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Technical and allocative efficiency gains from integrated soil fertility management in the maize farming system of Kenya

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Declining land productivity and *per capita* food availability poses challenges to overcoming land degradation and poverty in sub-Saharan Africa. There is a need to identify ways of improving land productivity particularly among smallholders. This study investigated the contribution of integrated soil fertility management (ISFM) practices to both technical and allocative efficiencies in the maize farming system of Kenya. To determine efficiency gains from ISFM, we compared efficiencies of two groups of smallholders: those within the contact areas and their counterfactuals. We estimated Cobb-Douglas stochastic functions based on maize production data collected from a stratified sample of 373 farmers. The results indicate that farmers who applied ISFM were more efficient both technically and allocatively than those who did not. Application of ISFM practices increased technical and allocative efficiencies by 26 and 30%, respectively. However, other favourable factors are required for farmers to realize maximum efficiency gains from maize farming activity. They included farming experience, extension contacts, off-farm income and market access. Therefore, policies and practices aimed at enhancing farming efficiency in smallholder agriculture should address these factors. We recommend increased dissemination of ISFM technologies to the wider farming community through effective and participatory approaches to increase efficiency and enhance farm returns.

Key words: Maize, land husbandry, productivity, small-scale, stochastic frontier.

INTRODUCTION

Sub-Saharan Africa (SSA) is the only region in the world where land productivity and *per capita* food availability continues to fall over time (Clover, 2003; Lambin et al., 2003). Declining soil fertility and high cost of purchasable inputs are the main contributory factors to low agricultural productivity among farming communities in SSA (CGIAR, 2002). Soil fertility loss is viewed as a key source of land degradation and environmental damage in the long-term

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(Henao and Baanante, 2006). This is because continuous farming without adequate replenishment of nutrients drains the productive potential of the soil. The soil becomes less fertile when the nutrients and trace elements are constantly used without taking proper care of the mass balance of the soil (Bojö, 1996). This problem is more profound among resource-poor, small-holder farming households because they lack knowledge on better soil management options. They also have low capacity to invest in soil nutrient replenishment—especially using chemical fertilizers—and have less ability to bear risk and wait for future payoffs from such investments (Jayne et al., 2010). According to Todaro and Smith (2008), widespread abject poverty can precipitate over-use and destruction of the natural resources where short-term survival goals and practices are pursued with little regard to long-term sustainability concerns.

Kenya, like many SSA countries, grapples with the twin problems of increasing poverty incidence and land degradation, especially in rural areas. Declining soil fertility in high agricultural potential areas of the country has raised concerns regarding the sustainability of the smallholder maize production system (Mureithi et al., 2002). For example, the resource-poor smallholders in Western Kenya hardly invest in farming activities due to liquidity constraints, experience more than twice the erosion rates and achieve less than one-third of potential maize yields (Mureithi et al., 2002). This raises food security concerns as smallholder farmers are the major producers of maize in the country; hence, there is a need for them to increase their farm productivity in order to satisfy the increasing food needs in Kenya. The low maize productivity attributable to both insufficient farm resources and inefficient allocation of available farm inputs, hinders progress in this direction (Seyoum et al., 1998). To bridge the resource insufficiency gap, low-cost, integrated soil fertility management (ISFM) technologies have been availed through participatory approaches such as farmer participatory research and farmer field schools, to tackle soil fertility loss and boost productivity in smallholder farming system of North-western Kenya (Nyambati et al., 2003). The promoted ISFM technologies included the application of organic residues and animal manure; inorganic fertilizers; integration of leguminous crops e.g. soya beans, groundnuts, pigeon peas, *Mucuna pruriens* and *Crotalaria spp;* and agro-forestry practices such as incorporation of *Tithonia diversifolia* residues. Others included integrated pest management using extracts from neem, hot pepper and tephrosia plants and low-cost soil conservation methods such as grass strips. However, knowledge about the efficiency contribution of the ISFM technologies within the maize farming system of Kenya remains unknown.

There is an increasing interest in determination of productive efficiency in various fields since the pioneering work by Farrell (1957), and analytical advancements that followed (Aigner et al., 1977; Battese and Broca, 1997; Coelli, 1996; Meeusen and van Den Broeck, 1977). Determination of actual efficiency levels is essential in effective policy-making and practical implementation of various economic activities. Therefore, many researchers have empirically investigated whether economic units such as farms, firms, and organizations, were utilizing the scarce resources to produce maximum quantities of goods and services.

