pruning can significantly reduce potential maize yields (Hayes, 1996b). A major advantage of improved fallows in this regard is that the management input required to achieve good results is much lower than for alley cropping. *Tephrosia vogelii* is relatively easy to establish by direct planting and even if undersown at the same time as maize is planted will not result in any shading or competition problems.

The dynamic linear programming model

Farm enterprises and other activities

In order to simplify the analysis, farm enterprise choices available to the smallholder farmer were limited to the most important crops. The current situation assumes smallholder farmers produce several crops that include unfertilized local maize, recycled unfertilized hybrid maize, hybrid maize with a low fertilizer rate, sorghum, cassava, burley and Northern Division Dark-Fired (NDDF) tobacco, cotton, groundnuts soyabeans and beans. Under the improved situation, farmers also have a choice of:

- fully fertilized hybrid maize
- unfertilized hybrid maize
- a hybrid maize 2-year fallow rotation with *Tephrosia vogelii*
- a hybrid maize undersown fallow rotation with *Tephrosia vogelii*
- a fertilized and unfertilized hybrid maize 1-year undersowing option with *Sesbania sesban*
- a fertilized and unfertilized long-term hybrid maize alley cropping option with *Senna spectabilis*
- a short-term hybrid maize alley cropping option with *Tephrosia vogelii*
- dispersed systematic interplanting of msangu (*Faidherbia albida*) with fertilized and unfertilized hybrid maize, (see details below)
- and, a local maize and msangu option.

One-year undersowing/Relay cropping

One of the agroforestry options used in the model is the relay cropping system with *Sesbania sesban* as described by Maghembe [ICRAF, 1994], but using bare-root seedlings. The term undersowing is used in this paper since the trees are planted at or soon after maize planting. This system involves a one year cycle with the trees planted at or soon after maize planting. Its advantage over the standard two-year fallow is that no land is taken out of crop production, but the lower biomass production will limit the maize response. Modifications alluded to earlier for the undersown fallow indicate the need to plant early to optimize biomass production and to reduce establishment costs by direct sowing.

Alley cropping

Alley cropping has been maligned recently as unsuitable for improving soil fertility under smallholder conditions in subhumid areas [Ong, 1994, Carter, 1995]. Major criticisms include long lag times for visible results at the farm level, high establishment and management costs, and intimations that research has over-estimated yields from improperly designed experiments. These are legitimate concerns which need to be addressed before dismissing the technology outright.

In Malawi, adaptations include careful assessment of species for different ecologies, reduced establishment costs by direct sowing, and identifying critical management practices to minimize shading and competition. On-farm results under MAFEP show significant yield improvements with proper hedge management after 3-5 years. Success depends on correct choice of species for the targeted ecology, and timely hedge pruning. Failure to faithfully follow these practices will retard potential benefits, and could depress yields (Hayes, 1996b[8]); [Bunderson et al., 1995]. It is assumed in the model that these management requirements and their recognition by farmers limit adoption to the better or more committed farmers, on a limited area of their landholding.

Dispersed systematic interplanting

This system involves interplanting msangu trees at an initial spacing of 10 x 10 m, with later thinning to 20 trees per ha as the trees mature. Farmers in Malawi and elsewhere in Africa have continuously cultivated crops beneath this tree with significant improvements in yields [Saka et al., 1994; Selenje et al., 1990; Felker, 1978]; (Hayes, 1996b). This is a long-term option which is in high demand by Malawi farmers.

LP formulation

Gross margins were constructed for crop enterprises for the 1995/96 season with all costs, including labour, and revenues discounted at 25% to take into account the time value of money over the twenty year horizon. Alternative activities to crop production are also included such as doing ganyu (casual) labor[9], employing ganyu labor, food-for-work (FFW) and maize buying. This data was then fed into a dynamic LP formulation to determine the mix crop of enterprises that smallholder farmers with different landholding sizes would choose to maximize their profits over the next twenty years. The dynamic LP results with the stated assumptions for the three different landholding categories are discussed in the following section.

The food security model

The food security model is based on an assumed progression from the current state of productivity in the smallholder sector to an improved state over a twenty year time horizon with the latter state generated by the LP model for three different farm sizes. With regard to farmer adoption rates of the improved situation, small, medium and large farmers are assumed to adopt at annual rates of 2, 3 and 4%, respectively which translates to about 50,000 farmers a year. Although these rates may seem high, even faster adoption rates have been achieved for hybrid maize seed over the ten year period commencing 1980/81 [Heisey and Smale, 1995].

Nonetheless, the flexibility of the model permits changes in the assumed rates of adoption if so required.

Model scenarios

The model is run under several scenarios which have been constructed to evaluate the effects of a number of different policy options on both national and household food security. A total of six scenarios were evaluated as follows:

> **Scenario 1: Continuation of current situation** - this scenario assumes that there is no change in current maize productivity over the next twenty years. The status quo is maintained.
>
> **Scenario 2: Proposed agroforestry strategy only** - in this scenario smallholders are offered the choice of the aforementioned agroforestry technologies in addition to their current cropping practices, and furthermore a 1:5 maize:legume rotation is introduced to promote better crop rotation.
>
> **Scenario 3: Proposed agroforestry strategy and raised maize producer price** - in addition to the agroforestry options, this third scenario assumes a substantial increase in the maize producer price in order to promote commercial maize production by the estate sector.
>
> **Scenario 4: Proposed agroforestry strategy and increased capital availability** - in this scenario, in addition to the agroforestry options, increased credit and cash/fertilizer are made available to small and medium farmers. Both categories receive K350 increased credit and K400 cash/fertilizer to cover the costs of about 2 bags of fertilizer and 5 kg hybrid maize seed, enough for about 0.2 ha of fertilized hybrid maize.
>
> **Scenario 5: Proposed agroforestry strategy, increased capital availability and raised maize producer price** - this scenario is an amalgam of Scenarios 3 and 4 and evaluates the effect on smallholder maize production of concurrently raising the maize producer price and making available extra capital.
>
> **Scenario 6: Proposed agroforestry strategy and reduced population growth rate** - this scenario evaluates the effect on national and household food security of promoting a substantial decline in the prevailing rate of population growth generating a fall in maize demand.

