AAAE Conference Proceedings (2007) 151-163

Soil Fertility Management And Maize Productivity In Malawi: Curvature Correct Efficiency Modeling And Simulation

Tchale H.[1] *and Sauer J*[2]
[1]*World Bank, Malawi*
[2]*Royal Veterinary and Agricultural University (KVL), Copenhagen, Denmark*

Abstract

We assess the level and determinants of relative technical efficiency of maize-based smallholder farmers using a translog stochastic frontier (TL) model and a symmetric generalized Barnett production function (SGB), both of which are tested for economic regularity conditions. In addition, we conduct a bootstrapping procedure in order to infer about the probability distributions and significance of the relative efficiency values for farmers using different soil fertility management options. The results indicate that higher levels of relative technical efficiency obtain when farmers use integrated soil fertility options compared to the use of chemical fertilizer only. The consistency of the results across the two models increase the robustness of the findings. The paper concludes that productivity growth under the maize-based farming systems is considerably higher when farmers use integrated soil fertility management options. Thus there is need for policy and institutional interventions that enhance farmers' adoption and scaling-up of integrated soil fertility management.

Keywords: Smallholder agriculture, relative technical efficiency, soil fertility management, Malawi

Introduction

The presence of inefficiencies among smallholder farmers means that output can be increased without additional inputs and technological improvements. Therefore empirically sound measures of efficiency are necessary in order to determine the magnitude of the gains that could be obtained by using appropriate agricultural practices such as integrated soil fertility management options. An important policy implication is that it might be more cost-effective to achieve short-run increase in output, food security and income by promoting the adoption and scaling-up of soil fertility management options that are relatively more efficient. This is particularly more important for Malawi because smallholder agriculture, which is dominated by maize production, is already operating at its land frontier and there is very little or no scope to increase the supply of land to meet the growing demand for food. The expansion in crop area which was the major source of maize output growth till the 1980s, is no longer possible due to population pressure. Thus the only plausible solutions to increasing food production lie in raising the productivity of land by improving the technical efficiency and/or through technological improvements. Efficiency gains will have a positive impact on raising farm incomes of these largely poor resource-endowed farmers.

Given such a background, the paper assesses the level and determinants of relative technical efficiency of hybrid maize production among smallholder farmers and identifies the factors that explain the variation in the efficiency of individual smallholder farmers. The analysis compares results from the translog model and a symmetric generalized Barnett production function (SGB), both of which are tested for economic regularity conditions. Furthermore, we conduct Monte Carlo bootstrapping procedure in order to infer about the probability distributions and the significance of the efficiency values under different soil fertility management options. The comparison of two methodologies is important because to the extent that the findings are consistent, the robustness of the findings will be enhanced. The central argument in this paper is that Malawi's smallholder maize productivity can be resuscitated through a combination of integrated soil fertility management and provision of public policy amenities such as credit and extension as well as infrastructure that support the efficient performance of input and output markets. Efficiency studies, especially focusing on the relationships between efficiency, policy indicators and farm-specific husbandry practices have not been widely conducted in Malawi. An understanding of these relationships would provide policy makers with information needed to design programmes that can contribute to increasing food production potential, among smallholder farmers, who happen to produce the bulk of the country's food.

The few studies that have measured efficiency among Malawian smallholder farmers have not tested either globally or locally the regularity of the functional forms used in efficiency analysis. As such it is highly likely that policy implications drawn from such findings may have been liable to error.

The rest of the paper is arranged as follows: the next section presents the policy environment in Malawi since 1980s and how it has generally impacted on the development of smallholder agriculture. This is followed by a review of related studies on factors that influence technical efficiency of smallholder farming systems in sub-Saharan Africa. Section four presents the discussion of stochastic frontier analysis as well as the symmetric generalized Barnett production function. Section five presents the data used in the analysis followed by section six which discusses the empirical results. Section seven concludes with main findings and their policy implications.

Agricultural policy environment in Malawi and its impact on smallholder farmers

The Government of Malawi adopted the Structural Adjustment Program in 1981 which among other objectives was aimed at instituting agricultural policy reforms aimed at removing distortions and biases against smallholder agriculture. Such reforms were envisaged to create a conducive environment and improve access to productive resources among all groups of smallholder farmers. As such, Government obtained a number of structural adjustment loans from 1981 to the early 1990s aimed at implementing reforms towards putting in place appropriate price policy in order to provide adequate incentives to producers and expanding the role of the private sector in the marketing of smallholder crops (Bhalla et al. 2000). Among many other researchers, Dorward et al. (2004a), Dorward et al. (2004b) and Kydd and Dorward (2001) provide detailed analysis and discussion of Malawi's agricultural policy issues and its subsequent impacts on the performance of the economy in general and smallholder agriculture, in particular.

In many of these policy discussions, the apparent outcome of policy reforms is that despite the de-regulated agricultural production and marketing environment, the improvement of technical efficiency still remains largely unattainable among the majority of the smallholder farmers. Chirwa (2003) and Zeller et al. (1998) indicate that there have been little improvements in terms of productivity gains and in fact, smallholder performance has largely been stagnant or has experienced some retrogression. This is evidenced by declining self-sufficiency in staple maize production. For instance, taking the case of the most important smallholder crops (maize and tobacco), all indicators show a mixed productivity trend, measured as output per hectare. As observed by Chirwa (2003), maize productivity has either marginally improved or remained stagnant since the 1980s until the 1990s in there was an increased evidence of a highly fluctuating yield trend despite government support towards the end of the decade. In the case of tobacco, the substantial yield gains attained in the early 1990s more especially after the repeal of the Special Crops Act have been reversed as average tobacco yield has been declining since the mid-1990s.

