Agroforestry Systems (2005) 64: 225–236
DOI 10.1007/s10457-004-2410-0

Improved tree fallows in smallholder maize production in Zambia: do initial testers adopt the technology?

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Received 17 February 2004; accepted in revised form 24 August 2004

Key words: Adoption intensity, Sample selection bias, Soil fertility depletion

Abstract

In eastern Zambia, population growth has reduced per-capita land availability to such an extent that traditional bush fallows can no longer be practiced, and low soil fertility is a major constraint to crop production. Improved fallows (IF) based on leguminous trees are a low cash-input agroforestry practice to restore soil fertility. The objective of the study reported here was to assess the adoption of IF by farmers who tested the technology, including the extent to which the technology is practiced relative to its potential scale. The socioeconomic and agroecological determinants of the incidence and scale of adoption are estimated using a two-stage Heckman regression model that corrects for sample selection bias. Seventy-five percent of the testers have adopted the technology, which shows that IF are a suitable practice under conditions of capital scarcity, inadequate access to markets for fertilizer, and relatively low population density, which prevail in large parts of southern Africa. Adopters practice the technology to 42% of its potential scale; a non-linear relationship was found between wealth and the incidence as well as the scale of adoption; land and labor availability limit further expansion. Hence, future on-farm research should emphasize IF options which reduce land and labor requirements such as intercropping IF species with maize, and IF species which can be seeded directly.

Introduction

The decline of soil fertility in smallholder farming systems is a major factor inhibiting equitable development in much of sub-Saharan Africa (Sanchez et al. 1997). In thinly populated savanna areas, farmers traditionally practiced shifting cultivation, alternating between cropping and fallowing (Ruthenberg 1980). But with population growth, the resulting land scarcity forces farmers to shorten fallow periods, which reduces soil fertility and, hence, crop yields (Boserup 1965; Ruthenberg 1980). In many developing countries, the lack of access to services and inputs such as mineral fertilizers curtails the adoption of 'Green Revolution' technologies as a means of ensuring household and national food security (Borlaug 1988). In Zambia, this was aggravated by the removal of subsidies for mineral fertilizer, leading to a sharp decline in fertilizer use in the early 1990s. Farmers who can neither afford nor rely on a regular supply of mineral fertilizers must obtain nutrients from alternative sources to restore soil fertility. Improved fallows (IF) using leguminous trees are a low cash-input agroforestry practice for supplying nutrients to subsequent crops (Kwesiga and Coe 1994). Following on-station and on-farm research, dissemination of the technology began in the late-1990s and by 2000, roughly 10,000 farmers had planted IF.

Several previous studies have investigated the potential for adoption of IF in different parts of Africa (Franzel 1999; Franzel et al. 2002), acknowledging that it was too early to definitively assess the acceptance of the technology. Based on data collected in eastern Zambia in 1998, Kuntashula et al. (2002) and Phiri et al. (2004) examined the association between the planting of IF and several farm and household characteristics using Chi-square and *t*-tests. Mudhara et al. (2003) developed a linear programming model to assess the adoption potential for IF in Zimbabwe. The same study investigated the determinants of the absolute area under IF using an ordinary least squares (OLS) regression model. However, such a model does not account for the non-normal distribution of the dependent variable caused by an accumulation of zero values for non-adopters of IF.

A major limitation of most agroforestry adoption studies is that they do not differentiate between experimentation and adoption. Such differentiation is not important in annual crops because farmers are able to assess the benefits of a new practice within months after trying it. In agroforestry, farmers need several years, four in the case of IF, before they are able to realize the full benefits and thus be able to evaluate the practice. Gladwell (2000) notes that the criteria for experimenting differ from those of adopting; thus an adoption model which assesses the factors influencing the planting of IF at a certain point in time without considering the practice of this technology in previous years is not valid.

The objective of the present paper is to assess the adoption of IF among early testers of the technology. We extend the existing literature in the following aspects: (1) the paper differentiates between testing and adopting IF; (2) with regard to adoption, a distinction is made between the decision whether or not to adopt IF, and the extent to which the technology is practiced relative to its potential scale; and (3) the socioeconomic and agroecological determinants of the adoption decision and the extent of the practice are assessed using a two-stage regression model which corrects for sample selection bias.

The paper proceeds as follows: Section 2 briefly describes the study area and reviews findings regarding the biophysical performance and profitability of IF as prerequisites to the adoptability of the technology. Section 3 presents the analytical framework employed in the study, and Section 4 describes the methodology applied in data collection. Section 5 contains the empirical results, and in Section 6 conclusions are drawn, and recommendations are given for future on-farm research and agricultural extension.