Model results

Food cropping pattern choices

Tables 11 - 13 detail the results of the LP model run under the six scenarios for the three landholding sizes. The first point of interest to note is the significant percentage of total landholding allocated to agroforestry options under the improved situation ranging from approximately 56% for small farmers to about 46% for large farmers. However, 2-year improved fallows are not selected, and the undersown variant is only selected by the medium and large farmers. For the smallest farmers this is a reflection of land scarcity as they prefer to opt for fertilized 1-year undersowing, fertilized msangu and fertilized long-term alley cropping, technologies which require no fallowing. As such, given the above range of agroforestry options, these results suggest that improved fallows are less preferred by smallholder farmers in land constrained circumstances, as in Malawi. Additionally, in all scenarios, labor requirements are not a constraining issue for any of the smallholder farm sizes.

With regard to the different scenarios, raising the maize price from MK1.55/kg to MK2.96/kg[10] in Scenario 3 generates a small decrease in the total area put to improved fallows, other agroforestry options, and all food crops. This result is biased by the inclusion of a food-for-work option for the smallest farmers, necessary for them to meet their minimum nutritional requirements in the face of the maize consumer price increase as they are deficit food producers.

Scenario 4 results in a decrease in the area put to improved fallows, agroforestry options and all food crops compared to Scenario 2 as the additional financial resources are primarily channeled into cash crops, particularly tobacco production. This result is of particular interest as it demonstrates the fungibility of financial resources. Although credit or fertilizer may be issued for maize production purposes, farmers will apply it to the crop giving the greatest marginal return, in this case burley tobacco. Nevertheless, the extra resources do enable a switch from lower to higher yielding maize options which result in an overall increase in food production. The main switch involves small farmers growing more fully fertilized hybrid maize, fertilized long-term alley cropping, fertilized hybrid maize under msangu and undersown hybrid maize, at the expense of undersown fallows and recycled hybrid maize with no fertilizer.

Scenario 5 evaluates the effect on smallholder maize production of concurrently raising the maize producer price and making available extra capital. The net effect on area put to maize is slightly negative compared to Scenario 2 as once again, in spite of the favorable maize price, the extra financial resources are primarily directed into cash crops. Scenario 6 assumes a reduced rate of population increase and has the effect of reducing the total area under maize production due to lower household food security requirements thus giving additional scope for cash crops.

The final point of interest is that no matter which scenario is under consideration, the percentage of total area put to the full range of agroforestry options remains substantial and fairly stable across all three landholding categories. This robustness derives from the wide range of agroforestry options, both with and without fertilizer, offered to smallholders in the model.

National food security

The projected national food security situation under each scenario in twenty years is illustrated in Table 14. With an estimated population of more than 19 million[11] in 2014/15 and an assumed food requirement of 232 kg per head [Malawi Government, 1993], Malawi will face an annual food requirement of some 4.5 million tons. If nothing is done to improve current productivity levels, as in Scenario 1, the country will face a food deficit of about 100 kg per capita. If the shortfall were to be filled by importing maize, this would entail a staggering cost of approximately US$650 million per annum. With the inclusion of the agroforestry options in Scenario 2, the deficit falls significantly to about 60 kg per capita. Maize importation in this case would require about US$400 million per annum, an improvement of US$150 million over Scenario 1.

As an alternative to spending scarce foreign exchange on food imports, another option is to encourage commercial maize production by the estate sector. This would entail raising the maize producer price substantially as in Scenario 3, which requires the estate sector to put some 28% of its total area to maize production. Although this would solve the national food security problem at a stroke, the ramifications of the producer price rise on the economy and household food security are serious. The maize consumer price would need to be increased by at least 44% resulting an initial inflationary boost of about 21%. In addition minimum wages would need to be increased by 44% to maintain the wage:maize price ratio and so the wage:price inflationary spiral would continue.

Nevertheless, in light of the massive bill for the importation alternative, this scenario may enhance the attractiveness of this option to policy makers. An additional point of interest is that raising the maize producer price by this substantial percentage produces a very small increase in total smallholder maize production. This is also the result if the model is run with the producer price raised even higher to MK3.50/kg, equivalent to the regional maize import parity price. As raising the price higher than this would not make economic sense, it stands to reason that in terms of national food security, Malawi needs to look beyond simply improving the maize:fertilizer price ratio by raising the maize producer price.

Scenario 4 investigates the limitations of the current smallholder resource base by allowing an increase capital availability through both credit and cash/fertilizer donations. This scenario is productive in terms of national food security in spite of causing a fall in the area put to maize as the increased financial resources, though primarily targeted on cash crops, enable a switch from lower to higher yielding maize options which result in an overall increase in food production. This is illustrated in Table 15 with Scenario 4 resulting in a 44% increase in the average yield for all maize varieties over 20 years, an average of 2.2% per annum. However, this increase is still lower than the population growth rate with the net food security situation in 2014/15 still deficit by about 54 kg per capita. However, the fact still remains that resolving smallholder resource limitations goes some way towards raising maize productivity and improving the food security situation. Scenario 5, with both increased capital and raised maize price, only improves on Scenario 4 by encouraging estate maize production. Nonetheless, this is at the expense of the maize consumer price and inflation as with Scenario 3.

In an attempt to evaluate the population issue, the last option, Scenario 6, assumes a sustained and substantial fall in the population growth rate to approximately 1% per annum in 20 years time. With this assumption and the introduction of the agroforestry proposal as in Scenario 2, the national food security shortfall drops sharply to about 40 kg per head. This will improve even more with the addition of the increased capital and a rise in the maize producer price.

Household food security

The household food security situation is summarized in Table 16. Under Scenario 1, the situation at the farm household level in twenty years is very grim with small and medium farmers being deficit food producers. The introduction of the agroforestry options in Scenario 2 improves the situation with small farmers still being deficit but realizing a cash surplus. Medium and large farmers are much better off under this scenario than the first, with the former moving into a surplus food production situation. As such, adoption of the agroforestry options, including improved fallows, will undoubtedly improve the household food security situation in Malawi for all household size categories, although the smallest households will still need additional off-farm options.