Efficiency studies in SSA have reported varied technical efficiencies ranging from 46% in Nigeria (Olowa and Olowa, 2010), 56% in Ethiopia (Seyoum et al., 1998) to between 64 and 76% among two groups of farmers in Lesotho (Mochebelele and Winter-Nelson, 2000). Two studies conducted in Kenya reported technical efficiency of 49% (Kibaara 2005) and 71% (Liu, 2006) in maize production, while in Malawi Tchale and Sauer (2007), found on average 87% technical efficiency among small-holder maize farmers. These empirical findings clearly show that SSA farming system generally is not efficient and produces less output than the possible potential. This suggests therefore that inefficiency is one of the principal causes of low productivity of agriculture in SSA. Consequently, there is a need to establish whether the application of ISFM practices contribute to efficiency in maize farming system and which factors are key to maximizing the efficiency benefits from ISFM practices. This is important because the greatest challenge to adoption of sustainable production practices is not only liquidity constraints but also a lack of knowledge on efficient production plans (Place et al., 2002). In fact, it is not only the lack of credit and poor farm revenue but also the absence of information that often prevent the poor from making the best resource-augmenting investments important for improving farm productivity (Todaro and Smith, 2008). As observed by Bationo et al. (2004), tackling poor soil fertility and low farm productivity requires both a long-term perspective and an all-inclusive approach to which this study aims to contribute.

The specific objective of this study was to estimate the prevailing technical and allocative efficiencies and examine their determinants in two maize producing systems of North-western Kenya. Unlike many efficiency studies conducted in SSA, which focus on technical efficiency alone (Mochebelele and Winter-Nelson, 2000; Olowa and Olowa, 2010; Seyoum et al., 1998; Sherlund et al., 2002; Tchale and Sauer, 2007), we concurrently estimate both technical and allocative efficiencies and evaluate farming efficiency gains from the ISFM technologies availed to smallholder farmers. Providing information on ways to enhance efficiency in maize production is essential in improving *per capita* output and farmers' incomes to re-invest in soil fertility improvement, including the use of available ISFM technologies in Kenya. This is in line with the Kenya government's vision that sustainable and efficient production practices within the smallholder agriculture is key to ameliorating the negative environmental

