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Analysis of Technical Efficiency of Sorghum Production in Lower Eastern Kenya: A Data Envelopment Analysis (DEA) approach.

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ABSTRACT
There has been an increase in food insecurity problem in ASALs of Kenya and this has necessitated a renewed interest in promoting drought-tolerant crops such as sorghum, among smallholder farmers in these regions. Promotion of such crops as sorghum has been emphasized in these regions but the yields are low. Using a field survey data of randomly selected sample of 143 smallholder farmers in Machakos and Makindu districts in Kenya this paper used DEA approach to estimate their technical efficiency scores. Results showed that the average technical efficiency was low, 41%. Innovative arrangements should be enhanced to increase farmers' capacity to efficiently use the available resources in sorghum production.
Key words: Technical efficiency, sorghum, Data Envelopment Analysis, Machakos, Makindu, Kenya

1. INTRODUCTION

Grain sorghum, *Sorghum bicolor (L.)* Moench is the fifth most important cereal crop grown in the world (U.S Grain Council, 2010). Probably because of its versatility and diversity (International Research Network, 2005), sorghum is mainly grown in the arid and semi-arid lands (ASALs) of Africa and Asia for rural food security. Sorghum is processed into a wide variety of attractive and nutritious traditional foods, such as semi-leavened bread, dumplings and fermented and non-fermented porridges. It is still largely a subsistence food crop, but it is increasingly forming part of the foundation of successful food and beverage industries after being proven the best alternative to barley for lager beer brewing (Taylor, 2010).
In Kenya sorghum is a traditional crop, which is grown in many parts of the country especially in the arid and semi-arid regions of the country. It is grown mainly for subsistence use, but the crop lost favour with farmers when maize became the preferred crop and staple food after its introduction by the white settlers. However, due to the desire to stabilize food security in the country there is now renewed interest in promoting drought-tolerant crops such as sorghum and pigeon pea, which are known to be well adapted to harsh environments (GoK, 2009).
A lot of research on sorghum breeding has been going on and there is substantial documentation about this within Sub-Saharan Africa (SSA). Stable, high-yielding sorghum varieties (HYSVs) have recently been developed (Olembo *et al.*, 2010). Sorghum production has widely been promoted among smallholder farmers because of its ability to thrive well in arid and semi-arid regions and the low input requirements compared with most staple cereals like maize. In Kenya, for example, the initiatives to promote sorghum production are mostly concentrated in the ASALs. This promotion is done as a government strategy to enable the country meet household food security needs and increase rural income (Ochieng *et al.*, 2011; GoK, 2009; Okuthe, 2008). These initiatives have great potential for growth and expansion of the crop and are expected to impact the livelihoods of many farmers through food security and income generation.
Eastern Kenya is characterized by increasingly frequent drought occurrences, sometimes extending for two to three years in a stretch. Over the last two decades, there have been repeated maize crop failures in many parts of eastern Kenya especially because of droughts (Nagarajan and Audi, 2007). Coupled with improved production technologies, improved sorghum varieties if grown in semi-arid areas like the eastern province, can survive and yield well in such unreliable climatic conditions (Karanja *et al*., 2009). To promote the crop, Kenya Agricultural Research Institute (KARI) has developed HYSVs with accompanying supporting production technologies for higher yields. In recognition of the role sorghum can play in food security especially in ASALs, the government through the Ministry of Agriculture (MoA) initiated projects such as the Eastern Province Horticulture and Traditional Food Crops project, an International Fund for Agricultural Development (IFAD)-funded project, and Orphan Crops project in these regions to promote the sorghum, among other crops. The main aim of these projects was to encourage farmers to adopt these improved varieties in order to improve food security and rural incomes.
The area under sorghum production 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 per hectare in 2005 to 0.5tons per hectare in 2009 (GoK, 2010). Several 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, for instance, 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 only realized production of up to 1.2tons ha^{-1} so far (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 (Fried *et al.*, 2008). Production increases depend mainly on the efficient use of available appropriate technologies but not necessarily on adoption rates of new technologies (Chiona, 2011). Therefore, improving efficiency in production allows farmers to increase their output (Chimai, 2011). Chimai also noted that for the 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 inefficiency may arise primarily due to managerial incompetence and therefore efficiency differences could 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 among smallholder farmers in Machakos and Makindu districts of lower eastern Kenya.