Description of the research area and performance of improved tree fallows

Eastern Zambia is characterized by an extensive dry season, capital scarcity, limited access to mineral fertilizer, and relatively low population density (25–40 persons per km^2), as is the case in large parts of southern Africa. Here, the International Centre for Research in Agroforestry (ICRAF) began on-farm research on IF in 1992/1993. By 1996/1997, roughly 3000 farmers spontaneously tested the technology (Kwesiga et al. 1999). The research area comprises four sub-districts of Chipata North and Chipata South districts of Eastern Province, Zambia, where IF had been actively promoted. Altitudes range from 900 to 1200 m above sea level. The main soil type is Alfisol, and soil texture ranges from sandy-loam to clay-loam (Franzel et al. 2002). Rainfall is unimodal and highly variable, averaging 1030 mm. Approximately 85% of the total amount is received within 4 months (AGROMET office, Msekera, Zambia, 2001). Maize is the most important crop accounting for 80% of the total cultivated area. Other crops include sunflower, groundnuts, cotton and tobacco (Kumar 1994).

Improved fallows with leguminous trees enrich the soil with nitrogen. They also improve soil physical properties by increasing the organic matter content (Juo and Lal 1977; Young 1989) and act as a break crop to suppress weeds, such as *Striga asiatica* (L.) Kuntze, a common weed in the region (De Rouw 1995). IF are mostly applied as a means to increase the yield of maize, the dominant staple food crop in many parts of southern and eastern Africa. *Sesbania sesban* L. Merr., an indigenous tree, was identified as a potential species for IF because of its wide distribution in Zambia, fast growth, ease of propagation and removal, and because it produces high levels of biomass which are easily degraded. Its stems can be used as fuelwood, and its foliage is an excellent supplement to protein-poor roughage in ruminant diets (Kwesiga and Coe 1994). Sesbania fallows are usually established from seedlings. In 12 on-farm trials in Eastern Province of Zambia, maize grain yields in the first year following a 2-year Sesbania fallow averaged 3.6 Mg ha^{-1} as compared to 1.0 Mg ha^{-1} for continuous, unfertilized, and 4.4 Mg ha^{-1} for continuous fertilized maize (Franzel et al. 2002). Over a 5-year-cycle of two fallow years plus three post-fallow cropping seasons, the IF option produced 8.8 Mg ha^{-1} of maize as compared to 4.8 Mg ha^{-1} for the continuous unfertilized treatment, which is the common practice among farmers in the area. Both returns to land and labor were much higher for IF than for continuous, unfertilized maize (Franzel et al. 2002).

Conceptual framework

Definition of dependent variables for incidence and scale of adoption

Many socioeconomic studies on the adoption of agricultural technologies restrict their analysis to the incidence of adoption, i.e., whether farmers have adopted them or not (Feder et al. 1985). However, the knowledge that a farmer is using a certain technology does not provide any information about the extent of its use, being a more policy-relevant variable as argued in the seminal paper by Feder et al. (1985).

With respect to incidence of adoption, we define the dichotomous dependent variable 'Decision to adopt Improved Fallows' (Y) as follows: Testers who have planted at least one IF after they experienced the effect of their initial IF on a subsequent crop are considered adopters. With respect to the scale of the IF practice, we have adopted an index applied by Pisanelli et al. (2003) for the case of densely populated western Kenya. Since the IF system usually involves a 4-year-cycle of two fallow years plus two subsequent cropping seasons, a farmer who practices the technology to its full extent would plant one quarter of his maize area with IF each year. Hence, the interval-scale dependent variable 'Intensity of Adoption of Improved Fallows' (IA) is defined as follows:

$$IA\ [\%] = \frac{\mathrm{IF}}{0.25 \cdot M} \cdot 100,$$

where IF = annual area planted with improved fallow, M = annual area planted with maize

Hypotheses to be tested related to determinants of adoption

Apart from the general biophysical performance and profitability, a range of observable and unobservable variables influence the adoption of an agricultural technology at the individual household level. In the case of IF, Franzel (1999) identified factors of potential relevance based on case studies in three countries of contrasting population densities in sub-Saharan Africa. However, this study was conducted in 1997, and the author stated that it was too early to definitively assess the acceptability of IF at any of the three sites (Franzel 1999, p. 313). Figure 1 depicts the factors we postulate to influence the adoption of IF among testers of the technology, measured by the incidence variable Y and the scale variable IA. They include socioeconomic determinants such as education, age and gender of the head of household, and availability of labor and land. Moreover, agroecological determinants such as soil texture and declining soil fertility are accounted for. These hypothesized influencing factors are

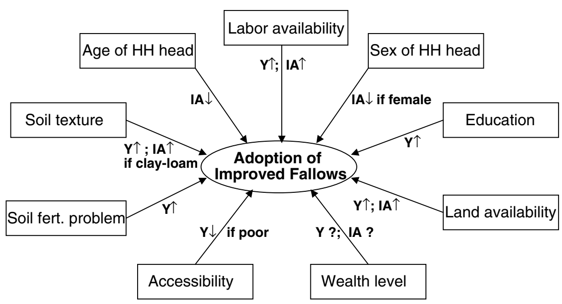

Figure 1. Hypothesized determinants of the adoption of improved fallows (IF) in eastern Zambia, and expected direction of influence (Y = decision to adopt IF; IA = extent to which IF are practiced).

based on the previous study by Franzel (1999), a systematic review of determinants of adoption of agricultural innovations by Feder et al. (1985), and our own insights during the field research.

