Analysis of technical efficiency of sorghum production in lower eastern Kenya

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Abstract

Most Kenyan rural households depend on agriculture for food and livelihoods. Declining agricultural productivity has resulted in increased food insecurity in the country. Consequently, there is a renewed interest in promoting drought-tolerant orphan crops such as sorghum for increased production in the arid and semi-arid lands of Kenya. However, performance of sorghum production among the smallholder farmers has remained low. This study was conducted to determine technical efficiency of sorghum production and its associated factors in Machakos and Makindu districts. The study surveyed 143 sorghum farming households during 2010-2011 growing seasons. The Data Envelopment Analysis and Tobit models were used to estimate efficiency scores and factors that influence the technical efficiency. Results showed that mean technical efficiency was 41%, which is considered low. The technical efficiency was influenced positively by farm and farmer characteristics. It is concluded that technical efficiency of sorghum production in the study districts can be improved further by 59%. Similarly, innovative institutional arrangements enhancing farmer training should be instituted to enhance farmer capacity to efficiently use available resources to improve sorghum production.

Key words: technical efficiency, sorghum, DEA, tobit.

Introduction

Grain sorghum (*Sorghum bicolor* L Moench.) is the 5th most important cereal crop grown in the world (U.S Grain Council, 2010). Because of its versatility and diversity, sorghum is grown mainly in the arid and semi-arid lands (ASALs) of Africa and Asia for rural food security. Although sorghum is largely a subsistence crop, it is increasingly becoming part of the successful food and beverage component of the lager beer brewing industry (Taylor, 2010).

In Kenya sorghum is a traditional subsistence crop, which is grown in many ASALs of the country. However, sorghum lost favour with farmers when maize became the preferred and staple food crop in Kenya after its introduction by the white settlers. Notwithstanding, there is renewed interest in promoting drought-tolerant crops such as sorghum and pigeon pea to stabilize food security in Kenya. These crops are also well adapted to harsh environments (GoK, 2009).

Substantial research on sorghum breeding has been going on in Sub-Saharan Africa resulting in sTable, high-yielding sorghum varieties (HYSVs) that are being promoted for adoption (Olembo *et al.,* 2010). In Kenya, initiatives for promoting sorghum production are concentrated in the ASALs. This is in line with the government strategy of enabling the country meet household food security and increased rural income (GoK, 2009).

Sorghum production is important in lower eastern Kenya partly because this area is characterized by increasing drought occurrences. Over the past two decades, there have been repeated maize crop failures in this region because of droughts (Karanja *et al.,* 2009). The HYSVs, coupled with improved production technologies, can survive and yield well in the ASALs such as the lower eastern Kenya (Karanja *et al.,* 2009). In recognition of the role sorghum plays in food security especially in ASALs, the government through the Kenya Agricultural Research Institute (KARI) has given priority to developing locally adapTable HYSVs with accompanying agronomic technologies. In addition the Ministry of Agriculture has initiated and implemented funded Orphan Crops projects to promote the production of crops like sorghum.

It is important to note that the area under sorghum production in Kenya has been increasing from 122,368ha in 2005 to 173,172ha in 2009, but the national average yield per hectare has been decreasing from 1.2tons/ha in 2005 to 0.5tons/ha in 2009 (GoK, 2010). Various public efforts supplemented by Non-Governmental Organizations (NGOs) and other stakeholders like International Sorghum and Millet (INTSORMIL) program and International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) have provided interventions for Harnessing Opportunities for Productivity Enhancement (HOPE), targeted at improving productivity and marketing of sorghum. These interventions include breeding, distribution of improved HYSVs that are pest and disease tolerant, and promotion of resource conserving management practices. Despite all these efforts, there has been variability in production from the expected potential yields and the actual yields. The expected potential yield for the Gadam sorghum variety is 2-2.5tons ha^{-1} but farmers have so far only realized production of up to 1.2tons ha^{-1} (GoK, 2009; Karanja *et al.,* 2009).