The declining productivity of these major crops is mostly explained by the low levels of chemical fertilizer application. The agricultural policy reforms entailed the de-control of agricultural input and output markets as well as the removal of input subsidies. As a result of the de-regulation of agricultural prices, the input/output price ratios increased tremendously resulting in a substantial reduction in the profitability of smallholder agriculture. This has crippled the capacity of smallholder farmers to afford chemical fertilizers thereby laying the fundamental basis for the low levels of productivity and widespread food insecurity experienced by the majority of smallholder farmers, particularly from the mid 1990s. These challenges have therefore acted as a precursor to unsustainable agricultural intensification and worsening poverty. Thus the development of integrated soil fertility management options has been widely supported as the only viable strategy to enable smallholder farmers to attain satisfactory levels of productivity while at the same time building the productive capacity of the soil through organic matter accumulation and biological nitrogen fixation. However, farmers' awareness of these technologies needs to be given a priority so as to positively influence their perception of such technologies. This study therefore aims at coming up with policy relevant findings on the impact of integrated soil fertility management options on relative technical efficiency so that researchers and technology transfer specialists can use these findings as a basis for their outreach campaigns.

Review of smallholder technical efficiency

Technical efficiency is a component of productive efficiency that reflects the ability of a farmer to maximize output from a given level of inputs. Theoretical developments in measuring technical efficiency started with the work of Farrell (1957).

There is now a growing literature on the technical efficiency of African agriculture. Recent notable studies focusing on Sub-Saharan Africa, in particular, include Heshmati and Mulugeta (1996); Fulginiti and Perrin (1998); Seyoum et al. (1998); Townsend et al. (1998); Weir (1999); Weir and Knight (2000); Mochebelele and Winter-Nelson (2000); Chirwa (2003); Sherlund et al. (2004) and Okike et al. (2004).

Most of these studies report low to moderate technical efficiencies that range from as low as 0.24-0.36 among farmers in Lesotho to 0.56 in Ethiopia, thus confirming the evidence that most countries in the developing world in general and SSA in particular, have been experiencing productivity declines in agriculture (Fulginiti and Perrin 1998). Among the factors that influence technical efficiency, farmers' education, extension, credit, market access, farmers' access to improved technologies through the market or public policy interventions and land holding size, have been given prominence in most of the studies. Most studies report positive impact of all these variables on technical efficiency. However, the relationship between farm size and technical efficiency has not been explicitly straightforward. While one would expect a positive relationship between farm size and technical efficiency due to the economies of scale argument, most studies have found an inverse or weak positive relationship (Townsend et al. 1998; Heshmati and Mulugeta 1996).

Some socio-economic variables such as gender of the farmers do not significantly influence efficiency, as reported by Mochebelele and Winter-Nelson (2000) in the case of Lesotho. However, Alderman et al. (1995) found that gender plays an important role especially in SSA Africa where the participation of women in agriculture is higher than for men.

Other studies have extended the specification of the variables affecting efficiency to include environmental and ecological variables, because of the belief that not doing so may result in omitted variable bias that lead to over-estimation of technical inefficiency (Sherlund et al. 2004; Okike et al. 2004). This is particularly important because most farming systems in SSA are rainfed and production decisions are greatly influenced by environmental factors such as on-set and cessation of rainfall.

One critical observation is that most of these studies have neither tested nor imposed economic regularity conditions on the estimated efficiency functions. It is therefore likely that most of the estimated functions may have violated the economic regularity conditions, thus invalidating the policy implications that may have been drawn from the studies. Secondly, one of the factors that is largely responsible for the increased inefficiency of smallholder farmers is the soil fertility status. This is critical because external input application to food crops such as maize is exceptionally low among smallholder farmers, more especially in SSA, due to the increase in the real prices of fertilizers relative to crop prices. Our study therefore aims at assessing the technical efficiency implications of alternative soil fertility management options such as the integrated soil fertility management (ISFM) options, developed by researchers specifically for smallholder farmers.

Modeling framework

Technical efficiency is measured through what are called frontiers, as proposed by Farell (1957). A frontier defines the maximum possible limit to observed production. The level of a farm's production is in relation to the frontier (which is defined as the best relative performance in a specified reference group) is taken as a conventional measure of its efficiency. Two types of frontiers have been used in empirical estimations: parametric and non-parametric frontiers. The former use econometric approaches to make assumptions about the error terms in the data generation process and also impose functional forms on the production functions while the later neither impose any functional form nor make assumptions about the error terms. Widely used examples of parametric frontiers are the Cobb-Douglas, the constant elasticity of substitution (CES) and the translog production functions. The most popular non-parametric frontier is the Data Envelopment Analysis (DEA), which has been used in Färe et al. (1994) and Townsend et al. (1998).

