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Small-Scale Irrigation and Production Efficiency among Vegetable Farmers in the Eastern Cape Province of South Africa: The DEA Approach

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Abstract

Despite the establishment and revitalization of small-scale irrigation schemes, input subsidies and tractor hire schemes in the rural Eastern Cape Province of South Africa productivity among small-scale farmers is recorded low and anticipated to decline. For survival, small-scale farmers have resorted to cultivating high value crops including vegetables. However, their vegetable productivity is far less than the estimated potential yields, and information regarding their production efficiency is limited. Therefore, this study was aimed at determining farmer's production efficiency to generate meaningful information necessary for designing feasible pro-poor policies aimed at catalysing increased the productivity and rural household incomes. The study was carried out at Qamata and Tyefu irrigation schemes, and approximately 158 farmers were interviewed. The Data Envelopment Analysis (DEA) approach was used to generate results. The findings in this article indicated that most farmers are old aged with low literacy levels. Farmers were also allocating few hectares of land for cabbage production with far less application of fertilizers and pesticides compared to the recommended amounts. Farmers at Qamata and Tyefu irrigation schemes are technically,

allocatively and economically efficient at 98%, 72% and 77% level, respectively. Thus, for improving the productivity, farmers need to maintain the same technologies and adjust on the amounts of fertilizers, seeds and pesticides used for improving allocative and economic efficiency. Results suggested that this can be achieved through encouraging more youth participation in farming, improved input-agronomic and agribusiness skills, catalysing processes of land reforms, and construction of more dams.

Keywords: smallholder farmers, irrigation, data envelopment analysis, technical efficiency, allocative efficiency, economic efficiency, cabbage production

1. Introduction

The importance of irrigation is informed by international experience (Montilla-López et al., 2016). Lipton *et al.* (2003) indicated that, regions like Eastern Asia and the Pacific, and North Africa and Middle East have experienced a greater poverty reduction, increased food security and employment because they established some large proportions of irrigated land for crop production. Establishment of irrigation schemes in semi-arid and areas prone to prolonged droughts in the rural communities of former homelands of South Africa was viewed as one of the development pathways for increased agricultural productivity, improved food security, increased employment and poverty alleviation (Van Averbeke *et al.*, 2011; Kibirige, 2013; DAFF, 2015; Montilla-López et al., 2016).

On realization of water scarcity, many irrigation schemes were established in the Transkei and Ciskei former homelands of the current Eastern Cape Province during the 1960s and 1970s. However, most of the established irrigations schemes were unsustainable due to numerous challenges (Van der Horst and Hebinck, 2017). In quest to revive the failed irrigation schemes, the government of South Africa embarked on revitalization of these schemes which began in 1994 through the introduction of canal irrigation schemes in the Eastern Cape. Irrigation schemes were established to stimulate economic growth and rural development (Kibirige, 2013; DAFF, 2015). These irrigation schemes included Ncora, Keiskammahoek, Tyefu, Shiloh and Zanyokwe. Despite these developments, smallholder farms still faced low outputs and productivity (Van Averbeke *et al.*, 2011). Moreover, the results in the Eastern Cape Province have not matched the international experience (Kodua-Agyekum, 2009; Manona *et al.*, 2010; Averbeke *et al.*, 2011; DAFF, 2015). For example, most rural communities like at Qamata and Tyefu irrigation schemes are still faced with high levels of poverty affecting 76% and 79.9% of the population, respectively (InsikaYethu Municipality, 2008; Ngqushwa Municipality, 2007; Kibirige, 2013).

According to Cousin (2013), several studies have indicated underutilization of communal arable land including irrigation schemes. The same author cited Andrew *et al.* (2003) indicating that small-scale farmers including irrigators are faced with numerous challenges like shortages of labour, capital and income to purchase inputs; poor supply of inputs and tractor services; poor soil fertility; high risks of crop damage by livestock due to lack of fencing; lack of agricultural markets and high competition from large-scale commercial farming, and the weakening of social bond resulting in declining cooperative activities. Most irrigations scheme facilities were old and hence reducing on their efficiency.