Variability in production is a function of differences in scales of operation, production technologies, operating environment and operating efficiency. Chimai (2011) noted that for small-holder farmers, variation in production due to differences in efficiency may be affected by various factors, which include regional and farm specific socio-economic factors. Technical efficiency (TE) differences could also be explained in the context of the management characteristics such as training, experience and motivation (Ahmed *et al.,* 2005).

The study sought to determine technical efficiency of sorghum production and identified farm and farmer characteristics that influence levels of TE among smallholder sorghum producers in the lower eastern Kenya.

Different approaches are used to determine technical efficiency. It is observed that TE studies have been conducted on various crops including maize, wheat, Irish potatoes, coffee and millet. Most of these studies have however reported as low as 0.24 to moderately high technical efficiencies (chiona, 2011, Chimai, 2011,Nyagaka, 2011).

Two of the most frequently used methods for determining TE are the Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA). As pointed out by various authors (Chiona, 2011; Coelli *et al.,* 2002; Chimai, 2011), DEA approach has several advantages. It uses mathematical programming to measure relative efficiency of decision making units (DMUs). It does not make *a priori* assumptions about the functional form of the production function and the inefficiency term. Instead it makes general assumptions of monotonicity and convexity, which result in a flexible frontier that allows the production function to vary across DMUs. Thus, many empirical studies have applied and extended the DEA technology in studies of efficiency worldwide (Chimai, 2011; Mussa *et al.,* 2011; Chiona, 2011).

There are also many studies that have determined factors that influence technical efficiency. A number of such studies have attempted to investigate relationships between technical efficiency and various socio-economic and demographic variables such as levels of education, age, family size, access to credit, extension services and experience (Chiona, 2011 and Nyagaka *et al.,* 2011). Other studies have shown how technical inefficiency is influenced by managerial incompetence (Ahmed *et al.,* 2005), and other factors such as membership to agricultural associations, land ownership, value of household assets, use of fertilizers and tillage methods adopted (Nyagaka *et al.,* 2011; Chimai, 2011). Many of these factors influence technical efficiency differently depending on unique characteristics of individual countries and agricultural products.

Materials and methods

Study area

This study was conducted in Makindu and Machakos districts of Makueni and Machakos counties respectively, both situated in the ASALs of the lower Eastern Kenya. The districts experience bi-modal rainfall distribution with two distinct cropping seasons. Machakos district lies at $1^{0}35^{1}$S and $37^{0}10^{1}$E and has a mean annual rainfall of 690mm, while Makindu lies at $2^{0}0^{1}$S and $37^{0}40^{1}$E with a mean annual rainfall of 580mm. Agriculture is mainly rainfed and crop and livestock production are constrained by low soil moisture and poor pastures because of erratic and unreliable rainfall(Kwena *et al.,* 2011a, 2011b). The Machakos and Makindu districts present great opportunities for improved production of appropriate HYSVs.

Sampling and data collection

The population of interest comprised of sorghum growing households (HHs) who grew sorghum in 2010-2011 cropping season. A sample size of 143 HHs (Makindu [71] and Machakos [72] was determined proportionately using total population of the districts. A multi-stage sampling procedure was employed.

Data was collected from the sampled HHs between June and August 2012 by use of pre-tested semi-structured questionnaires that were administered by trained enumerators. The questionnaires sought information on demographic, institutional, physical and socio-economic factors, and yields and inputs used during the 2010-2011 cropping season.

Data analysis

Data envelopment analysis model. This study employed Data Envelopment Analysis (DEA) model (Banker *et al.,* 1984) to analyse the collected data to determine technical efficiency of sorghum production. The model is based on output-orientation under variable returns to scale (VRS). VRS are assumed appropriate because sorghum farmers in the study areas were found to experience variations in agricultural production occasioned by multiple factors. The output-orientation seeks to determine the maximum proportional increase in output produced with inputs level held fixed.