Scenario 3 has positive results at the household level for all farm sizes in spite of the increase in the maize consumer price. The catch is that the only reason small farmers are better off, and indeed able to survive, is because of the inclusion of a FFW option. Furthermore, the negative impact on low-income urban household food security needs to be borne in mind with this option. The medium and large farmers are unquestionably better off from improved maize revenues being surplus maize producers. Scenario 4 results in small farmers producing less food than in Scenario 2, but being better off at the end of the year due to increased cash crop production. Medium farmers are also better off whilst producing slightly more food. Scenario 5 is less attractive than Scenario 4 from the small farmers point of view due to the maize consumer price increase, but both the medium and large farmers are substantially better off due to increased maize revenues. Scenario 6 is the most attractive option from the small farmer perspective as they are able to meet their food requirements from their own production and raise a reasonable cash surplus.

Cumulative area under agroforestry technologies

Table 17 details the projected cumulative area under agroforestry technologies by the year 2014/15 under the different scenarios. 2-year improved fallows are not selected under any scenario. Undersown fallows with *Tephrosia vogelii* rise to a maximum hectarage of 132,000 under Scenario 6. The area undersown with *Sesbania sesban* reaches a high of 185,000 ha under Scenario 5. Long-term alley cropping with *Senna spectabilis* attains a maximum area of 64,000 ha over 20 years under a number of scenarios. Short-term alley cropping with *Tephrosia vogelii* is selected only under Scenario 6, reaching a maximum area of 6,000 ha. The area put to msangu increases substantially over the twenty year horizon to a limit of approximately 300,000 ha. The total area under agroforestry options in 2014/15 translates into about 27-28% of the total area under smallholder crops. The incremental requirements needed to achieve these results are detailed in the next section.

Scenario incremental requirements

Table 18 details incremental seed demand for the various scenarios. Incremental hybrid maize seed requirements rise from about 800 MT to more than 16,000 MT per annum in 2014/15. *Tephrosia vogelii* seed requirements increase from a minimum of 5 MT to a maximum of 140 MT per annum over twenty years. Although seed demand will initially outstrip domestic supply, this problem can rapidly be overcome through adopting farmers producing seed as a commercial by-product[12]. *Senna spectabilis and Faidherbia albida* seed demands remain fairly low at about 0.85 MT and 0.60 MT per annum, respectively. *Sesbania sesban* seed requirements will most certainly stretch domestic supply rising from about 2.6 MT to a maximum of over 80 MT per annum by 2014/15. The answer in this case would be to use alternative species such as *Tephrosia vogelii* for which seed multiplication is less of a problem.

Scenarios 4 and 5 will require an annual credit injection of about MK270 (US$18) million per annum by the year 2014/15, with a cash/fertilizer donations of about MK300 (US$20) million per annum over the same time period. Although this is a substantial sum, the former should be recoverable in normal seasons, whilst the latter is much less than the savings made on imports as result of increased maize production.

Food security conclusions

In light of the above, agricultural policy makers are faced with a difficult choice in order to satisfy both national and household food security whilst keeping within budgetary limits. Ignoring Scenario 6 for the moment, Scenario 4 would be the option selected if small farmers had the choice. From the national standpoint, Scenario 3 may well be the preferred option in spite of the ramifications for inflation and household food security as it would avoid substantial and expensive maize importation, and avert the need to ameliorate smallholder resource constraints. Notwithstanding this dilemma, in light of the acceptability of the range of agroforestry technologies described above to both resource and land-constrained smallholder farmers and those without such constraints, it is safe to conclude from the foregoing that giving smallholder farmers the option to adopt these technologies is a step in the right direction for both household and food security.

General conclusions

Although improved fallows show high biological potential in Malawi, smallholder resource constraints preclude the use of standard 2-year fallows, which necessitate adaptations to reduce the fallow period. Other modifications include direct sowing to reduce establishment costs and early planting to optimize biomass production. More research is needed to identify a greater range of species and their management for increased adaptation to different environments, pests and diseases.

In conclusion, improved fallows in the undersown fallow form in Malawi successfully meet the socio-economic boundary conditions of landholding size, limited smallholder resource base, farm labor concerns and household food security. As such, improved fallows have the potential to play a significant role, along with other agroforestry and non-agroforestry options, in addressing future food security issues in Malawi. However, additional measures need to be taken to meet national food security requirements such as raising the maize producer price to encourage commercial estate maize production, and addressing population concerns. Failure to achieve a significant decrease in the population growth rate will result in increasingly serious food security problems in the future.

Acknowledgements

This paper was prepared with support from the Malawi Agroforestry Extension Project, Rockefeller Foundation and ICRAF. The MAFE Project is a cooperative grant agreement with USAID, WSU and the Ministry of Agriculture and Livestock Development. The Malawi-ICRAF Agroforestry Project is a collaborative research project between ICRAF and the Malawi Government. We would like to thank Professor J. Maghembe for the use of their relay cropping data in the model.

Notes

[1] Smallholder fertiliser sales increased from 81,105 MT in 1987/88 to approximately 138,000 MT in the 1992/93 season [Malawi Government, 1993] whilst the area under hybrid maize rose from 58,900 ha to 326,400 ha over the same period as indicated in Table 1.

[2] With Malawi's current demographic structure, an average daily intake of 2,200 calories per capita is needed to meet minimum requirements. About 190 kg of milled maize grain (mgaiwa) provides 80% of this which equates to 232 kg maize grain/person/year assuming 18% wastage. Other cereals have also been included on the same nutritional basis.

[3] Smallholder burley production has increased from just over 1,000 ha in 1990/91 to over 46,000 ha in 1995/96.

[4] The issue of risk and its effect on adoption is not evaluated in this paper due to time constraints. It will be included in the model at a later stage using the MOTAD approach based on minimizing gross margin deviations from their means using time series data [Hazell and Norton, 1986].

[5] Formulation run over more than one year.

[6] Blackie and Conroy (1993) report that only 25% of farmers have cash incomes greater than US$100 per annum and 38% have annual incomes less than US$25.