2. LITERATURE REVIEW

Most of African countries suffer from food insecurity. The domestic productions lag behind the demand and yields levels of many crops are below the global averages. The scarcity of land and other production resources necessitate a strategy to increase agricultural productivity by efficiently using the little available resources. This reveals the importance of technical efficiency and its linkage with agriculture. In the same ways, many authors (Choina, 2011; Fried *et al.,* 2008; Coelli *et al., 2002*) have recognized the crucial role of technical efficiency in productivity and agricultural growth.

In a production frontier, a technically efficient farmer is always located on the frontier while the inefficient farmer at the anterior (Coelli *et al.*, 2002). One way of reducing the cost of production in a farm is to increase farm output by increasing technical efficiency (Fried *et al.*, 2008). In this regard, it is necessary to quantify current levels of technical efficiency of farmers in order to estimate the losses in production attributed to inefficiency due to different socio-economic characteristics and management practices.

There is a growing body of literature on technical efficiency, using different approaches, in African agriculture so far. Literature (Fried *et al.,* 2008; Coelli *et al.,* 2002; Charnes *et al.,* 1978) suggests several alternative approaches to measure technical efficiency. Using these approaches TE studies have been conducted on various crops such as maize, wheat, millet, Irish potatoes, coffee, millet and sorghum. Most of these studies however have reported low to moderate technical efficiencies ranging from as low as 0.24. This confirms the evidence that most countries in the developing world in general and Sub Saharan Africa (SSA) in particular still experience relatively low efficiency levels in agriculture. These approaches are normally grouped into non-parametric, Data Envelopment Analysis (DEA) being the most commonly used and parametric frontiers, Stochastic Frontier Analysis (SFA) being the most commonly used.

A non- parametric, DEA model was used in this article. As pointed out by various authors (see for example, Chimai, 2011; Chiona, 2011; Abu, 2011; Yusuf and Malomo, 2007; Coelli *et al.*, 2002; Charnes *et al.*, 1978), DEA approach has several advantages. It uses mathematical programming to measure relative efficiency of DMUs. It does not make 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. Few empirical studies have argued on the disadvantages of DEA. One of the disadvantages lies in its deterministic nature where it fails to account for stochastic noise in data, which could be a potential bias to the estimated efficiency scores. Another disadvantage is that it is less robust to outliers and extreme values. However, a large number of empirical studies have extended and applied the DEA technology in the study of efficiency worldwide (Chimai, 2011; Abu, 2011; Chiona, 2011; Mussa *et al.*, 2011; Javed *et al.,* 2010; Yusuf and Malomo, 2007; Chavas *et al.*, 2005; Donthu and Yoo, 1998).

3. MATERIALS AND METHODS

Study Area

This study was conducted in Makindu and Machakos districts of Makueni and Machakos counties respectively. Both districts are situated in semiarid lands of the lower Eastern Kenya. They both experience bi-modal rainfall distribution pattern with two main distinct cropping seasons. Normally the long rains of these districts fall from March to May, while the short rains fall from October to December. Machakos district lies at $1^{0}35^{1}$S and

$37^0 10^1$E and has a mean annual rainfall of 690mm, with average annual temperatures ranging from a minimum of 11.0^0C and a maximum of 27.6^0C. Makindu district lies at $2^0 0^1$S and $37^0 40^1$E with a mean annual rainfall of 580mm, and average annual minimum and maximum temperatures of 14.5^0C and 31.5^0C respectively (Kwena *et al.,* 2011a and 2011b).