The problem of sample selection bias

Y is a dichotomous variable which takes on the value of 0 for non-adopting farm households or 1 for adopters. Values of IA are observed only if $Y = 1$. Therefore, the distribution of IA is not normal, but incidentally truncated, which means that an estimation of regressors using OLS can lead to biased results (Greene 2000, p. 927). Unobserved or unobservable characteristics of adopters which differentiate them from non-adopters may have an influence on the scale of adoption. Hence, the estimated regression coefficients on the hypothesized determinants of the IA may be affected by sample selection bias (Heckman 1979). In order to account for the non-randomness of the selection rule, Heckman (1979) proposed the following two-stage estimation procedure (summarized from Heckman 1979, pp. 154–156; Greene 2000, pp. 928–930): Let the equation which determines sample selection (i.e., decision to adopt IF [Y]) be

$$z^* = \gamma w + v,$$

and let the equation of primary interest (i.e. scale of IF practice [IA]) be

$$y = \beta x + \varepsilon,$$

where w, x = vectors of exogenous regressors; γ, β = vectors of parameters; v, ε = error terms

Selection mechanism

The dependent variable z^* can be interpreted as the difference in expected returns between adoption and non-adoption (Carletto and Morris 1999). Each household uses idiosyncratic criteria and will decide to adopt if $z^* > 0$. Since z^* is not directly observable, a binary variable z is defined which takes on the value of 1 if the household decides to adopt and the value of 0 otherwise:

$$z = \gamma w + v,$$

where

$$z = 1 \quad \text{if } z^* > 0 \quad \text{and} \quad z = 0 \text{ otherwise.}$$

$$\begin{aligned}\text{Prob}(z = 1) &= \text{Prob}(z^* > 0) = \text{Prob}(v > -\gamma w) \\ &= \text{Prob}(\gamma w) = \Phi(\gamma w),\end{aligned}$$

where Φ is the cumulative distribution at γw.

Regression model

$$y = \beta x + \varepsilon, \quad \text{observed only if } z = 1$$

v,ε are assumed to be distributed according to a bivariate Normal distribution with mean zero, standard deviation σ and correlation ρ. Then:

$$E[y \mid z = 1] = \beta x + \rho\sigma\lambda(\gamma w),$$

where

$$\lambda = \phi(\gamma w)/\Phi(\gamma w),$$

where ϕ is the density function at γw. λ is the inverse mills ratio (IMR) and $\rho\sigma$ equals the regression coefficient on the IMR, β_λ. As shown above, the IMR is the ratio of the value of the density function of a standard normal distribution calculated at γw and the probability of being in the adopter-subsample which equals the value of the cumulative distribution at γw for adopters and its complement to 1 for non-adopters. The IMR can be interpreted as a variable which captures all unobserved and unobservable characteristics which potentially could have an effect on the final outcome variable of interest, i.e., the IA. Examples are the individual level of risk aversion and former experiences with projects. By including the IMR in the second-stage equation, the sample selection bias is corrected for, and OLS can safely be used for the estimation of β (Carletto and Morris 1999). The two-stage procedure described above was applied as follows:

Decision to adopt improved fallows (Y).

$$Y = \gamma w + v.$$

A Probit model was used to obtain maximum likelihood estimates of γ. For each observation, the IMR λ was derived.

Intensity of adoption of improved fallows (IA).

$$IA = \beta x + \beta_\lambda \lambda + \varepsilon.$$

Table 1. Major indicators used to assess the wealth level of sample households in eastern Zambia

Wealth indicator	Wealth category			
	Well-off	Fairly well-off	Poor	Very poor
Brick house with roof made of iron sheets	Yes	No	No	No
Number of cattle	> 5	< 10	< 5	None
Ox-drawn implements	Yes	No	No	No
Able to send children to school	Yes	Some	Some (primary level)	No
Owns a bicycle	Yes	Yes	No	No
Cultivated area (ha)	> 2.5	> 1.5–2.5	1.0–1.5	> 1.0
Per capita cultivated area (ha/person)	> 0.50	0.50–0.75	0.25 to > 0.50	> 0.25
Hires labor	Yes	Yes	No	No
Sells labor	No	No	Yes	Yes

Source: Adapted from Phiri et al. (2004).

Using OLS, β was estimated conditional on adoption by regressing IA on x and λ, thus correcting for sample selection bias. The same procedure was followed by Kumar (1994), for example.

Methodology

The criterion for farmers to be included in the study was that they had to have 3 years of experience with IF, that is, that they had planted IF for the first time in the 1996/1997 growing season, or earlier. Lists containing this information were available from ICRAF and served as sampling frame. A random sample of 100 IF testers was selected, stratified by sub-district. Interviews were conducted in January and February 2001, using questionnaires measuring the variables depicted in Figure 1. The period covered to assess adoption were the growing seasons 1998/1999 to 2000/2001. Given the usual practice of a two-year fallow period, at least one IF had been cut by the end of 1998 so that at the end of the 1998/1999 growing season at least one post-fallow crop had been harvested. The data regarding IF which had already been cut at the time of the interview are based on farmer recall. If practicable distance-wise, information on currently established IF was cross-checked in the field.