Technical Efficiency scores are estimated by an output-oriented linear programming analytical model developed by Charnes *et al.* (1978). As defined in equation 1, parameters are solved *n* times – once for each HH in the sample:

$$\begin{aligned}
&Max \sum_{k=1}^{s} V_k Y_{kp} \\
&s.t \quad \sum_{j=1}^{m} U_j X_{jp} = 1 \\
&\sum_{k=1}^{s} V_k Y_{ki} - \sum_{j=1}^{m} U_j X_{ji} \leq 0 \qquad \forall i \\
&V_k, U_j \geq 0 \quad \forall k, j
\end{aligned} \tag{1}$$

All the DMUs with a score of 1 are regarded as being 100% technically efficient, while all the others scores less than 1 are regarded as technically inefficient.

The Tobit model. A two-step procedure, the most commonly applied, was used to estimate parameters in this study. In the 1st step, TE scores are estimated using the DEA output-oriented model, while in the 2nd step the estimated TE scores are regressed on farm and farmer characteristics variables to identify their influence on technical efficiency. Given that the TE scores range between 0 and 1, a two limit Tobit regression model (equation 2) (Coelli *et al*. (2002) was used as shown.

$$U_i^* = \beta_0 + \sum_{j=1}^{k} \beta_j Z_{ij} + \mu_i$$

$$U_i = \begin{cases} 1 & \text{if } U_i^* \geq 1 \\ U^* & \text{if } 0 \prec U_i^* \prec 1 \\ 0 & \text{if } U_i^* \leq 0 \end{cases} \tag{2}$$

Where i = the i^{th} DMU; U_i = efficiency scores of i^{th} DMU; U_i^* = latent efficiency; β_j = parameters that are estimated; Z_{ij} = farm and farmers characteristics variables; and μ_i = error term.

The analytical Tobit model used in this study is specified as:

$$\text{Eff score} = \beta_0 + \beta_1 \text{ Malehd} + \beta_2 \text{ H/age} + \beta_3 \text{ H/edu} + \beta_4 \text{ Prodadvice} + \beta_5 \text{ Adptill} + \beta_6 \text{ Hlabortill} + \beta_7 \text{ Offincm} + \beta_8 \text{ Asset} + \beta_9 \text{ Agrcredit} + \beta_{10} \text{ Othrincm} + \beta_{11} \text{ Srgmfarmsize} + \beta_{12} \text{ Ndependents} + \beta_{13} \text{ Srgmseed} + \beta_{14} \text{ Manure} + \beta_{15} \text{ Improvseed} + \beta_{16} \text{ Clubmbr} + \beta_{17} \text{ Expr} + \mu$$

Where: Malehd=Male headed HH, H/age=Age of HHH, H/edu=Education level of HHH, Prodadvice=Production advice, Adptill=Adopted tillage, Hlabortill=Hired labour, Offincm=Off farm income Asset=Household Assets, Agrcredit=Agricultural credit use, Othrincm=Income from other crops and livestock, Srgmfarmsize=Farm size used to produce sorghum, Ndependents=Number of dependants, Srgmseed=Sorghum seed rate, Manure=Improvseed=Improved seed varieties, Clubmbr=Club/association membership, and Expr=Experience in sorghum farming.

Results and discussion

Technical efficiency

For the TE scores, out of the 143 HHs surveyed, 22 HHs (15%) overall, 12 HHs (17%) Makindu and 15 HHs (20%) in Machakos were 100% technically efficient (Table 1).

The efficient HHs, defined the efficient frontiers and represents the best practices of decision making units (DMUs) in combining land, seeds and labour to produce maximum sorghum output possible. When the inputs are held constant, the HHs produce more output per unit area as compared with their inefficient counterparts. The overall mean TE was 41%, while the mean for Machakos and Makindu districts were about 43% and 48% respectively. This implies that more that 50% of the output was lost due to technical inefficiency. This also implies that there exits tremendous opportunity to improve technical efficiency among the HHs. On average, there was potential to increase farm output by 56.7% and 52.1% in Machakos and Makindu respectively using the existing levels of inputs. These results appear to concur with those of Chimai (2011) and Amaza *et al*. (2010) who estimated the TE of sorghum production in Zambia and Borno State in Nigeria respectively.