Agriculture in the study area is mainly rain fed and crop and livestock production are constrained by low soil moisture and poor pastures because of erratic and unreliable rainfall. Largely the majority of the households populations are classified as poor given that approximately 52% of HHs in Machakos district and 64% in Makindu district survive under poverty line (approximated as US$$1.^{00}$ per person per day). The types of crops normally planted in Machakos district are mainly maize, beans, pigeon peas, sorghum and cow peas; while in Makindu district the commonly planted crops are mainly maize, green grams, cowpeas, pigeon peas, dolichos, sorghum, millet and cotton (Kwena *et al*., 2011a, 2011b). The Machakos and Makindu sites present greater opportunities for improved production of appropriate HYSVs. Hence the sites were among the districts in which the projects to promote sorghum farming were initiated in the lower Eastern Kenya.

Sampling design and data collection

The population of interest comprised of sorghum growing households, at least the HHs that grew sorghum in the 2010-2011 cropping season. A sample size of 143 farm households, 71 and 72 farm households in Makindu and Machakos districts respectively was determined proportionately using total population of the districts. Two forms of sampling procedures were employed. First sorghum farmers were selected using purposive sampling method with the help of extension officers in the two districts and then the selected farm households were subjected to systematic simple random sampling where every 9^{th} sorghum farmer was selected to achieve the required sample size.

Data was collected from sorghum farmers between June and August 2012 by use of pre-tested semi-structured questionnaires administered by the trained enumerators. Information on yields and inputs used to grow sorghum by each HH in 2010-2011 cropping season were collected.

Data Analysis

This study used Data Envelopment Analysis (DEA) model to analyse its data bases. The model involves use of linear programming methods to conduct a non-parametric piecewise surface (or frontier) over the data to calculate efficiencies relative to this surface (Coelli *et al*., 2002). DEA can either be Constant Return to Scale (CRS) or Variable Return to Scale (VRS). CRS is appropriate when all DMUs are assumed operating at an optimal scale, or otherwise VRS is appropriate. Sorghum farmers in the study areas were found to experience variations in agricultural production occasioned by factors such as financial constraints, imperfect competition, fluctuating input prices and unreliable labour supply. The use of VRS was assumed appropriate in order to account for these variations. Technical efficiency was estimated based on output-orientation where a HH produces maximum output given a level of inputs and it determines the maximum proportional increase in output produced with inputs level held fixed. In DEA the performance of a farm is evaluated in terms of its ability to either shrink usage of an input or expand the output level subject to restrictions imposed by the best observed practices (Gul *et al*., 2009).

Assuming that there were *n* DMUs each with *m* inputs and *s* outputs the relative efficiency score for each DMU was obtained by solving an output-oriented equation with VRS of DEA model as developed by Banker *et al.* (1984) as shown below.

$$Max \quad \sum_{k=1}^{s} V_k Y_k$$

$$Max \quad \frac{\sum_{k=1}^{s} V_k Y_{kp}}{m \sum_{j=1} U_j X_{jp}}$$

$$s.t \quad \frac{\sum_{k=1}^{s} V_k Y_{ki}}{\sum_{j=1}^{m} U_j X_{ji}}$$

$$V_k, U_j \geq 0 \qquad \forall k, j$$

Where k= 1 to s; j= 1 to m; i= 1 to n;
V_k = weight given to output k;
U_j = weight given to input j
Y_{ki} = amount of output k produced by DMU *I;*
X_{ji} = amount of input j utilized by DMU *i.*

……………………………………………….. (1)

An output-oriented linear programming (LP) model developed by Charnes *et al.* (1978) as defined below was solved *n* times – once for each farm household in the sample:

$$Max \quad \sum_{k=1}^{s} V_k Y_{kp}$$

$$s.t \quad \sum_{j=1}^{m} U_j X_{jp} = 1$$

$$\sum_{k=1}^{s} V_k Y_{ki} - \sum_{j=1}^{m} U_j X_{ji} \leq 0 \qquad \forall \ i$$

$$V_k , U_j \geq 0 \quad \forall \ k, \ j \qquad \text{..........................} (2)$$