[7] A limited agroforestry adoption survey involving 108 respondents was conducted in the 1995/96 season in Kasungu and Machinga Agricultural Development Divisions funded by the Rockefeller Foundation and MAFEP.

[8] However, it is important to note that these results were generated in the first year in which the farmers were in a position to have sufficient biomass to affect yields through either good or poor management and have learnt from this experience.

[9] Off-farm labour.

[10] This increase ensures a 100% return to variable costs required to encourage commercial maize production by the estate sector.

[11] Extrapolated from 1987 Census data.

[12] A number of projects are already successfully buying *Tephrosia vogelii* seed from smallholder farmers at MK10.00 per kg.

References

Benson, T. (1996). Maize labor data, Unpublished Report, The Rockefeller Foundation, Lilongwe, Malawi.

Blackie, M. J. and A. C. Conroy (1993). Feeding the Nation: Breaking Out of Malawi's Yield Trap, Unpublished report, The Rockefeller Foundation, Lilongwe, Malawi.

Bunderson, W. T. and F. Bodnar (1997). A Preliminary Assessment of Undersowing Fast-Growing Shrubs: Effect of Different Methods and Time of Establishment on First Season Biomass Yields and Seed Costs, Unpublished Report, Malawi Agroforestry Extension Project, Lilongwe, Malawi.

Bunderson, W. T., Bodnar, F., Bromley, W. A., and Nanthambwe, S. J. (1995). A Field Manual for Agroforestry Practices in Malawi, Malawi Agroforestry Extension Project, Lilongwe, Malawi.

Bunderson, W. T. and I. M. Hayes (1995). Agricultural and Environmental Sustainability in Malawi. Paper presented at the Conference on Sustainable Agriculture for Africa, Abidjan, Cote d'Ivoire, July, 1995.

Carter, J. (1995). Alley Farming: Have Resource-Poor Farmers Benefited?, Rep. No. 3. Overseas Development Institute, Natural Resource Perspectives, June 1995.

Conroy, A. (1993). The Economics of Smallholder Maize Production in Malawi, with Reference to the Market for Hybrid Seed and Fertiliser, University of Manchester.

Conroy, A. (1995). The Inputs Sector: Fertiliser and Seed. In World Bank Agricultural Sector Memorandum Volume III, World Bank.

Felker, P. (1978). State of the Art: *Acacia albida*, Grant No. AID/afr-C-1361. University of California, Riverside, CA.

Hayes, I. M. (1996a). Preliminary Report on 1995/96 Survey Data, Unpublished Report for the Rockefeller Foundation, Lilongwe, Malawi.

Hayes, I. M. (1996b). Preliminary Studies of Maize Yields in Malawi Under Two Agroforestry Technologies: Intercropping with *Faidherbia albida* and Alley Cropping with *Senna spectabilis*, Unpublished Report for the Rockefeller Foundation, Lilongwe, Malawi.

Hazell, P. B. R. and R. D. Norton (1986). Mathematical Programming for Economic Analysis in Agriculture, Macmillan.

Heisey, P. W. and M. Smale (1995). Maize Technology in Malawi: A Green Revolution in the Making?, CIMMYT Research Report No. 4.

ICRAF (1994). International Centre for Research in Agroforestry: Annual Report for 1994, ICRAF, Nairobi, Kenya.

Kwesiga, F., Phiri, D., Mwanza, S., and Simwanza, P. C. (1995). Zambia/ICRAF Agroforestry Research Project: 1995 Annual Report, Chipata, Zambia.

Kwesiga, F., Phiri, D., Simwanza, P. C., and Mwanza, S. (1994). Zambia/ICRAF Agroforestry Research Project: 1994 Annual Report, Chipata., Zambia.

MacDicken, K. G. and N. T. Vergara, Eds. (1990). Agroforestry: Classification and Management, John Wiley & Sons.

Malawi Government (1990). Guide to Agricultural Production in Malawi 1990-1991, Extension Aids Branch, Ministry of Agriculture, Lilongwe, Malawi.

Malawi Government (1993). Situation Analysis of Poverty in Malawi. Lilongwe, Ministry of Women and Children's Affairs and Community Services, Lilongwe, Malawi.

Malawi Government (1993). Study on Agricultural Inputs for the Japanese Grant-Aid Programme - Increase of Food Production, Ministry of Agriculture, Lilongwe, Malawi

Malawi Government (Var). Ministry of Agriculture Crop Estimates, Ministry of Agriculture and Livestock Development, Lilongwe, Malawi.

Ministry of Forestry and Natural Resources. (1993). Forest resources mapping and biomass

assessment for Malawi. Satellitbild, Kiruna Sweden in cooperation with the Department of Forestry, Lilongwe.

Nair, P. K. (1990). The Prospects for Agroforestry in the Tropics, World Bank.

Ong, C. (1994). Alley Cropping - Ecological Pie in the Sky?, Agroforestry Today, July - September, 1994, 8-10.

Saka, A. R., Bunderson, W. T., Phombeya, H. S. K., Itimu, O. A., and Mbekeani, Y. (1994). The Effects of *Acacia albida* on Soils and Maize Grain Yields Under Smallholder Farm Conditions in Malawi. Forest Ecology and Management 64, 217-230.

Saka, A. R., Ntupanyama, Y., Phombeya, H. S. K., Jones, R. B., Minae, S., and Snapp, S. S. (1995). Agroforestry Commodity Team Annual Report 1994/95 Season, Department of Agricultural Research, Lilongwe, Malawi.

Selenje, M. B., Mgomezulu, M. A., and Mukunuwa, G. (1990). An Economic Analysis of Two Agroforestry Practices: A Case Study from Ntcheu Rural Development Project, Lilongwe. *In* Agroforestry Research and Development in Malawi: Proceedings of the First National Agroforestry Symposium on Agroforestry Research and Development, Bvumbwe Agricultural Research Station, Limbe, Malawi.

World Bank (1992). Economic Report on Environmental Policy: Volumes I & II, World Bank.

World Bank (1995). Malawi: Agricultural Sector Memorandum: Volume II: Main Report, Southern Africa Department, Agriculture and Environment Division, World Bank.