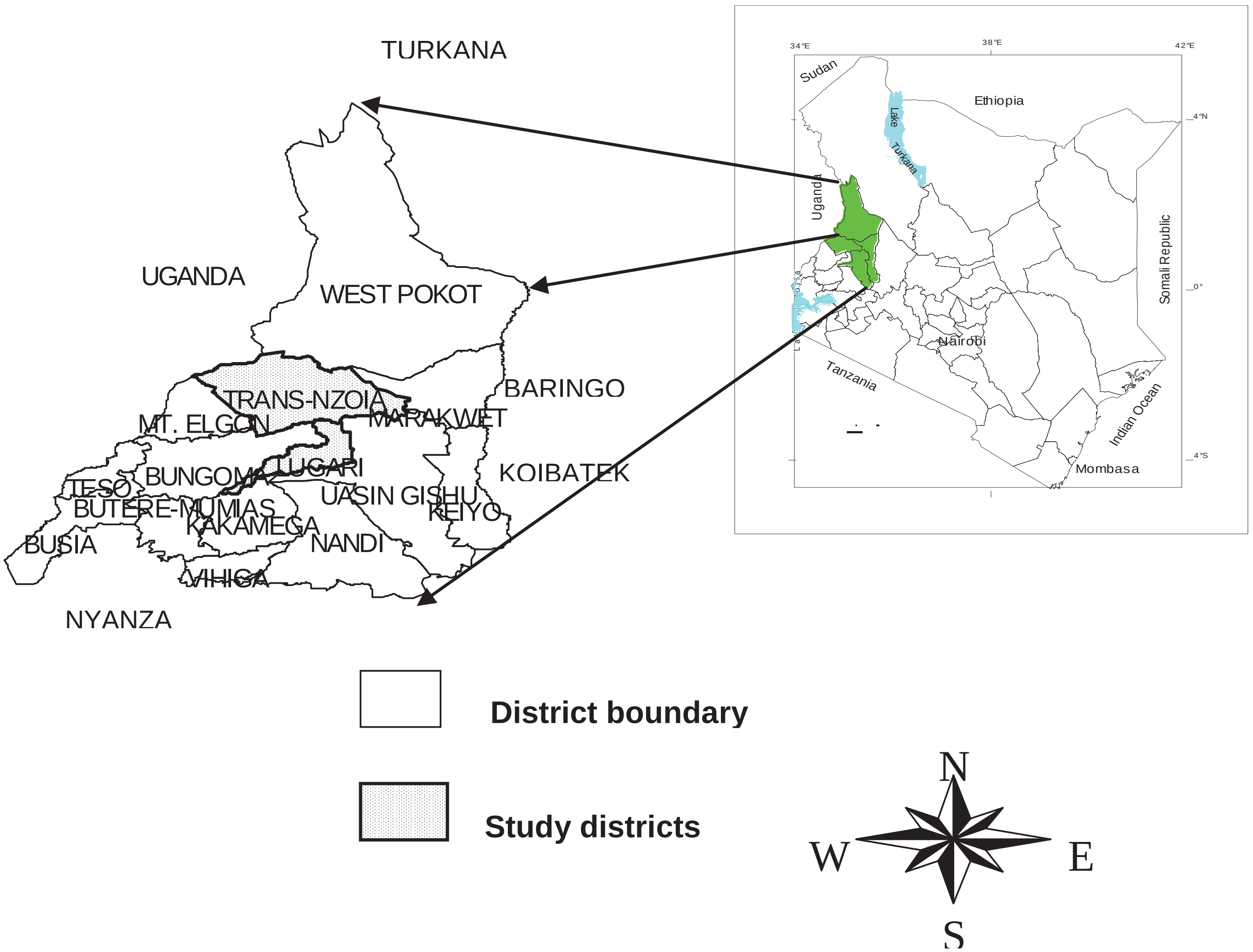

Figure 1. Map showing study districts (dotted) in North-western Kenya.

effects of poverty and improving better livelihoods in rural areas (Government of Kenya, 2004). As noted in the policy document, the greatest emphasis should be given to improving efficiency among smallholders so as to simultaneously mitigate poverty-related land degradation and raise agricultural productivity (Government of Kenya, 2005). This study therefore provides useful information on policy options and best practices to improve maize yields to enhance food security and sustainable land management not only in Kenya but also in other similar SSA countries.

METHODOLOGY

Study area

The North-western Kenya is a high agricultural potential region and accounts for about 90% of total maize output in the country. Trans Nzoia and Lugari Districts are located in this region (Figure 1). Trans Nzoia District dubbed, 'Kenya's granary' remains the major maize producer in the country (Wangia et al., 2002). Trans Nzoia District was selected for the study because yields have been declining in recent years. As a result, the district was targeted with ISFM options aimed to address low yields. On the other hand, we chose Lugari District because it has comparative maize farming system like that in Trans Nzoia, but was not covered by the soil management project.

The two districts receive between 1000 to 2100 mm of bimodal rainfall pattern. Rainfall received is considered reliable for agricultural activities. The elevation ranges from 1300 to 1900 m above sea level, with Upper Midlands (UM_4) being the predominant agro-ecological zone accounting for 94 and 47% of all land area in Lugari and Trans Nzoia Districts, respectively. This zone is the area of intensive maize cultivation in the study districts (Government of Kenya, 2006; Jaetzold et al., 2007). The major soil type is humic Acrisols, which is deep and well-drained. Soil fertility is moderate given that poor soil fertility is one of the most limiting factors to agricultural productivity in the study area (Government of Kenya, 2006; Nyambati et al., 2003). Farm sizes are on average 2.5 ha in

Lugari and 3.6 ha in Trans Nzoia. The common farming system is mixed crop-livestock production. Maize-bean production takes about 90% of total cropped land (Government of Kenya, 2006). Maize yields have been declining in both districts to as low as just 2 tha^{-1}. The declining trend has been blamed on among other factors, the soil fertility loss due to continuous monoculture cropping.

Population density is 328 people/km^2 for Trans Nzoia District and 437 people/km^2 in Lugari District (KNBS 2010). Poverty incidence is 50.2% for Trans Nzoia and 47% for Lugari District (Government of Kenya, 2011). In both districts, smallholders form the bulk of maize producers amid the waning importance of large-scale maize production due to continuous land sub-division (Mose et al., 2006).

Sampling techniques

Stratified sampling, based on agro-ecological zonation and concentration of smallholders, was applied to select two localities in each district for the study. These were: Kaplamai (UM_4) and Kiminini (LH_{3-4}) in Trans Nzoia District, as the contact areas where ISFM technologies was promoted for about a decade (Nyambati et al., 2003), and Mautuma (UM_4) and Matete (LM_3) in Lugari District, as the matching counterfactual areas.