As presented in Figure 1, the TE indices varied widely between the two districts in which 18% of the surveyed HHs were below 10% TE in Machakos against 10% in Makindu district. Most of the HHs in Machakos (> 50%) were operating < 30% TE, while in Makindu district HHs operating < 30% TE consisted of only 35%.

Majority of the technical inefficient HHs in Makindu operated between 30 and 39%, while in Machakos majority operated between 10 and 19% technical efficiency. Observed variations between Machakos and Makindu districts could be explained by the apparent variations in some of the farm and farmer characteristics.

Table 1: Frequency distributions of technical efficiency scores obtained by DEA

model

Efficiency scores	Frequency distribution of DEA		
	Overall TE VRS	Makindu TE VRS	Machakos TE VRS
1.00	22	12	15
>0.90<1.00	2	1	1
>0.80≤0.90	6	4	3
>0.70≤0.80	4	3	3
>0.60≤0.70	4	3	5
>0.50≤0.60	9	4	2
>0.40≤0.50	11	7	5
>0.30≤0.40	16	12	8
>0.20≤0.30	16	10	16
>0.10≤0.20	28	8	13
<0.10	25	7	72
Total DMUs	143	71	0.019
Minimum	0.015	0.032	1
Maximum	1	1	0.433
Mean	0.410	0.479	

TE VRS = Technical efficiency under variable return to scale assumption

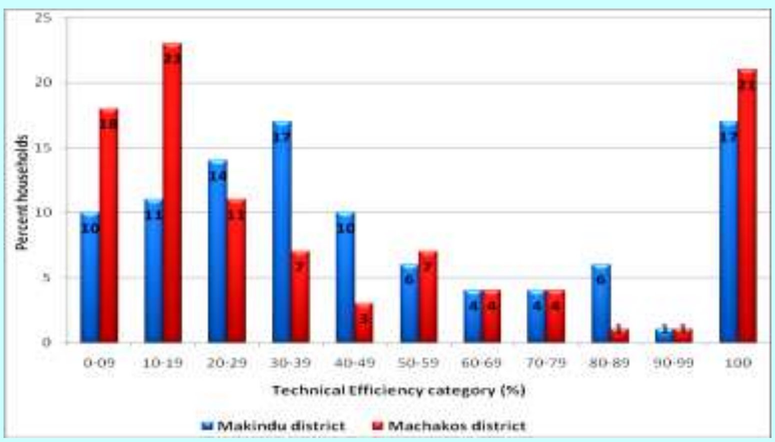

Figure 1: Technical efficiency distributions per district

Factors influencing technical efficiency

Many variables were relevant in explaining technical inefficiency obtained for sorghum production. Out of 18 variables, seven were influenced TE positively and statistically significant at 5% level (Table 2). These variables include formal education levels of HH heads, years of experience in sorghum farming, HH membership in farmer associations, size of land planted with sorghum, hired labour, use of manure and production advice on sorghum production. Their respective increase improved the TE of sorghum production. Only one variable, size of HHs, was found to influence TE negatively and significantly at 5% level. If the size of the household is big, the use of family labour could be very common hence reduction in labour efficiency which affects the overall efficiency of sorghum. These findings were found to be in line with those of Gul *et al*. (2009) but contrary to those of Ajewole and Folayan (2008).

Variables

Table 2: Tobit model results showing farm and farmer characteristics that influence technical inefficiency in lower eastern Kenya