The household wealth level was assessed based on indicators that Phiri et al. (2004) had identified in four ICRAF target villages in 1998, using participatory techniques. In each village, a group of key informants encompassing the village headman, an extension staff member, and male and female as well as poor and better-off farmers, determined the number of different groupings based on wealth endowment that existed in the village. After describing the differences between the groups, the informants drew up a list of wealth indicators (Table 1). Using these indicators, we identified the wealth category of each respondent household. Sources of off-farm income were also considered. Obviously, in the assessment of an individual household's wealth level not every single indicator can apply in each case, e.g., a large number of cattle can compensate for a relatively small cropping area, but the combination of all indicators made it possible to draw valid conclusions.

Results

Adoption rate

Eight categories of farmers were identified regarding the planting of IF in the three growing seasons from 1998/1999 to 2000/2001 (Table 2).

Farmers who had planted IF in two of the seasons (categories I and II) were classified as adopters. Farmers who had not planted during the two previous years or who claimed to be no longer interested (categories III, IV and V) were classified as non-adopters of IF. In six cases (categories VI, VII and VIII), it was not possible to reliably assess adoption to date. Thus, out of 94 respondents who could be categorized, 71 (75.5%) were adopters and 23 (24.5%) non-adopters.

Table 2. Categories of respondents regarding the planting of improved fallows (IF) in eastern Zambia

	Respondent category	No. of respondents	Adoption classification	No. of respondents within class
I	Planting IF without any outside support[a]	49	Adopter	71
II	Planting IF regularly with outside support[a]	22		
III	Planted one IF with outside support in 1998 but clearly lost interest	5	Non-adopter	23
IV	Planted IF > 2 years ago but intends to plant again if seed is provided	3		
V	Stopped planting IF	15		
VI	Planted IF > 2 years ago but intends to plant again this season using own seed	3	Adoption cannot be reliably assessed yet	6
VII	Was discouraged by failure of first IF but now tries again	2		
VIII	Insecure about own capability of planting IF	1		
Total		100		100

[a]'With outside support' means that NGOs provided farmers with seeds for IF. 'Without any outside support' means that farmers used seeds from previous IF for planting, or acquired seeds from other farmers.

Determinants of the decision to adopt Improved fallows

Three households were excluded from the regression analysis because their adoption intensity exceeded the mean *IA* by more than three standard deviations. Hence, the validity of the data obtained from these households had to be doubted. The results of the Probit model regarding the adoption decision are listed in

Table 3. Determinants of the adoption of improved fallows in eastern Zambia, *Y* (Probit estimates)

Explanatory variable	Coefficient	*t*-value	Mean
Constant	−0.5419	−1.969*	
POORACC	−0.2470	−2.010**	0.132
SOILPROB	0.4980	2.593**	0.956
SOILTEX	−0.1588	−1.591	0.462
HEADSEX	0.0194	0.198	0.275
HEADAGE	0.0028	0.779	48.407
EDUC	≤0.0001	−0.001	6.659
WEALTH1	−0.1005	−0.902	0.187
WEALTH3	0.2980	2.313**	0.286
WEALTH4	−0.3190	−1.943*	0.121
FARMSIZE	0.0318	1.942*	4.741
LABWEIGH	0.0524	1.722*	3.659
CAMP3	−0.4737	−3.054***	0.209
n = 91			
χ^2 = 38.04***			
Percentage predicted correctly = 82.42			

Dependent variable: *Y* = decision to adopt improved fallows (0 = no, 1 = yes), mean = 0.747. Definition of independent variables: POORACC = dummy = 1 if village is quite remote and not accessible by vehicle at the height of the rainy season, 0 otherwise. SOILPROB = dummy = 1 if low soil fertility is perceived to be a problem, 0 otherwise. SOILTEX = predominant soil texture (0 = sandy-loam, 1 = clay-loam). HEADSEX = sex of household head (0 = male, 1 = female). HEADAGE = age of household head (years). EDUC = years of formal education of the most educated household member. WEALTH1 = -dummy = 1 if household belongs to the 'very poor' wealth stratum, 0 otherwise. WEALTH3 = dummy = 1 if household belongs to the 'fairly well-off' wealth stratum, 0 otherwise. WEALTH4 = dummy = 1 if household belongs to the 'well-off' wealth stratum, 0 otherwise. FARMSIZE = farm size (ha). LABWEIGH = household labor availability during the cropping season. The working capacity of individual household members was weighted according to age and full or part-time availability for farm work. CAMP3 = dummy = 1 if household resides in Jerusalem Camp, 0 otherwise. *, **, *** Significant at the 10%, 5%, 1% level of error probability.

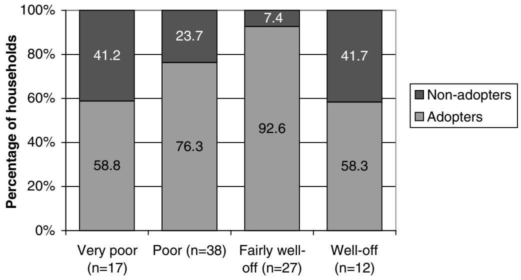

Figure 2. Adoption of improved fallows in eastern Zambia, differentiated by wealth category.