The optimum sample size was chosen in a two-step process (Rangaswamy, 1995). First, a total sample size of 373 farmers was derived based on the number of strata, total farming households and variance of maize yields (calculated from data reported in Mose (2007), in each district. The total sample was made up of 154 farmers for Trans Nzoia District and 219 farmers for Lugari District. Second, we used the Neyman allocation method to distribute the total sample across the four study strata. For each stratum, we developed updated sampling frames with the assistance of frontline agricultural extension staff and local leaders. We used randomly generated numbers in MS Excel computer program to select individual farming households for interviews.

Data collection

We conducted face-to-face interviews at each of the selected households using a detailed and pre-tested, semi-structured questionnaire. The questionnaire was administered to the household head or member knowledgeable about farm and off-farm activities. We obtained data on physical quantities and monetary value of farm inputs (that is, fertilizers, manures, labour, seeds, and land) and maize output. We also collected farm level data on the ISFM practices that they applied in maize production. In addition, we collected socio-economic data on farmer's age, number of years in farming, family members and their level of education. Farmers also provided information on the cost of market access, distance and condition of the main roads as well as access to credit and the number of contacts they had with agricultural extension agents during the year. Finally, we collected data on planting date, maize varieties grown, weeding frequency and pest control. These data were analysed applying the analytical procedures specified next.

Analytical framework

The economic theory of production provided the analytical framework for this efficiency study (Debertin, 1986). The fundamental idea underlying the measurement of technical efficiency is that of attaining maximum possible output from a set of physical inputs. A farmer is considered technically inefficient if little output is produced from a given bundle of inputs (Ogundari et al., 2006). Allocative efficiency on the other hand, reflects the ability of the farmer to use inputs they have in optimal combinations given their relative prices (Coelli, 1996). A farmer is deemed allocatively inefficient if excessive cost is incurred to achieve the same level of output.

Following Ogundari et al. (2006), two self-dual stochastic functions were estimated from production data to generate technical and allocative efficiency values. Stochastic functions used in this study attribute part of the inefficiencies to external factors and are suitable when analysing the role of measurable socio-economic factors in observed efficiency differences (Coelli, 1996). This made it possible to establish the effects of farmers' responsiveness to the incentive structure and technologies that defines their production environment. This was important in this study because efficiency gains from ISFM interventions had to be estimated taking into consideration all possible relationships (Tchale and Sauer, 2007).

We estimated a self-dual, stochastic Cobb-Douglas production (Equation 1) and cost function (Equation 2) to generate technical and allocative efficiency values, respectively.

$$\ln(y_i) = \ln\beta_0 + \sum_{i=1}^{4}\beta_i \ln(x_i) + \beta_5 dist + (v_i - u_i) \qquad [1]$$

Where y_i is maize output (tha^{-1}), and x_i are physical inputs (fertilizer, seeds, total labour and manure per ha). A binary variable *dist* (1=Trans Nzoia; 0=Lugari) accounted for the difference in physical attributes important for farm production such as natural soil fertility and rainfall. β_0 is a parameter common to all farms while β_i and β_5 are unknown coefficients estimated in the model. v_i is the ordinary two-sided error term assumed to be normally, identically and independently distributed and u_i is the one-sided error term assumed half-normal that captured technical inefficiency.

$$\ln(c_i) = \ln\alpha_0 + \sum_{i=1}^{4}\alpha_i \ln(r_i / w_i) + \alpha_5 \ln(y_i) + (v_i + u_i) \qquad [2]$$

Where c_i is the total variable cost of maize production (KES/ha), r_i are the unit prices for fertilizer, seed, ploughing, w_i is the labour wage and y_i is maize yield (tha^{-1}). α_0 is the intercept taking care of the fixed costs in maize production, while α_i is a vector of coefficients estimated for the prices of fertilizer, seed, ploughing, labour and yield. μ_i is the half-normal error term that measured allocative inefficiency.