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

Technical efficiency indices (TEIs) are the efficiency measures obtained from ratios of sums of weighted outputs to the sums of weighted inputs. In DEA these efficiency indices are generated as radial measures based on Farrell's (1957) concept. The radial measures can be radial contraction of inputs to the least level necessary for production of a specific level of output or expansion of outputs obtained from a given combination of inputs (Farrell, 1957). DEA constructs a piece-wise frontier enveloping most DMUs in the sample. In output orientation, the frontier is constructed based on the DMUs that are furthest from the origin. This is because the further they are the greater the ability to produce more from a fixed set of inputs and are therefore on a higher production possibility frontier (Coelli, 1996). This measure of performance is relative in the sense that the efficiency of each DMU is evaluated against the most efficient DMU. It is measured by the ratio of the actual output to maximal potential output. A DMU can be rated as fully (100%) efficient on the basis of available evidence if and only if the performance of the other DMUs does not show that some of its inputs or outputs can be improved without worsening the others inputs or outputs (Coelli *et al.,* 2002). The other DMUs with less than 100% technical efficiency score were rated as being inefficient.

4. RESULTS AND DISCUSSION

The variables used in DEA analysis were subjected to descriptive statistics as presented in Table 1, before the technical efficiency score were generated. These variables were similar in both districts and the same variables were used in the computation of the technical efficiency indices (TEIs) or scores using DEA model. As shown in the table, there were three inputs and one output. The inputs used included the land area in hectares planted with sorghum, the quantity of sorghum seeds planted and the labour used during production processes.

Technical efficiency scores summarized in Table 2 shows that out of 143 HHs surveyed in the lower eastern Kenya, only 22 HHs (15%) overall, 12 HHs (17%) in Makindu and 15 HHs (20%) in Machakos were efficient i.e. were 100% technically efficient. The efficient HHs, defined the efficient frontiers and they represent the best practices of DMUs for combining land, seeds and labour to produce the maximum sorghum output possible. When these inputs are held constant, the HHs produce more output per unit area as compared with their counterparts who had been deemed inefficient.

The overall mean technical efficiency (TE) was 41%. The mean for each district were about 43% and 48% for Machakos and Makindu districts respectively. This also implies that more that 50% of the output was lost due to technical inefficiency. The TE levels of the inefficient DMUs ranged from a minimum of about 1.5% to a maximum of about 97.8%. This 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% in Machakos and 52.1% in Makindu from the existing levels of inputs use. Policy strategies aimed at improving technical efficiency in the short run should emphasize on an effective and efficient use of the existing technology transfer instruments, which enhance capacity of the farms to efficiently use the physical inputs. These results appear to concur with those of Chimai (2011) who estimated a 34% TE of sorghum production in Zambia. Amaza *et al.* (2010) also found the TE of sorghum production in Borno State in Nigeria to be averaging 37%, while Wakili (2012) found an average TE of 72% for sorghum production in Adamana State in Nigeria.

As presented in table 3 technical efficiency indices varied widely between the two districts. As indicated, 18% of the surveyed households in Machakos district were below 10% TE against 10% in Makindu district. Most of the households in Machakos (more than 50%) were found operating below 30% TE, while in Makindu district the households operating below 30% TE were only 35%. Majority of the technical inefficient household in Makindu operated between 30 and 39%, while in Machakos majority of the HHs operated between 10 and 19% TE. Households termed as being relatively technical efficient were 23 and 24% in Machakos and Makindu respectively, with only 2 and 7% of them operating between 80 and 99% TE in the respective districts.

Each of the two districts in the lower eastern Kenya however has different estimated mean efficiency.

Disaggregating data by sites reveals that there existed site variations in technical efficiency. For instance, in Makindu district, the mean technical efficiency was 47.9% compared with 43% in Machakos district. On average, there is potential to increase farm output by 52.1% in Makindu and 57% in Machakos from the existing levels of input use. The observed variations between Machakos and Makindu districts could be explained by the observed variations in some of the farm and farmer characteristics in the two districts. These characteristics included membership to farmer associations, land preparation methods and years of sorghum farming experience, which differed between the two districts. These characteristics were found to have a

Output and input slacks

Slack problems arise when it is questionable whether a farm is on efficient point on the frontier. For example, input slack, which is also referred to as input excess, is the excess amount of any input that can be reduced and still produce the same output. The results of the DEAP model produce both the radial Farrell technical efficiency scores and residual slacks to provide an accurate indication of a DEA analysis. There were no output slacks as shown in table 4 by the zero values in all output slacks (Makindu, Machakos, and Overall). This implies that the outputs were not optimized.