Table 3. Starting from their mean values, the coefficients represent the change in the probability of adoption ($\in[0,1]$) for a one-unit change in each independent interval-scale variable, and the discrete change in the probability for each dichotomous variable, taking all other independent variables at their means.

The following variables were found to have a significant influence on the adoption decision ($p < 0.10$).

Accessibility of the village (POORACC): The probability of adopting IF decreases by 0.25 for households who reside in poorly accessible villages.

Perception of low soil fertility as a current problem (SOILPROB): The probability of adopting IF increases by 0.50 if low soil fertility is perceived to be a current problem.

Wealth level (WEALTH3, WEALTH4): The relationship between wealth and the adoption of IF is not a linear one. Adoption increases up to a certain wealth level, beyond which it drops sharply (Figure 2; Pearson chi-square test significant at $p < 0.05$). Relative to a household in the 'poor' wealth category, the probability of adopting IF increases by 0.30 for a household categorized to be 'fairly well-off', but it decreases by 0.32 for a 'well-off' household (Table 3).

Land availability (FARMSIZE): The probability of adopting IF increases by 0.03 if one additional hectare of land is available, relative to the mean farm size of 4.74 ha. Wealth and farm size are positively correlated ($p < 0.01$), but the correlation coefficient is relatively small at 0.51 since other wealth indicators were also taken into account, such as the number of animals owned, type of housing and sources of off-farm income (see Table 1). Hence, a positive relationship between farm size and adoption of IF does not contradict the ambiguous relationship between wealth level and adoption described above.

Labor availability (LABWEIGH): The probability of adoption increases by 0.05 if one additional man-equivalent of family labor is available, relative to the mean household labor capacity of 3.7 man-equivalents.

Residence in Jerusalem camp (CAMP3): The probability of adopting IF drops drastically (by 0.47) for households residing in the sub-district of Jerusalem. This variable was not anticipated to have an influence; therefore, it does not appear in the conceptual framework.

Scale of adoption of improved fallows

Table 4 presents the descriptive results regarding the area of IF planted, and the related 'Intensity of Adoption of IF' (*IA*). The 71 farmers categorized as adopters in this study planted an average of 1542 m^2 to IF each year over the 3-year-period. The average *IA* was found to be 42%; that is, the average adopter planted 42% of the land that a full adopter would plant. This measure is based on the maize area (see Section 3), but the maximum *IA* of 188% shows that the use of IF is being

Table 4. Area of Improved Fallow (IF) planted in eastern Zambia, and related adoption intensity

	n	Min	Max	Mean	SE	Median
Total area of IF planted between 1998/1999 and 2000/2001 (m^2)	78	200	36,750	3626	574	2000
Annual area planted with IF (m^2)[a]	71	108	12,250	1542	212	933
Intensity of Adoption of IF (%)[b]	68	1.1	188.4	42.3	7.45	29.3

[a]Regarding adopters only; i.e., farmer categories III, VII, and VIII are not considered (see Table 2).
[b]Three extreme values were identified using a boxplot. They were excluded from the regression analysis because the underlying data were based on recall and their validity was doubtful.

Table 5. Determinants of the intensity of adoption of Improved Fallows in eastern Zambia, *IA* (OLS estimate)

Explanatory variable	Coefficient	*t*-value	Mean
Constant	40.2069	1.543	
POORACC	0.9879	0.061	0.088
SOILTEX	16.5665	1.792*	0.471
HEADSEX	−17.8870	−1.696*	0.265
HEADAGE	−0.7455	−1.951*	49.059
EDUC	1.1165	0.857	6.750
WEALTH1	13.3021	0.823	0.147
WEALTH3	25.8104	2.253**	0.353
WEALTH4	−17.8681	−0.988	0.088
FARMSIZE	−1.6881	−1.115	5.089
FARMMEM	16.7714	1.717*	0.757
LABHAWEI	5.4967	1.417	1.862
IMR	15.7489	0.853	0.266
$n = 68$			
R^2 (adjusted) = 0.088			
$F = 1.54$			

Dependent variable: *IA* = intensity of adoption of improved fallows (%), mean = 42.342. Definition of independent variables as in Table 3, apart from: FARMMEM = per capita land availability (ha/person). LABHAWEI = weighted household labor availability during the cropping season per ha. IMR = inverse mills ratio. *,** Significant at the 10%, 5% level of error probability, respectively.

expanded to land intended for the cultivation of other crops as well. The median values presented are considerably smaller than the related means, indicating that the means are inflated by relatively few large values.

Determinants of the scale of adoption of improved fallows

The results of the second-stage OLS regression on the hypothesized determinants of *IA* are listed in Table 5. The Inverse Mills Ratio (IMR) can be interpreted as a variable which captures unobserved or unobservable characteristics potentially influencing the scale of adoption (see Section 3). The sign of its regression coefficient implies a positive influence of these unobserved characteristics within the subsample of adopters; however, it is statistically not significant.

The following variables were found to have a significant influence on *IA* ($p < 0.10$).

Predominant soil texture (SOILTEX): A clay-loam environment increases *IA* by 16.6 percentage points as compared to a sandy-loam environment.