Table 1. Smallholder Maize Area ('000 Ha)

Crop Year	Local	Composite	Hybrid	All Maize	% of All Crops
1983/84	1,067.5	26.1	89.0	1,182.6	
1984/85	1,048.4	21.4	74.9	1,144.7	67%
1985/86	1,104.6	20.1	68.6	1,193.3	68%
1986/87	1,131.5	13.8	37.1	1,182.4	65%
1987/88	1,137.6	18.7	58.9	1,215.2	67%
1988/89	1,160.0	25.1	85.8	1,270.9	72%
1989/90	1,184.0	24.7	135.0	1,343.7	74%
Pre 1990 Average	1,119.1	21.4	78.5	1,219.0	
1990/91	1,193.0	18.9	179.4	1,391.3	70%
1991/92	1,131.0	13.3	216.7	1,361.0	71%
1992/93	996.8	3.9	326.4	1,327.1	65%
1993/94	920.9	0.8	207.6	1,129.3	60%
1994/95	858.7	2.3	361.1	1,222.1	60%
1995/96	856.4	17.5	368.7	1,242.6	55%
1996/97	911.1	19.6	299.4	1,230.1	54%
Post 1990 Average	981.1	10.9	279.9	1,271.9	

Source: Malawi Government (Var)

Table 2. Average Smallholder Maize Yields (Kg/ha)

Crop Year	Local	Composite	Hybrid	All Maize
1983/84	1,040	1,790	2,760	1,182
1984/85	1,030	1,750	3,110	1,184
1985/86	960	1,730	2,940	1,085
1986/87	950	1,640	2,710	1,017
1987/88	1,090	1,200	2,670	1,174
1988/89	1,050	1,760	2,850	1,188
1989/90	813	1,400	2,555	999
Pre 1990 Average	990	1,610	2,799	1,118
1990/91	872	1,417	2,908	1,142
1991/92	330	403	1,307	482
1992/93	980	1,494	3,098	1,532
1993/94	580	784	1,369	725
1994/95	741	1,390	2,176	1,166
1995/96	1,009	1,474	2,450	1,443
1996/97	1,023	1,448	2,479	1,384
Post 1990 Average	791	1,201	2,255	1,125

Source: Malawi Government (Var)

Table 3. Historical Food Security Situation in Malawi

	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93	1993/4	1994/95	1995/96	1996/97
Population ('000)[a]	7,733	7,989	8,276	8,574	8,883	9,202	9,534	9,877	10,233	10,601	10,983	11,372
Smallholder Maize ('000 MT)	1,295	1,202	1,420	1,510	1,343	1,589	657	2,034	819	1,328	1,793	1,703
Smallholder Rice ('000 MT)	37	28	33	46	43	63	24	65	41	39	73	62
Smallholder Sorghum ('000 MT)	21	15	22	20	15	19	4	22	17	19	55	63
Smallholder Millet ('000 MT)	10	9	12	11	10	8	3	15	10	13	20	20
Smallholder Wheat ('000 MT)	1	2	2	1	2	1	1	1	0	2	2	2
Estate Maize ('000 MT)	225	225	225	225	225	225	225	225	225	225	225	225
Total Cereal ('000 MT)	1,589	1,480	1,713	1,813	1,638	1,905	914	2,362	1,112	1,626	2,168	2,075
Kg per Capita Production	205	185	207	211	184	207	96	239	109	153	197	182
Kg per Capita Consumption Requirement	232	232	232	232	232	232	232	232	232	232	232	232
Surplus(+)/Deficit(-)	-27	-47	-25	-21	-48	-25	-136	7	-123	-79	-35	-50

Source: World Bank (1995), Malawi Government (Var)

[a]Population growth is projected from the 1987 census of 7.99 million increasing at an annual rate of 3.6% from 1986/87 to 1994/95, thereafter falling by 0.05% per annum from efforts to reduce population growth.

Table 4. Above Ground Biomass 22 Months After Planting, ICRAF Biophysical Limits To Improved Fallows

1993/94 Sites	Chitedze		Mpingu		Chitala		Bembeke		Mwimba		Lisasadzi		1993/94 Sites	
Biomass tons/ha[a]	SS	TV	SS	TV	SS	TV	SS	TV	SS	TV	SS	TV	SS	TV
Tree Fallows														
Total Fresh	27.75	17.63	18.09	8.90	18.16	7.06	3.64	1.13	35.63	9.60	-	2.09	20.65	7.74
Leaf	0.40	0.73	0.28	0.08	0.20	0.21	0.02	0.01	0.56	0.39	-	0.14	0.29	0.26
Litter	0.83	2.68	1.71	1.47	6.44	1.02	0.05	0.03	7.68	2.52	-	-	3.34	1.55
Leaf+Litter	1.23	3.41	1.99	1.55	6.64	1.23	0.07	0.04	8.24	2.91	-	0.14	3.63	1.80
Twigs	0.39	0.45	0.51	0.13	0.12	0.11	0.04	0.06	0.18	0.14	-	-	0.25	0.18
Wood	18.87	8.42	3.05	4.20	14.28	2.37	2.79	0.58	22.02	7.78	-	0.66	12.20	4.00
Pods	0.15	0.98	0.14	0.60	0.19	0.27	0.03	0.04	-	2.05	-	0.41	0.13	0.73
Grass/Herb Fallows														
Herbaceous Plants	0.73		0.69		0.73		0.72		0.68		0.79		0.72	

At Lisasadzi and Bembeke, both *Sesbania* and *Tephrosia* were heavily attacked by root-knot nematodes. * Indicates negligible biomass.

Table 4. continued.