	Overall			Makindu District			Machakos District		
	Coefficient	Std error	t-ratio	Coefficient	Std error	t-ratio	Coefficient	Std error	t-ratio
Male-headed HHs	0.0151	0.0602	0.25	0.0127	0.0917	0.14	-0.1275	0.0965	-1.32
Age of the HHH	0.0031	0.0022	0.166	-0.0041	0.0035	-1.17	0.0043	0.0038	1.11
Education of the HHH	0.3397*	0.1122	3.03	0.3161*	0.1402	2.25	0.3861*	0.1584	2.44
HH size	-0.0109	0.0168	-0.65	-0.0159*	0.0060003	-2.61	-0.0143	0.0295	-0.48
Number of dependents	0.0187	0.0162	0.67	0.0334	1.10e-07	1.10	0.0010	0.0257	0.04
Assets	1.41e-08	5.67e-08	0.25	2.81e-08	0.0202	0.25	1.48e-07	8.69e-08	1.70
Experience in sorghum farming	0.1346*	0.5284	2.55	0.0456*	0.0588	2.26	0.1420*	0.0670	2.12
Membership to farmer associations	0.1446*	0.0509	2.84	0.1933*	0.0034	3.29	0.3164*	0.1457	2.17
Seed rates used	0.00002	0.0029	0.01	0.0003	0.1400	0.08	0.0009	0.0034	0.27
Use of improved seed variety	0.0617	0.0682	0.90	0.0088	0.1838	0.06	0.0237	0.1015	0.23
Size of land planted with sorghum	0.1318	0.6955	1.89	0.5603*	0.0911	3.05	0.4210	0.3281	1.28
Land preparation method	-0.0626	0.0583	-1.07	-0.0430	0.0807	-0.47	-0.0455	0.0997	-0.46
Hired labour	0.1096*	0.0542	2.01	0.1968*	0.0540	2.44	0.2789*	0.1064	2.62
Manure use	0.1832*	0.0531	3.45	0.1660*	0.0679	3.07	0.2706*	0.0883	3.07
Production advice	0.2610*	0.0549	4.76	0.2474*	1.24e-06	3.64	0.2208*	0.1101	2.00
HH off-farm income	-9.26e-07	7.57e-07	-1.22	1.28e-06	0.1543	1.04	1.38e-08	1.26e-06	0.01
Credit use	0.1021	0.0932	1.1	0.1061	0.0993	0.69	0.1157	0.1018	1.14
Income from other farm activities	-0.0057	0.0476	-0.12	0.1157	-	1.16	-0.0622	0.0733	-0.85
Region	0.1015	0.0705	1.44	-	0.2697	-	-	-	-
Constant	0.4263*	0.1859	2.29	1.1141*		4.13	0.5372*	0.2439	2.20
Software used STATA	N=143; LR χ^2 df=111.91			N =71; LR χ^2 df=78.68			N =71; LR χ^2 df=55.81		
* Significance at 5%	Prop> χ^2 =0.00 Pseudo R^2=0.6741			Prop> χ^2 =0.00 Pseudo R^2=0.9761			Prop> χ^2=0.00 Pseudo R^2 =0.5483		
	Log likelihood=-27.047463			Log likelihood=0.96331317			Log likelihood=22.988456		
	Sigma coefficient 0.2551064			Sigma coefficient 0.2125154			Sigma coefficient 0.2828562		
	Left censored=0 Uncensored=121			Left censored=0 Uncensored=59			Left censored=0 Uncensored =57		
	Right censored=22			Right censored=12			Right censored=15		

Notes: HH=Households, HHH=Household head

However, there were other variables that influenced TE positively but not statistically significant. Some of those factors include male-headed HHs, number of dependants, HH assets, use of improved seed varieties, seed rate, HH off-farm incomes, income from other farm activities, and use of credits. Increase in these variables could have an impact on the technical efficiency of sorghum production.Variables such as age of the HH head and land preparation methods influenced TE negatively but not statistically significant.

Conclusion and recommendations

It is concluded that majority of the sampled smallholder sorghum producers were technically inefficient. The HHs were operating on a mean TE of 41%, with some of them in fact operating in as low as 1.5% TE regime. This gives potential opportunity for efficiency improvement. Several factors including years spent by HH heads in school, experience in sorghum farming and HH membership in farmer associations influenced TE of sorghum production positively and statistically significant.

It is recommended that a policy review, targeting formal education, youth capacity building in sorghum farming, collective actions and use of optimal inputs, be undertaken to provide an enabling environment to improve HHs' ability to enhance sorghum product value chains.

Acknowledgement

The authors are grateful to the ASARECA for funding and KARI Director and KARI-Katumani Centre Director for logistical support. Any views expressed here are those of the authors and errors are sole responsibility of the authors.

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