Wealth level (WEALTH3): Belonging to the 'fairly well-off' wealth stratum increases *IA* by 25.8 percentage points. In contrast, the regression coefficient for the 'well-off' category is negative. Unlike in the case of the Probit model with respect to the adoption decision, the coefficient for the very poor group is positive. Consistent with this result, the only statistically significant difference regarding IA is observed between the fairly well-off and well-off stratum. In the case of the latter, the coefficient of variation is particularly large (Table 6).

Per capita land availability (FARMMEM): *IA* increases by 16.8 percentage points per hectare of land available per person. However, it is important to note that the regression coefficient on the variable FARMSIZE is negative. Farm size is positively correlated with the area planted with maize, which *IA* is based upon (Pearson correlation coefficient = 0.48, $p < 0.01$). *IA* and maize area are negatively correlated (Pearson correlation coefficient = − 0.26, $p < 0.05$). Adopters cited lack of land (62%) and labor (61%) as the main constraints to the further expansion of IF on their farms.

Age of the household head (HEADAGE): *IA* decreases with increasing age of the household head, by 0.75 percentage points per year.

Gender of the household head (HEADSEX): For female headed households, *IA* decreases by 17.9 percentage points.

Table 6. Intensity of adoption of improved fallows in eastern Zambia (*IA*, %), differentiated by wealth category

Wealth category	*n*	Mean[a]	SE	CV (%)[b]	Median
Very poor	10	36.3ab	9.13	79.6	21.6
Poor	28	36.6ab	4.99	72.3	29.0
Fairly well-off	24	57.0b	10.56	90.8	37.3
Well-off	6	20.7a	9.83	116.3	12.2

[a]Homogeneous subsets (a, b) are based on Games–Howell test, $p < 0.10$.
[b]Coefficient of variation.

Discussion and implications for agricultural research and extension

An overall adoption rate of 75% of those farmers who tested the technology confirms the assessment by Franzel et al. (2002) that, in general, IF are a suitable practice under the socioeconomic and biophysical conditions of smallholder agriculture in eastern Zambia. Hence, the question whether 'initial testers adopt the technology' can be answered in the affirmative. Of course, since this figure applies to farmers who have tested IF only, no statement can be made regarding the overall adoption rate in the study region.

An average adoption intensity of 42% of the potential scale of the practice is also an encouraging result (Table 4). However, only 10 adopters (14%) reported that they would expand the practice in the near future. Regarding more than 60% of the testers, very limited land and/or labor resources constrain further expansion.

The following exogenous factors were found to influence the adoption decision (Y) and/or the scale at which IF are practiced (IA). The significantly influenced variables are shown in parentheses:

Current problem of soil depletion ($\rightarrow$ Y)

As hypothesized, the farmers tend not to adopt IF as a preventive measure since land would have to be fallowed which is still productive.

Accessibility of the village ($\rightarrow$ Y)

The probability of adoption is substantially lower in villages which are poorly accessible. Especially during the period of testing the technology, the farmers are dependent on outside seed sources and advice. If their first IF fails, they easily become discouraged if they do not receive any project support. Once this critical initial stage of experimentation is over and the farmers become independent of outside seed supply, accessibility does not significantly influence the extent of the practice.

Soil texture ($\rightarrow$ IA)

The data do not support a significant influence of the soil texture on the adoption decision. But the intensity of adoption is higher on clay-loam soils where IF perform better because they retain more moisture than sandy-loam soils. On the latter, farmers also adopt the technology since other options for improving soil fertility are limited. However, the risk of failure of IF is higher; therefore, farmers may limit the practice to a relatively small portion of their farm.

Wealth ($\rightarrow$ Y, IA)

There is a non-linear relationship between wealth and the decision to adopt IF (Y), and between wealth and the scale of adoption (IA). Although wealth level and farm size are positively correlated, the relationship is not strong enough to make it possible to use the two variables interchangeably. As far as farm size is concerned, 'well-off' farmers do not differ significantly from 'fairly well-off' farmers, but on the average they own 12.1 heads of cattle as compared to 2.9 for farmers in the 'fairly well-off' category. The difference is statistically significant at $p < 0.01$. Cattle are kept in fenced areas near the homestead at night. Ninety-two percent of 'well-off' farmers collect their manure and use it for soil fertility maintenance, as opposed to only 30% of the farmers in the 'fairly well-off' stratum. Furthermore, 'well-off' farmers have different sources of off-farm income which can be assumed to be more profitable than those tapped by farmers in the other wealth categories, allowing them to purchase more adequate amounts of mineral fertilizer. Hence, well-off farmers had a relatively low adoption rate because, after testing IF, many probably returned to using other options to maintain soil fertility.

The poor and very poor had lower rates than the fairly well-off perhaps because they were more risk averse: Any innovation entails a subjective risk (there is less certainty with respect to the yield if an unfamiliar technique is adopted) and objective risks (Feder et al. 1985). In the case of IF, the objective risks are mainly related to weather variation, bushfire, and susceptibility to pests. When farmers evaluate risk, they take a number of factors into consideration, including their perception of the probability of success and the consequences of making a wrong decision. Poor farmers with access to only very limited land resources protect their family's subsistence needs first and, therefore, tend to plant food or other preferred crops (Upton 1987, p. 47).