On the other hand, input slacks were experienced in the lower eastern Kenya. The average land sizes planted with sorghum, the quantity of seeds planted and the labour persondays used in the entire sorghum production process in lower eastern Kenya had slacks. This implies that these inputs were not optimally used in the production process. The farms were radically inefficient in their input usage; hence; the sampled households were under utilizing their resources. The households were not optimizing their outputs.

All the slacks were positive. Positive slack indicates that the linear combination can produce at least much of every output using no more of any input (Thrall, 1996). This implies that more output could be produced with the same quantity and mix of inputs than what was achieved. As evident from the results, labour input was the most underutilized.

5. CONCLUSION AND RECOMMENDATIONS

Sorghum enterprise has been performing dismally in the lower eastern Kenya and the reasons for this have not been well established and understood. Yield gaps between the on-station and on-farm research on one side and the farmer practice on the other are wide. This study, therefore, was undertaken to provide an assessment of technical efficiency among smallholder sorghum producers in the lower eastern Kenya. The study estimated technical efficiency using the DEA model. The major conclusion on the findings of this study is that many sampled smallholder sorghum producers were technically inefficient. They were found operating on a mean technical efficiency of 41%, with some HHs in fact operating in as low as 1.5% technical efficiency regime. Most sampled households (48%) operated below 30% technical efficiency, while only 20% of them operated above 80% technical efficiency. In general, the technical efficiency levels found in the lower eastern Kenya were low but were quite comparable with those obtained in other African countries whose mean technical efficiency ranged from 30 – 70%.

It is further concluded that farmers in these regions were not optimizing on their sorghum outputs mainly due to the fact that most of the inputs used for sorghum production were underutilized. Labour was the most underutilized resource compared with the other inputs used.

Sorghum farmers are not fully technically efficient. If they operate at full efficiency, they can reduce production cost by 57%. There is a great potential of enhancing production through improved efficiency of available resources. This can be undertaken by addressing important variables that either positively or negatively influence levels of technical efficiency in these regions of Kenya through policy formulation or review.

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APPENDIX

Table 1: Summary statistics of variables used in the technical efficiency analysis

	Makindu District				Machakos District			
Input / Output variables	**Min**	**Max**	**Mean**	**S.D.**	**Min**	**Max**	**Mean**	**S.D.**
Output								
Sorghum grains harvested (Kgs)	18	1350	322.30	302.35	4	720	117.32	170.53
Inputs								
Sorghum land size (Ha)	0.10	4.04	0.52	0.55	0.03	0.80	0.17	0.17
Seed Quantity (Kgs)	0.5	30	3.55	4.64	0.25	5	1.68	1.03
Amounts of labour used (persondays)	4	180	37.74	31.47	2	79	21.55	17.60

Table 2: Frequency distributions of technical efficiency scores obtained with DEA model

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

N/B: TE VRS – Technical efficiency under variable return to scale assumption

Table 3: Technical efficiency distributions per district

Technical efficiency categories (%)	Percentage Household	
	Makindu	Machakos
0-9	10	18
10-19	11	23
20-29	14	11
30-39	17	7
40-49	10	3
50-59	6	7
60-69	4	4
70-79	4	4
80-89	6	1
90-99	1	1
100	17	21

Table 4: Output and input slacks from DEA model in Machakos and Makindu districts

Input / Output variables	Slacks		
	Makindu district	Machakos district	Overall
Output			
Harvested sorghum grains (Kgs)	0	0	0
Inputs			
Sorghum land size (Ha)	0.03	0.03	0.02
Seed quantity (Kgs)	0.48	0.11	0.22
Labour persondays used	7.79	5.31	8.85