We applied a one-step maximum likelihood estimation procedure (Wang and Schmidt, 2002) to estimate each of the above equations simultaneously with those determinants of technical and allocative efficiency in maize production, specified in Equation 3.

$$\begin{aligned}\mu_i = {} & \delta_0 + \delta_1 EXP_i + \delta_2 EDU_i + \delta_3 CRAC_i + \delta_4 HSIZ_i + \delta_5 OFIN_i \\ & + \delta_6 SFM_i + \delta_7 EXT_i + \delta_8 MAC_i + \delta_9 AEZ_i + \varepsilon\end{aligned} \qquad [3]$$

Where μ_i is the inefficiency (technical or allocative) score; *EXP* is farming experience of the farmer (years); *EDU* is formal education level of the decision-maker (years of schooling); *HSIZ* is the number of household members (those living and eating in the same household); *OFIN* is a binary variable for off-farm income earning (1 = for household with positive earnings; 0 = otherwise). *CRAC* is a binary variable for credit access (1 = for households that obtained credit; 0 = otherwise); *SFM* is binary variable for soil fertility management practice (1 = for ISFM practices; 0 = fertilizer alone). *EXT* is the number of extension contacts during the year; *MAC* is market access (transport cost/bag of maize in KES). *AEZ* is a binary variable for agro-ecological zone (1 = Upper Midland; 0 = otherwise) controlling for the influence of natural soil fertility, rainfall and temperature and ε is the error term. The selection of these variables was based on past studies that found their significant influence on various efficiency measures (Mochebelele and Winter-Nelson, 2000; Mutoko et al., 2014; Ogundari et al., 2006; Olowa and Olowa, 2010; Seyoum et al., 1998; Sherlund et al., 2002; Tchale and Sauer, 2007). We used FRONTIER 4.1(c) for efficiency estimations (Coelli, 1996).

Before estimations, we tested for the violations of classical assumptions of OLS commonly expected in cross-sectional data used in this study, such as heteroscedasticity, multi-collinearity and endogeneity (Gujarati, 2005). The Breusch-Pagan-Godfrey test did not show evidence of heteroscedasticity in the data; hence, the parameter estimates were unbiased, consistent and efficient. The endogeneity test ensured that the error term μ_i and the explanatory variables do not co-vary. Since the estimation of the stochastic production and cost frontiers is based on the distribution of this error term, this independence is critical for two reasons. First, the variables describing the inputs in the stochastic frontier functions need to be independent from the socio-economic variables explaining inefficiency effects. Second, the stochastic frontier functions and the equation explaining inefficiency have to be estimated simultaneously. If the independence condition were not satisfied, the parameter estimates from both functions would be biased and inconsistent (Verbeek, 2008). The procedure to establish independence between the error term and the explanatory variables involved a regression of each variable against the others in the set and assessing the strength of the R^2 (Verbeek, 2008). Those R^2 values greater than 0.5 indicate high dependence and therefore such a variable is endogenous (Gujarati, 2005). Soil fertility management choice had the highest value (R^2=0.4) whereas all the other variables in Equation 3 had lower values ($R^2 \leq 0.2$). Given that all R^2 values were less than 0.5, we concluded that none of the explanatory variables was endogenous. Following Maddala (2001), we confirmed the presence of multi-collinearity based on the high degree of variance inflation factors for seed and fertilizer. Gujarati (2005), recommends expressing variables as deviations from the mean as one practical ways of reducing the effect of multi-collinearity in estimations. We followed this suggestion with the implication of the transformation being that the results had to be interpreted at the mean values. Independent samples t-tests were used to determine statistical difference on key variables between the two main study districts.

RESULTS AND DISCUSSION

Description of the maize production system

Survey results indicate that maize farmers were on average 48 years old, decision-makers were mostly male (70%) with eight years of formal schooling. The average family had six members out of which two had attained secondary education level. This result implies that each household had appreciable levels of both physical and technical aspects of human capital. However, the low active participation of the youth and women may influence the degree of interest in and implementation of new technologies including ISFM practices.

Off-farm earnings averaged only KES 2,400 per month per household, mainly from casual employment and remittances. Only 6% of the farmers obtained agricultural credit, mainly from informal sources including ‘merry-go-rounds’, input stores, family members and neighbours. Most farmers blamed low access to credit on the lack of information about credit providers and lack of land title deeds (by 62%) that would serve as collateral for the loan. Some farmers cited the main deterrent as stringent requirements imposed by formal credit institutions and the perceived risks in case they defaulted re-payment. This finding indicates poor injection of liquidity into the farming system from external financial sources thereby limiting farmers’ affordability of essential inputs. Most of the maize production costs (61%) were financed from farm income demonstrating the need to improve farm returns to guarantee considerable investments in maize production.

Agricultural extension contacts with the farmers were low (only 27%), on average just one visit per year. This is because farmers were yet to embrace the new demand-driven extension delivery system. In the earlier system, the extension agents were entirely responsible for making visits to individual farmers or organizing group trainings in order to provide them with better agricultural knowledge and skills.