The relationship between wealth and adoption intensity (IA) is almost analogous. ‘Fairly well-off’ farmers practice IF to the largest extent, and ‘well-off’ farmers to the smallest (Table 6). However, unlike in the model of the adoption decision as such, the difference in the scale of the practice between ‘very poor’ and ‘fairly well-off’ farmers is statistically not significant. Contrary to the ‘well-off’ stratum, the regression coefficient for ‘very poor’ farmers is positive. This means that if they do adopt the technology, they practice it to a relatively large extent which is logical because they do not have any other means for improving the fertility of their fields (Table 5).

Land availability ($\rightarrow$ Y, IA)

In contrast to the wealth level, a positive relationship was found between the adoption decision (*Y*) and total farm size since the IF technology requires taking part of the available land resources out of production. In this respect, IF seem to be ideally suited for farmers in the ‘fairly well-off’ category whose land resources are large enough to allow fallowing part of them, while other means of soil fertility restoration (fertilizer and manure) are still rather limited, in contrast to the well-off stratum. In accordance with the above considerations, per capita land endowment was found to positively influence *IA*. The more land is available per household member, the more can be fallowed before reaching a threshold area which needs to be cultivated in order to ensure sufficient production. Despite this positive relationship, the *IA* tends to decline with increasing total farm size (Table 5). Since total farm size and maize area are positively correlated, the absolute area planted with IF has to be larger on a large farm in order to reach a given level of IA. It appears that, eventually, labor availability becomes the limiting factor, resulting in a declining IA with increasing farm size.

Labor availability ($\rightarrow$ Y, IA)

The absolute household labor capacity positively affects the adoption decision (Table 3). Labor availability per ha was found to be positively related to the *IA*, but its regression coefficient is statistically not significant (Table 5). However, beside the limitations in land resources available for fallowing, a lack of labor was the most frequently cited constraint to the expansion of the practice.

Age of the household head ($\rightarrow$ IA)

Age does not influence the adoption decision, but older farmers practice IF to a smaller extent (Table 5). A potential explanation may be that with increasing age of the household head there are less mouths to feed because children marry and set up their own households. Hence, the pressure to increase maize production is less pronounced and therefore older farmers may see no need to plant IF extensively. However, within our sample there is no negative correlation between the age of the household head and the number of household members. Other explanations may be that older farmers are more risk averse, or that declining strength at older age makes the cutting of large IF plots difficult.

Gender of the household head ($\rightarrow$ IA)

Both male and female headed households equally adopt IF, but female headed households practice the technology to a smaller extent (Table 5). However, it is important to note that the difference in median *IA* is only 4.8 percentage points, indicating that the mean *IA* of male headed households is inflated by relatively few large values. In many instances, a distinction by gender of the household head is not meaningful since male heads of households may earn off-farm income while the spouse runs the farm. However, in our sample all male heads of household work on the farm full time during the cropping season. In 38% of these households both the household head and his spouse are involved in farm decision making, in the remaining households it is mainly the household head. Differences in land and labor endowment as well as wealth status found between male and female headed households are accounted for by our model. Women may practice the technology at a slightly smaller scale because the cutting of IF requires considerable physical strength.

Moreover, the extent of the IF practice may be limited by the multiple roles and tasks of women.

Residence in Jerusalem camp ($\rightarrow$ Y)

The relatively low adoption rate in Jerusalem Camp may be due to poor performance of IF on the particularly sandy soils in this area.

These findings suggest several implications for agricultural research and extension. First they confirm the attractiveness of IF to all wealth groups and to both male and female farmers. Although the adoption rate is relatively low at 59% among the 'very poor' stratum, this shows that there are no barriers preventing this group from using the technology. And once farmers in the two lower wealth strata have decided to plant IF, they practice the technology on relatively large portions of their farms.

Since a lack of labor for planting and weeding IF is a serious constraint which affects both the adoption and expansion of the technology, further research should emphasize methods for reducing labor use, such as tree species which can be direct-seeded. For the same reason, the practice of intercropping IF species with maize should be given greater attention since this reduces both land and labor requirements. However, since these labor and land-saving options lead to a less pronounced impact on subsequent crop yields, further agro-economic research will be crucial to assess their profitability.

'Well-off' farmers should not be a high priority group regarding extension activities. Other options for soil fertility maintenance such as manure and mineral fertilizer are available to them; therefore, both their adoption rate and adoption intensity are comparatively low. The 'fairly well-off' stratum eagerly adopts IF. Hence, extension workers do not need to invest a lot of time and effort in encouraging this group to test IF. The greater share of extension efforts should thus be directed towards 'very poor' and 'poor' farmers. For these groups it may be difficult to take land out of production for the planting of IF even though this would increase future harvests and enhance long-term food security. Hence, alternative extension strategies may be necessary to encourage adoption, such as the provision of food aid until the maize crop following the first IF can be harvested. Furthermore, care should be taken not to neglect the monitoring of IF testers in remote villages. If the farmers' first IF fails and they do not receive any project support and encouragement, they tend to abandon the technology. Finally, the study shows the importance of distinguishing between planters and adopters. Whereas all of the sample farmers had planted IF, almost one-third had not adopted. Moreover, the extent of planting IF varied among adopters, and the factors associated with the extent of planting differed from those associated with adoption.