While the non-parametric frontier assumes that the total deviation from the frontier is as a result of inefficiency, the stochastic frontiers attribute part of the deviation to random errors (reflecting measurement errors and statistical noise) and farm specific inefficiency (Forsund et al. 1980; Battesse 1992; Coelli et al. 1998). Thus, the stochastic frontier decomposes the error term into a two-sided random error that captures the inefficiency component and the effects of factors outside the control of the farmer. The theoretical foundation of such a model was first proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977). Thus we assume a suitable production function defined as:

$$\ln\left(q_i\right) = f\left(x_{ij}, \beta\right) + \varepsilon_j \qquad [1]$$

where q_i defines the output, x_{ij} is the quantity of input *j* applied to crop *i*. $\varepsilon_j = v_j - u_j$ and v_j is the two-sided error term while u_j is the one-sided error term. The two-sided random error is assumed to be identically and independently distributed with zero mean and constant variance and is independent of the one-sided error.

The distribution of the inefficiency component of the error (one-sided error) is assumed to be asymmetrical. In a farm environment, the sources of inefficiency are related to the willingness, zeal, skill and effort of the farm manager as well as the workers. In the original model of Meeusen and van den Broeck (1977), the one-sided error was assumed to be exponentially distributed. However, other distributions are also specified, such as the half-normal distribution as in Aigner et al. (1977). Although the stochastic model can be estimated through a number of approaches, such as the corrected ordinary least squares (COLS), most studies use the maximum likelihood approaches. Following Battesse and Coelli (1995), the maximum likelihood estimation for equation 1 are obtained from the following log-likelihood function:

$$\ln L = -\frac{N}{2}\ln\left(\frac{\theta}{2}\right) - \frac{N}{2}\ln\sigma^2 + \sum_{j=1}^{N}\ln\left[1 - F\left(\frac{\varepsilon_j\sqrt{\delta}}{\sigma\sqrt{1-\delta}}\right)\right] - \frac{1}{2\sigma^2}\sum_{j=1}^{N}\varepsilon_j^2$$

[2]

where L is the log-likelihood function, N is the number of observations and $F(.)$ is the standard normal distribution function. σ^2 is the overall standard deviation equal to the sum of the standard deviations of the two error terms and δ is the proportion of the overall error term that is explained by one-sided error. Assuming the half-normal distribution of the one-sided error term, the relative technical efficiency score defined at the mean is given as:

$$E\left[\exp\left(-u_j\right)\right] = 2\left[\exp\left(-\delta\sigma^2/2\right)\right]\left[1 - F\left(\sigma\sqrt{\delta}\right)\right] \qquad [3]$$

The measurement of farm level efficiency requires the estimation of the non-negative one-sided error that also depends on the assumptions regarding the distribution of the two and one-sided error terms. Based on Battesse and Coelli (1988), the best predictor of technical efficiency of farmer *j* is given as:

$$E\left[\exp\left(-u_j \setminus \varepsilon_j\right)\right] = \left[\frac{1 - F\left(\sigma_w + \delta\varepsilon_j/\sigma_w\right)}{1 - F\left(\delta\varepsilon_j/\sigma_w\right)}\right]\exp\left(\delta\varepsilon_j + \sigma_w^2/2\right)$$

where $\sigma_w = \sqrt{\delta\left(1-\delta\right)\sigma^2}$. The likelihood function is expressed in terms of the variance parameters i.e. $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\delta = \sigma_u^2 / \sigma^2$. The estimation procedure for the maximum likelihood is explained in the section that follows on the empirical model.

Analytical method: empirical model

To obtain the parametric measure of efficiency, a functional form for the stochastic production frontier is chosen. Ideally, the functional form should be flexible and computationally straightforward. To satisfy these properties, most empirical studies widely use the translog function. Following Battesse and Coelli (1995), the translog specification is mathematically expressed as

$$\ln(q_j) = \beta_0 + \sum_{i=1}^{n}\beta_i\ln(x_{ij}) + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=i+1}^{n}\beta_{ij}\ln(x_i)\ln(x_j) + v_j - u_j$$

where q_j is the crop output, x_{ij} are the inputs, $\beta_0 \ldots \beta_{ij}$ are the parameters to be estimated, v_j is a two-sided random error and is assumed to be identically and independently distributed with zero mean and constant variance and is independent of the one-sided error, u_j. We then specify the one-sided technical efficiency effect as being related to the exogenous factors that influence crop production:

$u_j = f(z)$ where z is a vector of determinants of technical efficiency, such as household socio-economic characteristics, policy and institutional variables, soil biophysical properties and asset endowment as highlighted in Table 2. In the estimation of the translog function, we impose some key regularity conditions such as monotonicity and diminishing marginal productivity of all inputs, in order to ensure consistency of the results to economic regularity. The estimation for the efficiency model is conducted in STATA.

Data and Materials

The main data set used for the analysis is the farm household and plot level data collected from nearly 376 households (or 573 plots) in Mzuzu, Lilongwe and Blantyre Agricultural Development Divisions (ADD) from May to December 2003. Malawi's agricultural extension administration is channeled through a hierarchy of levels of agro-ecological zones starting with an Agricultural Development Division (ADD) at a regional level, a Rural Development Project (RDP) at a district level and an Extension Planning Area (EPA) at a local level. EPAs are further sub-divided into sections that are manned by frontline extension staff that are in direct contact with farmers. There are eight ADDs, 28 RDPs and over150 EPAs. Our choice of the three ADDs was purposefully done for two main reasons: (i) these are well representative of Malawi's diverse farming systems, in terms of production potential and heterogeneity in resource endowments, more especially land, with Blantyre ADD being the most land constrained (ii) these agro-ecological zones have adequate numbers of smallholder farmers who have been involved in soil fertility improvement programmes, involving both public institutions and non-governmental organizations for over a decade. A two-stage stratified random sampling approach was used to draw the sample. In each ADD, the sampling focused on one Rural Development Project (RDP) from which two Extension Planning Areas (EPA) were chosen, one in an easily accessible area and another from a remote area. A representative sample for each enumeration area was obtained through a weighting system in which district population and population density were considered.