The average cost structure of maize production included expenditure on chemical fertilizers (34%), land preparation (20%) and seed (12%). These were the major costs taking about two-thirds of all variable costs incurred in maize production. To enhance smallholders’ access to these inputs, there is need for appropriate policy intervention to minimize transaction costs thereby making their acquisition more affordable. All other expenditures on labour input accounted for 34% of total production costs, indicating that labour was not a limiting resource in the study area.

Forty per cent of the sampled farmers used some components of low-cost ISFM options, which included incorporation of maize crop residues (30%), use of farmyard (24%) and compost manures (22%) as well as integration of crotalaria (10%) and groundnuts (6%). The preference of these ISFM practices was due to the availability of the manures or the bonus benefits to the household from the legumes. Within such farming environment therefore, we hypothesized that the average maize yield of 2.6 tha^{-1} was below the technically feasible and allocatively efficient levels.

Status of efficiency in maize production

Results in Table 1 indicate that overall farmers on the average achieved 64% technical efficiency. Therefore, it is possible to improve yields by an additional 36% through adoption of better farm practices such as improved soil fertility management, early land preparation, timely planting; proper spacing, use of hybrid maize varieties and effective weed control. The significant gamma (γ) estimate indicates that 65% of the technical inefficiencies can be explained jointly by the socio-economic variables in the technical inefficiency equation. The coefficients for chemical fertilizer and seed are statistically significant. This means that inorganic fertilizer

Table 1. Stochastic production function estimated using maximum likelihood method to determine technical efficiency in maize production.

Variable	Parameter	Coefficient	SE[a]
Production frontier function			
Intercept	β_0	0.50*	0.30
Fertilizer	β_1	0.19**	0.05
Seed	β_2	0.20*	0.13
Labour	β_3	-4.26***	1.68
Manure	β_4	0.03	0.07
District	β_5	0.06***	0.01
Efficiency measures			
Sigma-squared, $\sigma_\mu^2+\sigma_v^2$	σ^2	0.31**	0.08
Gamma, $\sigma_\mu^2/(\sigma_\mu^2+\sigma_v^2)$	γ	0.65**	0.18
Mean technical efficiency[b]	TE	64%	

[a]SE is standard error of the estimate, [b]Technical efficiency estimates a farmer's actual yield in relation to the optimal yield, given a production technology. The maximum possible technical efficiency level is 100%. Significant at the following levels: *10%; **5%; ***1%.

and seed are the main limiting inputs in maize production because as shown by positive coefficients, their use beyond the current levels will increase yields. The practised seed rate of 24 kgha^{-1} was closer to the recommended rate of 25 kgha^{-1}; hence, yield increases can only be realized by planting improved varieties. Therefore, the results demonstrate that the current stage of production is inefficient (Debertin, 1986). The expectation in this study was that when efficiency is improved in the use of available inputs, farmers are more likely to expand their scale of production, since most of them are constrained by lack of finances to invest in farming consistent with Jayne et al. (2010).

The coefficient for labour is negative indicating that at the mean, increased labour use has a decreasing effect on maize yields because the current level is beyond the optimal amount required for efficient production. Since most of the labour (67%) was from own family, it was likely under-valued and over-used. The result is consistent with past findings (Seyoum et al., 1998; Tchale and Sauer, 2007) that associated negative marginal product for labour with production systems that relied on cheap family labour and usually employed it beyond the economically optimal level.

The significant coefficient for district showed that on average farmers in Trans Nzoia realized higher maize yields than those in Lugari. This is due to the relatively large farm sizes of better quality and favourable climatic conditions over there, confirming the considerable role of conducive environmental conditions in farm productivity (Sherlund et al., 2002).

The estimates of the cost frontier showed that maize farmers on average exceeded the minimum cost of production by 34% (Table 2). We calculated allocative efficiency score as the inverse of allocative inefficiency value. This translated to allocative efficiency level of 75% and meant that there was opportunity to enhance efficiency by up to 25% through better allocation of scarce financial resources in maize production.