1994/95 Sites	Bembeke		Lifuwu		Mzimba-C		Mzimba-L		Mzimba-M		1994/95 Sites		All Sites	
Biomass tons/ha[a]	SS	TV	SS	TV	SS	TV	SS	TV	SS	TV	SS	TV	SS	TV
Trees														
Total Fresh	12.60	17.84	9.47	5.13	4.16	1.90	15.39	14.75	18.22	12.63	11.97	10.45	16.31	8.97
Leaf	0.05	0.49	0.10	0.08	0.08	0.08	0.19	0.22	0.31	0.37	0.15	0.25	0.22	0.25
Litter	1.33	2.82	0.54	3.29	0*	0.69	0.05	4.07	0.19	3.45	0.42	2.86	1.88	2.20
Leaf+Litter	1.39	3.31	0.63	3.37	0.08	0.77	0.24	4.30	0.50	3.81	0.57	3.11	2.10	2.26
Twigs	0.83	0.78	0.41	0.23	0.08	0.07	0.20	0.44	0.16	150	0.33	0.33	0.29	0.26
Wood	8.25	7.99	7.30	3.52	3.03	1.10	12.67	10.22	14.77	9.47	9.20	6.46	10.70	5.12
Pods	0.17	1.74	0.31	0.54	0.11	0.09	1.06	0.48	1.33	0.71	0.59	0.71	0.39	0.72
Grass/Herb Fallows Herbaceous Plants	1.61		5.90		2.34		2.75		4.16		3.35		1.92	

Source: ICRAF Biophysical Limits Trial, Lilongwe Cluster

[a]All values are dry matter based on oven dry weights, except as indicated under Total Fresh Biomass which excludes litter. Litter values include material only from current season. Pod values include only pods still on the tree at the time of harvest. Blanks indicate there was no biomass to measure. Leaf biomass was low since most had fallen as litter at the time of harvest.

Table 5. First Year Maize Yields after Improved Fallows at Different Sites

1995/96 Season	Maize Yield (Kg/Ha) By Site						
	Chitedze	Chitala	Mwimba	Lisasadzi	Mpingu	Bembeke	Mean
Fallows							
Sesbania	5,993	5,160	1,520	177	2,143	709	2,617
Tephrosia	6,649	4,712	643	121	2,144	81	2,392
Grass/Weed	1,449	7,174	514	302	1,074	616	1,855
Continuous Maize							
No Fertilizer	3,555	3,049	355	32	887	27	1,318
138 N & 60 P_2O_5	7,656	4,119	6,033	1,781	3,301	100	3,832
Elevation (m a.s.l.)	1149	565	1125	1209	1162	1550	
1995/96 Rainfall	946	814	1133	883	950	1294	

Source: ICRAF Biophysical Limits Trial, Lilongwe Cluster

Table 6. Estimated First Year Maize Yields (Kg/ha) after Improved Fallows at Mzimba

1996/97 Season	Estimated Maize Yield From 4 Farms
Fallows	
Sesbania No Fert.	1200 - 1600
Tephrosia No Fert.	1400 - 1800
Grass/Weed No Fert.	400 - 600
Continuous Maize	
No Fertilizer	400 - 600
138 N & 60 P_2O_5	4000 - 6000
Elevation (m a.s.l.)	1350
1996/97 Rainfall to Feb 2	399.5

Source: Data from MAFEP at 3 ICRAF sites and 1 MAFEP on-farm site.

Table 7. Effect of Method and Time of Undersowing on Seed Cost and Biomass of *Tephrosia vogelii* and *C*

Species & Method of Establishment	% Establishment of Seed Rate			Seed Cost MK/ha		
	Early	Late	Mean	Early	Late[b]	Mean
Tephrosia vogelii						
Broadcast	26%	17%	21%	176	1,805	990
Direct Sown in Stations	44%	51%	47%	84	75	80
Cajanus cajan[a]						
Direct Sown in Stations	70%	63%	66%	11	15	13

Source: Bunderson and Bodnar (1997)

Early = At or after 1st Weeding   Late = At or after 2nd Weeding

[a]*Cajanus cajan* was established only by direct sowing between maize stations using 1-3 seeds per station.

[b]A high seed rate of 275 kg/ha was used for *Tephrosia* by ICRAF and Carr to increase biomass production.

Seed Costs were MK 3.30/kg for *Cajanus cajan* and MK10/kg for *Tephrosia.* These costs exclude transport, supervision, packaging and storage.

Table 8. Effect of Early and Late Undersowing on Biomass of *Tephrosia vogelii* and *Cajanus cajan* at high, medium and low altitudes

Species	Total Biomass (Fresh tons/ha) >1250 m	750-1250 m	<750 m	Mean
Tephrosia vogelii				
Early	2.24	NA	14.54	8.39
Late	1.29	3.02	2.22	2.18
Cajanus Cajan				
Early	17.75	NA	NA	17.75
Late	1.16	5.10	NA	3.13

Source: Bunderson and Bodnar (1997)

NA = This treatment not planted by farmers in this location.

Table 9. 2-year Fallow Labor Data (Mandays)

	Year1	Year 2	Year 3	Year4
Maize Labor: Field Preparation	15.7			
Ridging			10.4	15.7
Planting			10.7	10.7
Weeding			24.0	24.0
Banking			38.3	38.3
Harvesting			37.0	37.0
IFallow Labor: Planting	10.7			
Weeding 1	6.2			
Weeding 2	6.2			
Cutting			5.5	
Total Labor	38.8	0	125.9	136.1

Table 10. Undersown Fallow Labor Data (Mandays)

	Year 1	Year 2	Year3	Year 4
Maize Labor: Field Preparation	15.7			
Ridging	10.4		10.4	15.7
Planting	10.7		10.7	10.7
Weeding	24.0		24.0	24.0
Banking	38.3		38.3	38.3
Harvesting	37.0		37.0	37.0
IFallow Labor: Planting	10.7			
Weeding 1				
Weeding 2				
Cutting			5.5	
Total Labor	146.8	0	125.9	136.1

Table 11. Improved Situation - Small Household (0.55 ha) Cropping Pattern in 2014/15