Table 1 presents the definitions of the variables we have used in the analysis, how they were measured and their descriptive statistics. In the estimation of efficiency, we have only considered hybrid maize because of its high yield response to inputs compared to local varieties. While most farmers still grow local maize varieties, there has been an increase in the number of farmers that have been growing either open pollinated varieties (OPV) or hybrids. In our sample, 98.6% and nearly 44% of the plots were cultivated with local or OPVs and hybrid maize varieties, respectively. The main variable inputs used in maize production include fertilizer, labour and seed. In analyzing the factors that influence efficiency, we have included land husbandry practices including precipitation intensity and selected policy variables. The specification of most of these is based on literature (c.f. Seyoum et al. 1998; Chirwa 2003; Helfand and Levine 2004; Okike et al. 2004). Among the policy related variables, access to credit, markets and extension feature highly in most policy discussions regarding agricultural performance. As discussed earlier, Malawi has gone through a number of challenges in the previous decade that have greatly influenced farmers' access to such public policy support. For example, there has been a change in the administration of smallholder credit from a state-sponsored Smallholder Agricultural Credit Administration (SACA) to a more private oriented credit institution, the Malawi Rural Finance Company (MRFC). Marketing of agricultural inputs and outputs has been completely deregulated from the state-sponsored parastatal, the Agricultural Development and Marketing Corporation (ADMARC), which is also undergoing substantive changes towards commercialization. There has also been drastic reduction in public support in the provision of agricultural extension from 12% of total public expenditure in early 1990s to about 5% after 2000 (see Fozzard and Simwaka, 2002). We also include a dummy of the soil fertility management option adopted by the farmers. We differentiate between integrated management, which involves the use of inorganic fertilizer and the low-cost 'best-bet' options such as grain legumes e.g. groundnuts (Arachis hypogea), soybeans (Glycine max.), pigeon peas (Cajanas cajan) and velvet beans (Mucuna pruriens) and the use of inorganic fertilizer only as the main input.

Table 1. Descriptive statistics for variables included in efficiency model

Variable	Description	Mean	Std.
Production factors			
Yield	Hybrid maize yield (kg/ha)	914.9	886.6
FERTILIZER	Fertilizer intensity (kg/ha)	30.9	38.3
LABOUR	Labour intensity (mandays/ha/month)	67.3	34.8
SEED	Seed intensity (kg/ha)	25.7	15.6
Efficiency determinants			
SFM	Soil fertility management (1=ISFM;0=fert)	0.6	0.5
WEEDING	Frequency of weeding	1.4	0.8
PLANTING	Date of planting (1=early; 0=later than first rains)	1.7	0.5
RAIN	Rainfall in mm	899.1	59.0
EXT_FREQ	Frequency of extension visits per month	0.8	1.0
CREDIT	Access to credit (1=yes; 0=no)	0.4	0.5
MACCESS	Market access (1=accessible; 0=remote)	0.4	0.5

Source: Own survey (2003)

Results and Discussion

Table 2 presents the results from the estimation of determinants of technical efficiency. The performance of the estimated models, given by the significance of the model fit (as measured by the adjusted R^2 and F-values) is good enough given the cross-section data that we used. The Translog model is highly consistent (about 94%) in the case of monotonicity but tends to perform very poorly in the case of quasi-concavity (about 14%). The SGB model however performs much better in terms of its consistency to both monotonicity and quasi-concavity (i.e. about 98% and 100% of the cases are consistent with monotonicity and quasi-concavity, respectively).

All the parameters for the factors have the expected signs. The translog model results indicate that application of chemical fertilizer and seed rate significantly ($P<0.000$) increases maize yield, as expected in soils which are highly deficient of nutrients. In the case of the SGB, both chemical fertilizer and seed rate have positive signs but are insignificant in both the restricted and unrestricted versions of the model. Labour is also positive and insignificant in both models, implying that it is not a binding constraint in smallholder maize production, as indicated also by Zeller et al. (1998).

The results from the restricted and unrestricted version of both models consistently indicate that integrated soil fertility management options significantly ($P<0.05$) increase the level of relative technical efficiency. The results of the relative technical efficiency scores shown in Table 3 indicate a wide difference between farmers that apply integrated soil fertility management options (ISFM) and those that apply chemical fertilizer only. On average the relative technical efficiency score among the former is 91.1% compared to only 14.3% in the later. This implies that there is a remarkable difference in terms of efficiency gains from using integrated soil fertility management options. Moreover, the consistency of the results from the two models used in the analysis increases the robustness of these findings.