The significant estimate of the intercept indicates that there were considerable fixed costs in maize production. When farmers do not engage in any maize farming activity (and total variable costs are zero), they still incur significant opportunity cost of land. Cost of ploughing, price of seed and labour wage have positive and significant coefficients indicating that a marginal increase in their unit prices has sizeable effect on the production cost of maize. This implies that pricing of these inputs was beyond reach of many resource-poor smallholders. Therefore, efforts targeted at reducing cost of purchasable inputs will go a long way in enhancing affordability and access by majority of the resource-poor farmers. Similarly, an increase in yields would raise total cost of production, an indication that farmers were operating in the inefficient stage I of production (Debertin, 1986). This implies that there existed scope for increasing the scale of production without necessarily raising production costs so much by improving technical efficiency to benefit from economies of scale.

Assessment of differences in farming efficiencies

Farmers in the project area where they were exposed to ISFM practices achieved higher technical efficiency and lower allocative inefficiency compared to those in the counterfactual area (Table 3). The difference in estimated efficiency levels between farmers within the project area and those outside the project area represents ISFM contribution to technical and allocative efficiencies in

Table 2. Stochastic cost function estimated using maximum likelihood method to determine allocative efficiency in maize production.

Variable	Parameter	Coefficient	SE
Cost frontier function			
Intercept	α_0	6.771***	0.476
Fertilizer price	α_1	-0.026	0.077
Seed price	α_2	0.116**	0.058
Labour wage	α_3	0.109**	0.026
Ploughing cost	α_4	0.282***	0.037
Yield	α_5	0.118**	0.030
Efficiency measures			
Sigma-squared, $\sigma_\mu^2+\sigma_v^2$	σ^2	0.074**	0.013
Gamma, $\sigma_\mu^2/(\sigma_\mu^2+\sigma_v^2)$	γ	0.351***	0.029
Mean allocative inefficiency[c]	AE	34%	

[c] Allocative efficiency measures by how much the farmer exceeded the minimum feasible cost of production for a given level of output. We subtract 100 from the allocative inefficiency percentage to estimate the excess costs incurred by the farmer or group of farmers above the minimum efficient cost. This computation is implicit in all interpretations of differences in allocative inefficiency. Significant at the following levels: *10%; **5%; ***1%.

Table 3. Differences in technical and allocative efficiencies between farmers within and outside the project area.

Efficiency by site	Technical efficiency (%)		Allocative efficiency (%)	
	Mean	SD	Mean	SD
Within project area	84***	11	110***	16
Outside project area	58***	19	140***	17
Efficiency gain	26		30	

SD is standard deviation; *** Significantly different at 1% level.

maize production.

As presented in Table 3, significant differences (p=0.001) between the two sites (i.e. within and outside the project areas) demonstrate that adoption of ISFM practices has potential to narrow the yield gap by 26%, (84% less 58%), which is comparable to 30% reported in Tchale and Sauer (2007) and reduce cost incurred in maize production by 30% (140% less 110%). This clearly indicates that there is room to increase yields through more use of ISFM options to improve returns for smallholder farmers who cannot afford recommended rates of chemical fertilizers.

Factors influencing technical and allocative efficiencies

Table 4 shows the influence of the factors identified to contribute to farming efficiencies in maize production. They include farming experience, education level of the household head, household size (proxy for family labour), extension contacts and soil fertility management option. Others were credit access, off-farm income, market access and agro-ecological zone. We reversed the signs for all coefficients to enable direct inferences in relation to efficiency gains as opposed to inefficiency effects.

The coefficient for farming experience is significant and negative indicating that technical efficiency decreased with every year spent in farming (Table 4), in contradiction with previous findings (Külekçi, 2010; Seyoum et al., 1998). Although we expected higher efficiency among farmers with longer experience, the knowledge and skills gained over time may become less relevant with new technologies and constraints. However, farming experience enhanced allocative efficiency, supporting the view that the ability to acquire and process useful financial information increases with time, in line with Ogundari et al. (2006). The finding indicates that most experienced farmers gain various cost-saving strategies over time, which they apply in maize production. For instance, experience must have taught the seasoned maize producers to purchase key inputs such as fertilizers and seeds, and plough maize fields before the peak planting period when costs rise rapidly.

Formal education was found to increase technical efficiency, consistent with Külekçi (2010). The result points to

Table 4. Maximum likelihood estimates of factors affecting technical and allocative efficiency in smallholder maize production.