Percentage of Landholding[a]	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
H. Maize Undersown Fallow	0%	0%	0%	0%	0%
H. Maize 2-year Imp. Fallow	0%	0%	0%	0%	0%
Total IFallow	0%	0%	0%	0%	0%
H. Maize 1-year Undersowing	0%	0%	0%	0%	0%
H. Maize 1-year Unders. Fert	25%	25%	25%	25%	25%
H.Maize A.Cropping STerm	0%	0%	0%	0%	0%
H.Maize A.Cropping LTerm	0%	0%	0%	0%	0%
H.Maize A.Cropping LTerm Fert	5%	5%	5%	5%	5%
HMaize Msangu	0%	0%	0%	0%	0%
H.Maize Msangu Fert	25%	20%	24%	25%	25%
Local Maize Msangu	0%	0%	0%	0%	0%
Total other Agroforestry	56%	51%	55%	56%	56%
Total All Agroforestry	56%	51%	55%	56%	56%
Total Other Maize	5%	5%	4%	4%	2%
Total All Maize	62%	56%	58%	60%	58%
Sorghum	2%	2%	2%	2%	2%
Cassava	15%	15%	15%	15%	15%
TOTAL ALL FOOD	78%	73%	75%	76%	75%
Total Cash Crops	18%	27%	24%	24%	25%

[a]May not sum to 100% due to rounding

Table 12. Improved Situation - Medium Household (1.40 ha) Cropping Pattern in 2014/15

Percentage of Landholding[a]	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
H. Maize Undersown Fallow	21%	18%	0%	0%	21%
H. Maize 2-year Impr. Fallow	0%	0%	0%	0%	0%
Total IFallow	21%	18%	0%	0%	21%
H. Maize 1-year Undersowing	0%	0%	0%	0%	0%
H. Maize 1-year Under. Fert	0%	0%	14%	14%	0%
H.Maize A.Cropping STerm	0%	0%	0%	0%	1%
H.Maize A.Cropping LTerm	5%	0%	0%	0%	4%
H.Maize A.Cropping LTerm Fert	0%	5%	5%	5%	0%
HMaize Msangu	21%	25%	25%	25%	20%
H.Maize Msangu Fert	0%	0%	0%	0%	0%
Local Maize Msangu	0%	0%	0%	0%	0%
Total other Agroforestry	26%	30%	44%	44%	25%
Total All Agroforestry	46%	48%	44%	44%	46%
Total All Maize	52%	54%	49%	49%	52%
Sorghum	3%	3%	3%	3%	3%
Cassava	14%	14%	13%	13%	14%
TOTAL ALL FOOD	69%	71%	65%	65%	69%
Total Cash Crops	32%	30%	35%	35%	32%

[a]May not sum to 100% due to rounding

Table 13. Improved Situation - Large Household (2.91 ha) Cropping Pattern in 2014/15

Percentage of Landholding[a]	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
H. Maize Undersown Fallow	5%	5%	5%	5%	5%
H. Maize 2-year Improved Fallow	0%	0%	0%	0%	0%
Total IFallow	5%	5%	5%	5%	5%
H. Maize 1-year Undersowing	0%	0%	0%	0%	0%
H. Maize 1-year Undersowing Fert	10%	11%	10%	11%	10%
H.Maize A.Cropping STerm	0%	0%	0%	0%	0%
H.Maize A.Cropping LTerm	1%	0%	1%	0%	1%
H.Maize A.Cropping LTerm Fert	4%	5%	4%	5%	4%
HMaize Msangu	25%	25%	25%	25%	25%
H.Maize Msangu Fert	0%	0%	0%	0%	0%
Local Maize Msangu	0%	0%	0%	0%	0%
Total other Agroforestry	41%	41%	41%	41%	41%
Total All Agroforestry	46%	46%	46%	46%	46%
Total Other Maize	7%	6%	7%	6%	7%
Total All Maize	52%	52%	52%	52%	52%
Sorghum	2%	2%	2%	2%	2%
Cassava	13%	13%	13%	13%	13%
TOTAL ALL FOOD	68%	68%	68%	68%	68%
Total Cash Crops	32%	32%	32%	32%	32%

[a]May not sum to 100% due to rounding

Table 14. National Food Security - Estimated Situation in 2014/15

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Total Food Requirement (‘000 MT)	4,551	4,551	4,551	4,551	4,551	3,960
Total Food Production (‘000 MT)	2,569	3,328	4,551	3,489	4,551	2,308
Kg per Capita Surplus/Deficit	-101	-62	0	-54	0	-40.7
Required Maize Imports (‘000 MT)	1,982	1,223	0	1,062	0	695
International Importation (US$)	$652 mill	$402 mill	0	$349 mill	0	$229 mill
Maize Producer Price (MK/kg)	1.55	1.55	2.96	1.55	2.96	1.55
% Increase	0%	0%	91%	0%	91%	0%
Maize Consumer Price (MK/90kg)	250	250	361	250	361	250
% Increase	0%	0%	44%	0%	44%	0%
Inflationary Effects:						
1. Price Inflation Increase	0%	0%	21%	0%	21%	0%
2. Minimum Wage Urban (MK/day)	K11.85	K11.85	K17.11	K11.85	K17.11	K11.85
Minimum Wage Rural (MK/day)	K8.70	K8.70	K12.57	K8.70	K12.57	K8.70
% Increase	0%	0%	44%	0%	44%	0%

Table 15. Average Maize Yields - 2014/15

Kg/ha	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Local Maize	918	918	918	918	918	918
Hybrid Maize	2,424	2,323	2,325	2,538	2,531	2,308
Recycled Hybrid Maize	1,065	1,065	1,065	1,065	1,065	1,065
All Maize	1,407	1,862	1,890	2,027	2,024	1,848

Table 16. Household Food Security Situation - 2014/15

	Scenario 1	Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6	
	Current	Current	Improved	Current	Improved	Current	Improved	Current	Improved	Current	Improved
HHold A											
Food Surplus/Deficit (kg)	-1,066	-1,066	-189	-1,066	-119	-1,066	-246	-1,066	-238	-776	0
Year End Cash Balance (MK)	-2,824	-2,824	1,606	-4,140	1,998	-2,824	2,042	-4,140	1,757	-2,108	2,864
HHold B											
Food Surplus/Deficit (kg)	-64	-64	773	-64	1,005	-64	1,104	-64	1,104	226	1,046
Year End Cash Balance (MK)	122	122	3,971	43	5,151	122	4,544	43	6,100	650	4,391
HHold C											
Food Surplus/Deficit (kg)	1,302	1,302	4,119	1,302	4,083	1,302	4,119	1,302	4,083	1,592	4,409
Year End Cash Balance (MK)	2,607	2,607	11,269	4,443	16,970	2,607	11,269	4,443	16,970	3,056	11,718