A number of studies have also reported the positive impact of integrated soil fertility management options on relative technical efficiency in a number of crops. For example, Rahman (2003) reported that promotion of effective soil fertility management improved the technical efficiency of rice farmers in Bangladesh. Similarly, Weight and Kelly (1998) indicated that productivity of poor smallholder farmers in Sub-Saharan Africa can greatly be improved by a combination of chemical and organic based sources of soil fertility. Their study concluded that a soil fertility strategy based on only one option, such as inorganic fertilizer is unlikely to be effective among smallholder farmers because while the nutrient content of chemical fertilizer is high and nutrient release patterns are rapid enough for plant growth, farmers are unlikely to afford optimal quantities. On the other hand, the quality and quantity of organic sources of fertility is often a deterrent, especially in cases of highly nutrient deficient soils. Besides, the very high recommended quantities are associated with prohibitive labour demands which smallholder households can hardly satisfy. In the case of grain legumes, the process of biological nitrogen fixation is greatly compromised in the case of low soil fertility (Giller 2001).

Although the parameters on the land husbandry variables are all insignificant, the relative efficiency scores in Table 3 indicate that early planting and frequent weeding are important and they all improve the level of technical efficiency. There is a lot of evidence in literature that these variables are critical especially in maize production under rainfed conditions. According to agronomic recommendations, early planting enhances yields because it ensures vigorous establishment of the crop with the first rains as well as increasing the chances that the crop will complete its physiological growth process before the cessation of the rains. Likewise, weeding is an important husbandry practice and low weeding frequency is known to result in substantial yield losses. Keating et al. (2000), using simulation modeling has shown that investment in weeding could be equivalent to investing in a 50 kg bag of N fertilizer (such as ammonium nitrate) by removing competition between the crop and weeds on soil water and nutrients. Although the actual economic yield losses from low weeding would be variable depending on a range of factors such as seasonal rainfall, soil fertility, weed pressure and type, in Malawi it has been estimated to be as much as 25% on average (Kumwenda et al. 1998). These results are also reinforced through the bootstrapping procedure which was conducted to test the statistical robustness of the model findings. The results of the bootstrapping procedure are presented in Annex 1 and 2.

Although all the selected policy variables have expected signs, they are all insignificant at 10% level. This result may reflect the low levels of farmers' access to credit, extension services as well as the poor market access in most areas of rural Malawi. For instance, credit access is very low among smallholder farmers, most likely due to collateral requirements and high interest rates associated with seasonal agricultural loans from the Malawi Rural Finance Company. In addition, seasonal lending for maize production is unlikely to meet demand because of concerns among credit institutions that maize is a high-risk crop (Zeller et al. 1998). In the case of agricultural extension, the provision of this service to smallholder farmers has been reduced particularly since the last decade. This is attributed to two main reasons. First, the Government curtailed the training of agricultural extension officers, mostly as a result of budgetary hiccups experienced in the mid 1990s. Secondly, the lack of trained personnel has been exacerbated by high staff attrition levels due to the HIV/AIDS pandemic, on the one hand and low levels of staff motivation on the other. As such the number of farmers per extension officer has tremendously increased over the last decade, thereby placing a burden on the few extension workers to effectively and frequently conduct farmer visits. With respect to the market access, most of Malawi can rightly be classified as rural and remote given the poor condition of the rural feeder roads.

Despite the insignificance of the policy variables, there is still a marked difference in terms of the relative technical efficiency scores among farmers that are exposed to some level of favourable access to credit, extension and markets compared to those that are not. The relative technical efficiency score presented in Table 3 indicate that for instance, farmers that have access to agricultural credit are 7.8% more efficient than those that do not have access to credit. Similarly, farmers that are visited most frequently by extension workers (at least three visits per month) operate on the production frontier while those that are not visited at all are on average 20% less efficient. Farmers that have easy access to the market are about 67% more efficient compared to those that are located in remote areas. These results imply that these policy and institutional variables are relevant in order to improve the relative technical efficiency of smallholder farmers. On the basis of the p-values obtained from the bootstrapping procedure, all the policy variables are significant mostly at 1% and 5% levels (see Annex 1 and 2).

Table 2. Estimation Results

Parameter	Translog unrestricted	Translog Restricted	sgb unrestricted	sgb restricted
Constant	-1.050 (0.659)	-0.515 (0.546)		
ln(labour)	0.049 (0.150)	0.132 (0.087)	0.094 (0.219)	0.034 (0.218)
ln(fertilizer)	0.480*** (0.112)	0.315*** (0.093)	0.108 (0.144)	0.101 (0.143)
ln(seed)	1.105*** (0.411)	1.207*** (0.341)	0.607 (0.870)	0.165 (0.865)
ln(labour_sq)	-0.104 (0.085)	-0.012 (0.071)		
ln(fertilizer_sq)	0.017*** (0.004)	0.011*** (0.003)		
ln(seed_sq)	0.673 (0.556)	0.864* (0.461)		
ln(labour)X ln(fertilizer)	-0.003 (0.011)	-0.002 (0.009)	0.160 (0.458)	0.058 (0.455)
ln(labour) X ln(seed)	0.520* (0.327)	0.268 (0.271)	-0.388 (1.200)	-0.027 (1.193)
ln(fertilizer) X ln(seed)	0.005 (0.029)	0.007 (0.023)	0.201 (0.534)	0.311 (0.531)
SFM	0.312** (0.194)	0.436** (0.160)	0.317** (0.110)	0.315** (0.110)
Rainfall	0.179 (0.206)	-0.267 (0.171)	-0.290 (0.199)	-0.253 (0.198)
Weeding frequency	0.077 (0.177)	0.249* (0.147)	0.255 (0.169)	0.213 (0.168)
Planting date	0.184 (0.149)	0.062 (0.124)	0.066 (0.064)	0.035 (0.064)
Market access	0.023 (0.099)	0.093 (0.082)	0.106 (0.098)	0.094 (0.097)
Extension frequency	-0.004 (0.108)	0.037 (0.089)	0.129 (0.107)	0.137 (0.106)
Credit access	0.439 (0.629)	0.076 (0.521)	0.220 (0.355)	0.030 (0.353)
Adj. R^2	0.956	0.963	0.828	0.344
F-value	1455.367	2122.155	5.932	6.000
Prob>F	0.000	0.000		
Monotonicity (%)		94.048		97.619
Quasi-Concavity (%)		13.889		100.00
Regular (%)		-		
# Obs.	253	253	253	253