Factor	Coefficient	SE	Coefficient	SE
	Technical efficiency		Allocative efficiency	
Constant	0.54	1.55	0.34	0.56
Farming experience	-0.03**	0.01	0.01*	0.001
Education level	0.03*	0.02	-0.01*	0.007
Household size	-0.04*	0.03	0.01	0.01
Extension contacts	0.05*	0.04	0.03***	0.003
Soil fertility management	0.01***	0.001	0.02**	0.005
Credit access	-0.22	0.20	-0.05	0.09
Off-farm income earning	-0.61	0.55	-0.09*	0.08
Market access	-0.004**	0.001	-0.01**	0.001
Agro-ecological zone	0.23*	0.13	-0.08	0.15

Significant at the following levels: *10%; **5%; ***1%.

the importance of human capital in making and implementing informed and timely farming decisions. This means that most educated farmers have the capacity to source for, interpret and apply technical information well than the less educated ones. Moreover, better adoption of complex production technologies may call for technical knowledge and skills. Therefore, it is possible that these decisions and skills certainly benefit from some level of formal education. However, we found that higher education reduced allocative efficiency, consistent with Ogundari et al. (2006). This was surprising because it contradicts the view that the higher the number of years of schooling, the better the ability of farmers to match input use to their relative costs. Nevertheless, higher education level is likely to give farmers other off-farm income generating alternatives, which compete with maize production for management attention.

Agricultural extension contacts were associated with relatively higher technical and allocative efficiencies. The result demonstrated the value of providing farmers with skills and modern production techniques to improve yields and minimize production constraints. This finding is in agreement with other studies (Seyoum et al., 1998; Tchale and Sauer, 2007), which established that the farmers that regularly received extension information recorded higher technical efficiency compared to their counterparts. In fact, this study indicates that farmers who applied ISFM practices operated closer to their efficient frontiers. Therefore, promoting these practices through an effective extension approach will lead to greater efficiency gains in the entire farming system.

The application of ISFM practices in maize production contributed to both technical and allocative efficiencies than the use of chemical fertilizers alone. This observation point to the beneficial role played by organic nutrient sources in improving the productive capacity of the soil (Nyambati et al., 2003; Zingore et al., 2008). Further analysis already presented clearly show that those farmers who implemented some ISFM practices incurred on average 30% less costs of production at the same level of maize output. This confirms findings in other studies that have advocated for combination of inorganic and organic nutrient sources in different farming systems (Ranamukhaarachchi et al., 2005; Tchale and Sauer, 2007; Wanyama et al., 2010).

Off-farm income generation had an impact on allocative efficiency but not on technical efficiency contrary to the finding by Mochebelele and Winter-Nelson (2000). This is probably due to the possibility that farmers who earn more income away from the farm engage hired labour to carry out most activities in maize farming. However, hired labourers are less thorough in implementing agronomic activities. Moreover, owing to high demand for labour during peak periods, the implementation of critical agronomic activities such as planting, weeding and top-dressing may be untimely and this may eventually lead to low yields. The significant contribution to allocative efficiency was due to better financial capacity that enabled households that had off-farm income sources to acquire farm inputs timely before prices rose rapidly.

Higher cost of accessing the input-output markets led to lower technical and allocative efficiencies in maize production. This result can be associated with low use of purchasable inputs such as chemical fertilizers and hybrid seeds because of poor roads and costly transport system. The cost of accessing markets adds an extra financial burden to farmers located in remote areas characterized by poor roads network. The finding indicates the importance of enhancing access to input and output markets in order to improve farm productivity as also found by Tchale and Sauer (2007).

CONCLUSIONS AND RECOMMENDATIONS

Determining and overcoming possible constraints to efficiency in smallholder farming system can contribute to sustainable use of farm resources in sub-Saharan Africa (SSA). Efforts aimed at enhancing overall efficiency among smallholders aims to improve maize productivity, net farm returns and soil fertility management in the maize farming system of Kenya. We investigated whether the availed integrated soil fertility management (ISFM) technologies have had impacts on both technical and allocative efficiencies in maize production.

We found that overall farmers achieved only 64% technical efficiency and 75% allocative efficiency. Farmers who applied ISFM practices were closer to their efficient frontiers compared to those who did not. We established that ISFM contributed about 26% to technical efficiency and 30% to allocative efficiency. Other factors that were found to determine efficiency gains included farming experience, provision of extension services, market access and off-farm income. These factors indicate the need for farming knowledge and profitability, and that farmers were responsive to policy-induced incentives. Therefore, we recommend the promotion of ISFM technologies through farmer groups and participatory extension system, in order to achieve greater efficiency gains in maize production in the country. We suggest the integration of efficiency considerations in agricultural research and policy formulation processes to ensure continued use of improved technologies and for enhanced food availability and incomes among the rural poor in similar SSA countries.

Conflict of Interest

The authors have not declared any conflict of interests.

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