On realising farmers' challenges, the government of South Africa has continued its efforts of revitalizing irrigation schemes and initiating some agricultural support programmes like *Siyazondla* (Homestead food gardening), *Siyakhula* (Small-scale farmers) and Massive Food Production Programme (MFPP) (GoSA Information, 2008; Fanadzo and Ncube, 2018). These programmes are in line with the agrarian reform policy and provide farmers with inputs subsidises like seed, fertilizers and farm implements. Though the programmes are trying to ease access to land, water and variable inputs, farmers' crop production is recorded low and thought to decline more at an increasing rate (Tregurtha, 2009; Fay, 2011). Tregurtha (2009) and Fay (2011) identified more anticipated factors resulting in farmers' low productivity and these are inefficient utilization of land, water and other inputs, and low adoption of new technologies.

Kibirige (2013) cited Farrell (1957) defining efficiency as the ability to produce a given level of output at the lowest cost. Efficiency can be divided into two concepts, the technical and allocative efficiency. Technical efficiency is the ability of the farm to produce a maximum level of output given a similar level of production inputs. Allocative efficiency literally can be defined as generating of output with the least cost of production to obtain maximum profits. Economic efficiency is a product of both allocative and technical efficiency and it is achieved when the producer combines resources in the least combination to generate maximum output as well as ensuring least cost to obtain maximum revenue (Chukwuji *et al.*, 2006). Therefore, for increased productivity and profitability, farmers need to improve on the management practices through trainings and transfer of knowledge and skills from less to more efficient farmers or increase on adoption of new available technologies (Padilla-Fernandez and Nuthall, 2001).

2. Methodology

2.1 Field Methods

This study was purposively carried out at Qamata and Tyefu located in the Eastern Cape Province of South Africa to assess the impact of irrigation schemes on farmers' production efficiency. Cabbage is among vegetable crops grown by small-scale farmers especially during winter for both home consumption and incomes. Primary survey data was collected through administering structured questions and physical observations and used to generate results of this study. Farm/farmer characteristics, farm production and market related data was collected. One hundred eight and 50 smallholder farmers were interviewed in Qamata and Tyefu communities, respectively, making a total sample of 158 respondents.

2.2 Analytical Methods

This article employed the Data Envelopment Analysis approach. This approach is one of the most common non-parametric methods used to estimate production efficiencies (Coelli, 1996; Speelman *et al.*, 2007; and Lemba *et al.*, 2012). Following Coelli (1996), Speelman *et al.* (2007) and Lemba *et al.* (2012), one of the principle assumptions of the DEA model is that there is a linear relationship between K farm input and farm output M of each of N farms.

The input data (X_i) from each individual farmer i and output data (Y_i) from each individual farmer is arranged in a column vector form of X_i and $Y_{i,}$ respectively. In this article, the variables presented in the input matrix X_{ij} included size of land cultivated, seeds quantity, fertilizer quantity, agro-chemicals like quantities of pesticide, herbicides used, and the value of capital invested, whereas the output matrix Y_{ij} included the output quantity of i^{th} farm & j^{th} crop enterprise. Following earlier studies carried out by Speelman *et al.* (2007) and Lemba *et al.* (2012), the DEA model was presented by the linear programing equations used to establish the relationship between input and output, thereby estimating production efficiency. The linear programming equations can be presented as:

$$Min_{\lambda} \quad (1)$$

Subject to:

$$-Y_{ij} + Y\lambda \geq 0,$$

$$\theta X_{ij} - X\lambda \geq 0,$$

$$N1'\lambda = 1,$$

$$\lambda \geq 0$$

Where

θ = scalar, $N1$=$N\ x\ 1$ vector of ones, and λ = vector of constants. θ value = technical efficiency score for a given farm i. In most cases, the value of θ is greater than zero but less than one or equals to one. The farm is reported to be 100% efficient if the value of θ equals to one and the score value is located on the frontier line, and if there is a reducing trend in the value of θ from one towards zero then the farm is reported to be inefficient. The Variable Returns to Scale (VRS) represented in the equation as $N1'\lambda = 1$ assumes a non-linear relationship between the input and output, thus referred to as convexity constraint. If this condition is not expressed in the linear programming equation, then efficiency is estimated under the Constant Return to scale (CRS) specifications, implying the frontier is considered to be a straight diagonal curve. The equation can further be expressed using input cost minimization to maximize output according to Färe *et al.* (1994). To estimate efficiency for a selected individual variable input k for the ith farm, the following linear programme equation can be used.

$$Min_{\theta\lambda}\theta_k \tag{2}$$

Subject to

$$-Y_i + Y\lambda \geq 0,$$

$$\theta_k X_i^k - X^k\lambda \geq 0,$$

$$X_i^{n-k} - X^{n-k}\lambda \geq 0,$$

$$N1'\lambda = 1,$$

$$\lambda \geq 0,$$

Where; θ_k = input k sub-vector T.E for farm i. The second constraint with terms X_i^k and X^k includes only the K^{th} input and in the third constraint which contains terms X_i^{n-k} and X^{n-k} it excludes (thus, $n-k$) the K^{th} input. Other variables in this equation are defined in equation 1.