Note: *** P<0.000; **P<0.05; *P<0.10; Figures in parentheses are standard errors

Conclusions and policy recommendations

The results of this study indicate that integrated soil fertility management options provide the scope for improving maize production efficiency among smallholder farmers, thus ensuring increased output without necessarily increasing the input levels or technological shift. Thus from a policy perspective, the results indicate that it is worthwhile to scale-up smallholder farmer adoption of integrated soil fertility management options made available by the Department of Agricultural Research. Since an effective ISFM package needs to include hybrid maize, inorganic fertilizer and improved grain legume seeds, it is highly unlikely that smallholder farmers can afford such a package. From the findings of our study and others, farmers are unable to effectively engage in sustainable soil fertility management due to financial setbacks. Consistent use of hybrid maize, grain legume seed and chemical fertilizer require financial outlays that farmers are either unable to afford or can hardly risk to part with, without assurance of expected benefits. Therefore the role of agricultural policy in such circumstances is to enhance the provision of agricultural credit to enable farmers procure inputs as well as the provision of extension services in order to enhance farmers' awareness of the available soil fertility management options. The experience in Malawi is that most smallholder farmers are unable to take advantage of market provisions. As such adoption of agricultural technologies, particularly those that involve high financial outlays should be enhanced through well designed and targeted policy strategies. For example, safety-nets input programmes such as fertilizer - for - work have been seen to work because they simultaneously address a number of problems that affect smallholder farmers.

Another important policy intervention is the market-based development of edible grain legumes. The dual purpose of edible grain legumes such as groundnuts, soybeans and pigeon peas makes them highly effective in addressing food security while simultaneously building up the soil fertility through biological nitrogen fixation. Furthermore, because they are scale-neutral options, they can easily be incorporated into the smallholder farming systems in line with the crop diversification strategies. However, market-based development of these options will be a tenuous process without the provision of the necessary public goods such as public infrastructure that reduces traders' transactions costs thereby creating favourable demand prospects for the grain legumes. This will motivate farmers to grow these soil fertility 'best-bet' crops.

For effective transfer of improved crop technologies from research to farmers, the importance of ensuring viable extension services need not be overemphasized. Government need to devise strategies of dealing with the critical challenge brought by the HIV/AIDS which has increased the human resource attrition levels within the extension service. One viable way to address this is to forge effective networks with development NGOs/CBO that work closely with farmers. In the longer-term, there is need to revamp the training of more agricultural extension officers.

More importantly, any intervention programmes need to be timely so as to enable farmers to conform to the key husbandry practices such as weeding and dates of planting that are consistent with efficiency.

Acknowledgements

This research was made possible through funding by the Robert Bosch Foundation to the Policy Analysis for Sustainable Agricultural Development (PASAD) Project of the Center for Development Research, University of Bonn. The authors sincerely acknowledge the funding. However, the opinions expressed in this paper are those of the authors and do not reflect the views of PASAD, Center for Development Research or University of Bonn. These organizations do not guarantee the accuracy of the results of this study and will accept no responsibility for any consequences of their use.

References

Adesina, A.A. 1996. Factors affecting the adoption of fertilizers by rice farmers in Cote d'Ivoire. *Nutrient Cycling Agroecosystems* 46: 29-39.

Adesina, A.A. and M.C. Zinnah. 1993. Technology characteristics, farmers' perceptions and adoption decisions: a Tobit model application in Sierra Leone. *Agricultural Economics* Vol. 9: 297-311.

Adesina, A.A., D. Mbila, G.B. Nkamleu and D. Endamana. 2000. Econometric Analysis of Adoption of Alley Farming by Farmers in the Forest Zone of South West Cameroon. *Agriculture, Ecosystems and Environment* 80: 255-265.

Alderman, H., J. Hoddinott, L. Haddad and C. Udry. 1995. Gender differentials in farm productivity: Implications for household efficiency and agricultural policy. Food Consumption and Nutrition Division Discussion Paper No. 6. International Food Policy Research Institute.

Bhalla, A., C. Chipeta, H. Taye and M. Mkandawire. 2000. Globalization and sustainable human development: Progress and challenges for Malawi. Occasional paper. UNCTAD/UNDP.

Boserup, E. 1981. Population and Technical Change. A Study of Long-term Trends. Chicago. University of Chicago Press.

Charnes, A., W. Cooper and E. Rhodes. 1978. Measuring the efficiency of decision-making units. *European Journal of Operations Research* 2(6): 429-444.

Chirwa, E.W. 2003. Sources of technical efficiency among smallholder maize farmers in southern Malawi. Department of Economics, Chancellor College, Zomba, Malawi.

Coelli, T., R. Prasada and N. Battese. 1998. An Introduction to Efficiency and Productivity Analysis. Boston. Kluwer Academic Press.