Acknowledgements

The authors gratefully acknowledge the kind support of the staff of Msekera Research Station, eastern Zambia, and the willingness of the interviewed farm households to participate in the survey.

References

Borlaug N.E. 1988. Challenges for global food and fiber production. J. Roy. Swedish Acad. Agric. Forest., Suppl. 21: 15–55.

Boserup E. 1965. The Conditions of Agricultural Growth. George Allen and Unwin, London, UK.

Carletto C. and Morris S.S. 1999. Designing methods for the monitoring and evaluation of household food security in rural development projects. Technical Guide No. 10. International Food Policy Research Institute (IFPRI), Washington, DC, USA.

De Rouw A. 1995. The fallow period as a weed-break in shifting cultivation (tropical wet forests). Agric., Ecosyst. Environ. 54: 31–43.

Feder G., Just R.E. and Zilberman D. 1985. Adoption of agricultural innovations in developing countries: a survey. Econ. Develop. Cult. Change 33: 255–294.

Franzel S. 1999. Socioeconomic factors affecting the adoption potential of improved tree fallows in Africa. Agroforest. Syst. 47: 305–321.

Franzel S., Phiri D. and Kwesiga F.R. 2002. Assessing the adoption potential of improved tree fallows in eastern Zambia. In: Franzel S. and Scherr S.J. (eds), Trees on the Farm: Assessing the Adoption Potential of Agroforestry Practices in Africa. CAB International, Wallingford, UK, pp. 37–64.

Gladwell M. 2000. The Tipping Point: How Little Things Can Make A Big Difference. Little, Brown & Co., New York, USA.

Greene W.H. 2000. Econometric Analysis, 4th Ed. Prentice-Hall International, Upper Saddle River, USA.

Heckman J.J. 1979. Sample selection bias as a specification error. Econometrica 47: 153–161.
Juo A.S. and Lal R. 1977. The effect of fallow and continuous cultivation on the chemical and physical properties of an Alfisol in western Nigeria. Plant Soil 47: 567–584.
Kumar S.K. 1994. Adoption of hybrid maize in Zambia: effects on gender roles, food consumption, and nutrition, Research Report No. 100. International Food Policy Research Institute (IFPRI), Washington, DC, USA.
Kuntashula E., Ajayi O.C., Phiri D., Mafongoya P. and Franzel S. 2002. Factors influencing farmers' decisions to plant improved fallows: a study of four villages in Eastern Province of Zambia. In: Kwesiga F., Ayuk E. and Agumya A. (eds), Proceedings of the 14th Southern African Regional Review and Planning Workshop, 3–7 September 2001, Harare, Zimbabwe. ICRAF Regional Office, Harare, Zimbabwe, pp. 104–110.
Kwesiga F.R. and Coe R. 1994. The effect of short rotation *Sesbania sesban* planted fallows on maize yield. Forest Ecol. Manage. 64: 199–208.
Kwesiga F.R., Franzel S., Place F., Phiri D. and Simwanza C.P. 1999. *Sesbania sesban* improved fallows in eastern Zambia: their inception, development, and farmer enthusiasm. Agroforest. Syst. 47: 49–66.
Mudhara M., Hilderbrand P.E. and Nair P.K.R. 2003. Potential for adoption of Sesbania sesban improved fallows in Zimbabwe: a linear programming-based case study of small-scale farmers. Agroforest. Syst. 59: 307–315.
Phiri D., Franzel S., Mafongoya P.L., Jere I., Katanga R. and Phiri S. 2004. Who is using the new technology? The association of wealth status and gender with the planting of improved tree fallows in Eastern Province, Zambia. Agricult. Syst. 79: 131–144.
Pisanelli A., Franzel S., De Wolf J., Rommelse R. and Poole J., submitted for publication. The adoption of improved tree fallows in western Kenya: farmer practices, knowledge, and perception. Agroforest. Syst. (accepted)
Ruthenberg H. 1980. Farming Systems in the Tropics, 3rd ed. Clarendon Press, Oxford, UK.
Sanchez P.A., Shepherd K.D., Soule M.J., Place F., Buresh R.J., Izac A.N., Uzo Mokwunye A., Kwesiga F.R., Nderitu C.G. and Woomer P.L. 1997. Soil fertility replenishment in Africa: an investment in natural resource capital. In: Buresh R.J., Sanchez P.A. and Calhoun F.G. (eds), Replenishing Soil Fertility in Africa. Calhoun SSSA Special Publication No. 51. Soil Science Society of America and American Society of Agronomy, Madison, WI, pp. 1–46.
Upton M. 1987. African Farm Management. Cambridge University Press, Cambridge, UK.
Young A. 1989. Agroforestry for Soil Conservation. CAB International, Wallingford, UK.