Table 17. Estimated Cumulative Area Under Agroforestry Technologies 2014/15 (Ha)

	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
2-Year Improved Fallow	-	-	-	-	-
Undersown Fallow	129,786	113,600	28,871	26,949	131,893
1-Year Undersowing	116,323	118,425	183,040	184,962	115,706
Alley Cropping Long Term/Msangu	64,283	64,283	64,283	64,283	57,909
Alley Cropping Short-Term	-	-	-	-	6,033
Faidherbia DSI	301,056	309,375	319,367	320,442	296,254
Total Area Under Agroforestry	611,448	605,683	595,561	596,636	607,795
% of Total Smallholder Cropped Area Under Agroforestry	28%	28%	27%	27%	28%

Table 18. Incremental Seed Requirements Year 1 vs Year 20 (MT)

	Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6	
	Year 1	Year 20	Year 1	Year 20	Year 1	Year 20	Year 1	Year 20	Year 1	Year 20
Hybrid maize seed	818	16,453	852	17,158	837	16,754	837	16,775	816	16,152
T.vogelii seed	26	137	23	120	6	30	5	28	27	140
S.spectabilis seed	0.80	0.85	0.80	0.85	0.80	0.85	0.80	0.85	0.73	0.77
F.albida seed	0.55	0.58	0.56	0.59	0.58	0.61	0.58	0.61	0.53	0.56
S.sesban seed	2.63	52.49	2.67	53.35	4.13	82.59	4.18	83.46	2.62	52.21

Fig. 1. Site Locations of ICRAF Biophysical Limits Trial

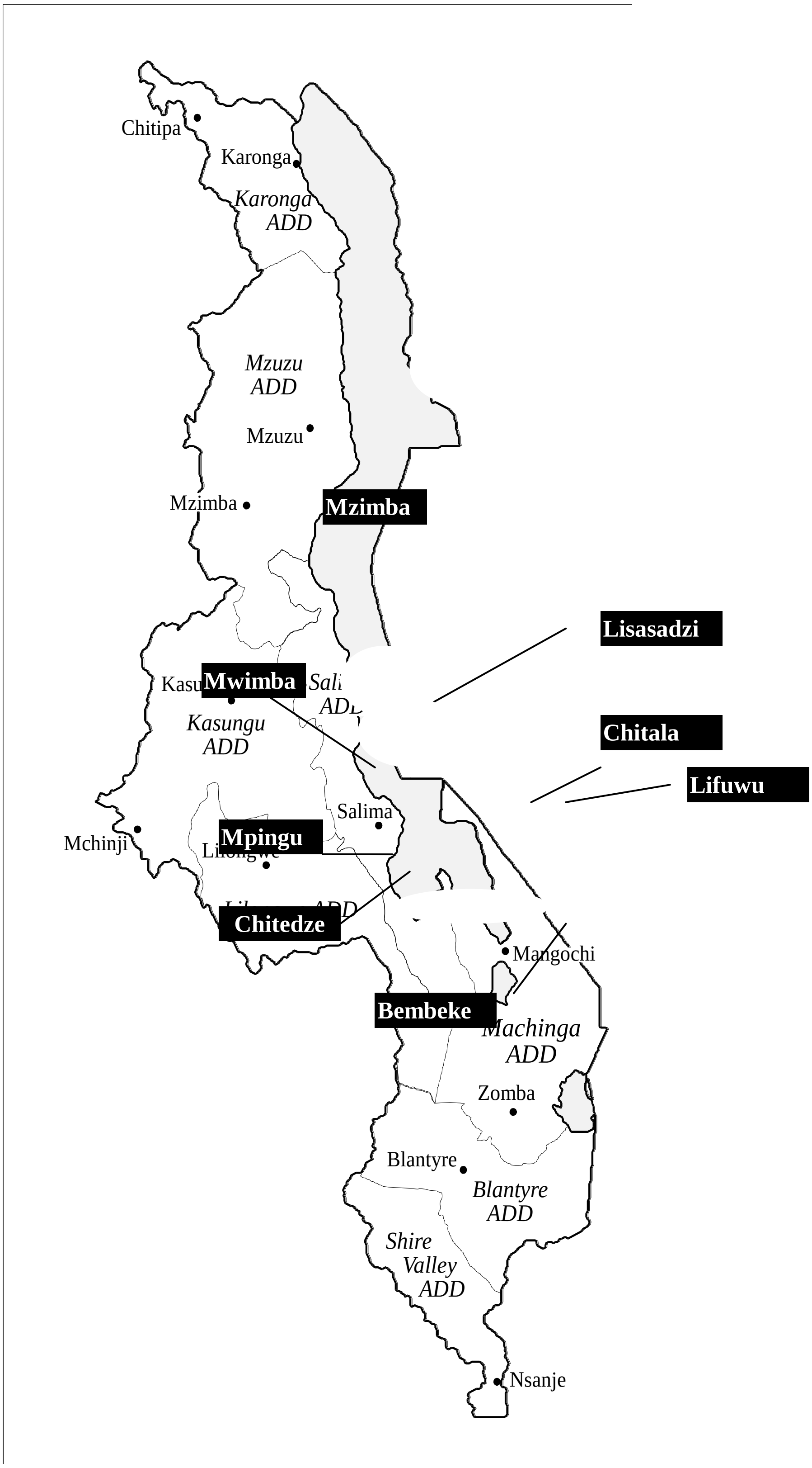

Fig. 2. Undersown Fallow in a 4-Year Rotation with a Species suitable for direct sowing, such as *Tephrosia vogelii*

Year 1 Hybrid Maize undersown with *Tephrosia vogelii* at or soon after maize planting.	**Year 2** *Tephrosia* left fallow with no crop cultivation.
Year 4 Cultivation continues with hybrid maize.	**Year 3** Cultivation resumes with hybrid maize after cutting *Tephrosia* down and leaving the biomass in situ.