Dorward, A., J. Kydd, J. Morrison, and I. Urey. 2004a. 'A policy agenda for pro-poor agricultural growth. *World Development* Vol. 32(1): 73-89.

Dorward, A., P. Wobst, H. Lofgren, H. Tchale and J. Morrison. 2004b. Modeling pro-poor agricultural growth strategies in Malawi. Lessons for policy and analysis. Journal of African Economies (forthcoming).

Edriss, A., H. Tchale and P.Wobst. 2004. The impact of labour market liberalization on maize productivity and rural poverty in Malawi.

Working paper. Policy Analysis for Sustainable Agricultural Development (PASAD). Center for Development Research, University of Bonn, Germany.

Färe, R., S. Grosskopf, and C. Lovell. 1994. Production Frontiers. New York, NY: Cambridge University Press.

Farrell, M.J. 1957. The measurement of productive efficiency. *J.R. Stat. Soc. Ser. A* 120(3): 253-290.

Freebairn, D.K. 1995. Did the green revolutions concentrate incomes? A quantitative study of research reports. *World Development*, Vol. 23: 265-279.

Forsund, F.R., C.A.K. Lovell, and P. Schmidt. 1980. A survey of frontier production functions and of their relationship to efficiency measurement. *Journal of Econometrics* 13: 5-25.

Fozzard, F., and C. Simwaka. 2002. How, when and why does poverty get budget priority: Poverty reduction strategy and public expenditure in Malawi. Overseas Development Institute.

Fulginiti, L.E., and R.K. Perrin. 1998. Agricultural productivity in developing countries. *Agricultural Economics* Vol. 19(1-2): 45-51.

Giller, K.E. 2001. Nitrogen Fixation in Tropical Cropping Systems, 2nd/Ed. CAB International, Wallingford, 423 pp.

Government of Malawi (GOM) (2002): Qualitative impact monitoring (QIM) of poverty alleviation policies and programmes: Survey findings. National Economic Council, Lilongwe.

Helfand, S.M., and E.S. Levine (2004): Farm size and determinants of productive efficiency in the Brazilian Center-West. *Agricultural Economics* 31(2004): 241-249.

Heshmati, A. and Y. Mulugeta. 1996. Technical efficiency of the Ugandan matoke farms. *Applied Economic Letters* (3): 491-494.

Kumwenda, J.D.T., S.R. Waddington, S.S. Snapp, R.B. Jones and M.J. Blackie. 1997. Soil fertility management in the smallholder maize-based cropping systems of Africa. In: The Emerging Maize Revolution in Africa: The Role of Technology, Institution and Policy. Michigan State University, USA.

Kumbhakar, S.C., and C.A.K. Lovell. 2000. Stochastic frontier analysis. Cambridge University Press, Cambridge 333.

Kydd, J. and A. Dorward. 2001. The Washington Consensus on poor country agriculture: analysis, prescription and institutional gaps, *Development Policy Review*, Vol. 19: 467-478.

Mochobelele, M.T., and A. Winter-Nelson. 2000. Migrant labour and farm technical efficiency in Lesotho. *World Development* 28(1): 143-153.

Mosley, P., and A. Suleiman. 2004. Aid, agriculture and poverty in developing countries. Paper presented to the conference on Political Economy of Aid, Hamburg, December 2004.

Okike, M., A. Jabbar, V.M. Manyong, J.W. Smith and S.K. Ehui. 2004. Factors affecting farm-specific production efficiency in the Savanna Zones of West Africa. *Journal of African Economies*, Vol. 13(1): 134-165.

Owusu, K., and F. Ng’ambi. 2002. Structural damage: The causes and consequences of Malawi’s food crisis. *World Development Movement*, UK.

Seyoum, E.T., G.E. Battese and E.M. Fleming. 1998. Technical efficiency and productivity of maize producers in Eastern Ethiopia: A survey of farmers within and outside Sasakawa-Global 2000 Project. *Agric. Economics* 19: 341-348.

Sherlund, S.M., C.B. Barrett and A.A. Adesina (2004): Smallholder technical efficiency: Controlling for environmental production conditions. *Journal of Development Economics* (forthcoming).

Smale, M., and T. Jayne. 2003. Maize in Eastern and Southern Africa: Seeds of success in retrospect. Environment and Production Technology Division. Discussion paper No. 97. International Food Policy Research Institute, Washington D.C.

Tchale, H., J. Sauer and P.Wobst. 2004. Productivity and profitability of alternative soil fertility management options in the maize-based smallholder farming systems in Malawi. ZEF Discussion Paper No. 98. Center for Development Research, University of Bonn, Germany.

Tchale, H. and P.Wobst. 2004. Soil fertility management choice in the smallholder maize-based farming systems in Malawi. Draft working paper to be submitted to *Agricultural Systems*.

Townsend, R.F., R.F. Kirsten, and N. Vink. 1998. Farm size, productivity and returns to scale in agriculture revisited: A case study of wine producers in South Africa. *Agricultural Economics* 19: 175-180.

Weir, S. 1999. The effects of education on farmer productivity in rural Ethiopia. Working Paper CSAE WPS99-7. Center for the Study of African Economies. University of Oxford.

Weir, S. and J. Knight. 2000. Education externalities in rural Ethiopia. Evidence from average and stochastic frontier production functions. Working paper CSAE WPS/2000.4. Center for the Study of African Economies. University of Oxford.

Weight, D., and V. Kelly. 1998. Restoring soil fertility in Sub-Saharan Africa. Policy synthesis No. 37. Office of Sustainable Development. United States Agency for International Development (USAID).

Zeller, M., A. Diagne and C. Mataya. 1998. Market access by smallholder farmers in Malawi: Implications for technology adoption, agricultural productivity and crop income. *Agricultural Economics* 19: 219-229.

Table 3. Relative technical efficiency scores (%) by functional form

	TL0	TL3	Mean	SGB0	SGB3	Mean	Average
Inorganic Fertilizer Only	20.4	0.0	10.2	20.6	20.5	20.6	14.3
Isfm	70.2	100.0	85.1	100.0	100.0	100.0	91.1
Weeding Frequency (N)							
No Weeding	95.7	91.3	93.5	84.2	84.7	84.4	89.9
Weeding Once	100.0	77.1	88.5	37.6	44.4	41.0	69.5
Weeding Twice	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Planting Date							
Late Planting	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Early Planting	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Market Access							
- No	0.0	0.0	0.0	7.1	7.5	7.3	2.9
- Yes	48.1	51.0	49.6	85.1	100.0	92.6	66.8
Extension Visits (N)							
No Visit/Month	76.0	66.9	71.5	99.6	95.3	97.5	81.9
One Visit/Month	90.7	89.6	90.2	100.0	87.9	94.0	91.7
Two Visits/Month	100.0	100.0	100.0	95.5	79.2	87.3	94.9
Three Visits	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Credit							
- Yes	13.6	4.2	8.9	6.4	6.2	6.3	7.8
- No	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note: TL0 = unrestricted translog; TL3 = restricted translog; SGB0 = unrestricted Symmetric Generalized Barnett Production Function and SGB3 = restricted Symmetric Generalized Barnett Production Function

Annex

Annex 1. Bootstrapping results for the Translog model

	mean	min	Max	stdev	t-value	p-value	confint(0.05; 0.95)	
ISFM	1.000	1.000	1.000	0.000		0.000	1.000	1.000
Chemical fertilizer only	0.216	0.160	0.282	0.030	7.248	0.000	0.208	0.224
no weeding	0.999	0.974	1.000	0.004	271.004	0.000	0.998	1.000
weeding once	0.771	0.536	1.000	0.124	6.228	0.000	0.737	0.805
weeding twice	0.403	0.000	0.823	0.212	1.899	0.063	0.345	0.462
early planting	1.000	1.000	1.000	0.000		0.000	1.000	1.000
late planting	0.006	0.000	0.070	0.017	0.348	0.729	0.001	0.010
Market Access	1.000	1.000	1.000	0.000		0.000	1.000	1.000
No Market Access	0.063	0.004	0.107	0.023	2.768	0.008	0.057	0.070
No extension visit/month	0.848	0.000	1.000	0.280	3.031	0.004	0.771	0.926
One extension visit/month	0.869	0.000	1.000	0.215	4.046	0.000	0.809	0.929
Two extension visits/month	0.663	0.000	0.989	0.310	2.135	0.038	0.577	0.749
Three extension visits/month	0.786	0.339	1.000	0.172	4.569	0.000	0.738	0.834
Credit	1.000	1.000	1.000	0.000		0.000	1.000	1.000
No Credit	0.047	0.000	0.111	0.029	1.625	0.111	0.039	0.055
Consistency range								
Quasi-Concavity	100.00	100.00	100.00	0.00		0.00	100.00	100.00
Monotonicity	59.81	1.05	100.00	28.29	2.11	0.04	51.97	67.65

Annex 2. Bootstrapping results for the SGB model

	mean	min	Max	stdev	t-value	p-value	Confint (0.05; 0.95)	
ISFM	1.000	1.000	1.000	0.000		0.000	1.000	1.000
Chemical fertilizer only	0.002	0.000	0.075	0.011	0.141	0.888	0.000	0.004
no weeding	0.981	0.834	1.000	0.034	28.813	0.000	0.972	0.991
weeding once	0.942	0.000	1.000	0.144	6.563	0.000	0.902	0.982
weeding twice	0.882	0.677	1.000	0.078	11.298	0.000	0.860	0.904
early planting	1.000	1.000	1.000	0.000		0.000	1.000	1.000
late planting	0.048	0.000	0.220	0.065	0.735	0.466	0.030	0.066
Market Access	1.000	1.000	1.000	0.000		0.000	1.000	1.000
No Market Access	0.000	0.000	0.000	0.000		0.000	0.000	0.000
No extension visit/month	0.924	0.062	1.000	0.147	6.279	0.000	0.883	0.965
One extension visit/month	0.719	0.000	1.000	0.246	2.924	0.005	0.651	0.787
Two extension visits/month	0.881	0.044	1.000	0.142	6.199	0.000	0.842	0.921
Three extension visits/month	0.911	0.101	1.000	0.186	4.909	0.000	0.860	0.963
Credit	1.000	1.000	1.000	0.000		0.000	1.000	1.000
No Credit	0.051	0.000	0.153	0.042	1.202	0.235	0.039	0.063
Consistency range								
Quasi-Concavity	27.97	2.78	55.95	11.52	2.43	0.02	24.78	31.16
Monotonicity	89.12	11.51	93.65	11.26	7.91	0.00	86.00	92.24