According to Coelli (1996), when estimating efficiency using the DEA model, there are two scale assumptions generally employed, namely, the constant returns to scale (CRS), and variable returns to scale (VRS). Farmers operate at different levels and this can be demonstrated graphically based on whether or not observed levels along the frontier corresponding to a particular returns to scale. The behaviour of the curves generated by the DEA approaches depends on the scale assumptions considered when modelling. The VRS consider both increased and decreased returns to scale while CRS assumes that output changes by the same proportion with a change in inputs employed. Further, VRS recognise variation in technologies (Coelli, 1996).

Based on the assumptions that inputs are fixed and farms are producing optimally, figure 1 presents both the CRS and VRS frontiers. Assuming constant returns to scale, all farms operating below point C on the CRS frontier are considered inefficient and underutilizing resources. Assuming variable returns to scale, all farms operating below the VRS frontier defined by points A C D are considered inefficient. Thus, a farm operating at point B is considered in efficient.

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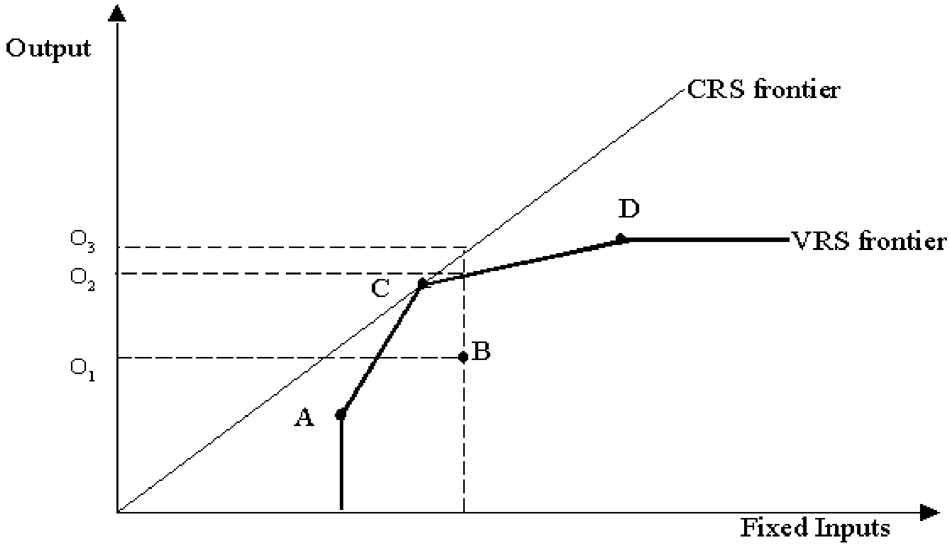

Figure 1. CRS and VRS Frontier

Source: Coelli (1996)

3. Results

In his study, Kibirige (2013) indicated that most small-scale farming is dominated by male farmers (69%) in the study area and this may be attributed to loss of jobs through retrenchment policies and retirement. Further, Kodua-Agyekum (2009) indicated that over 90% farm plots on irrigation schemes and dry land were allocated to men biased towards the African cultural rules and norms which deny women's legal rights to own such a crucial agricultural resource.

Table 1. Demographic characteristics of smallholder farmers the study area (n=158)

Characteristics	**Description**	**Percentage**
Non-continuous variables		
Sex of household head	Male	69
	Female	31
Level of formal education	Non	28
	Primary	42
	Secondary	29
	Tertiary	01
Major occupation	Farmer	92
	Self-employed	05
	Civil servant	03
Continuous variables		
	Average mean value	**Standard deviation**
Household size	4.469	2.344
Age of farmer (Years)	61.066	12.703
Years spent in school	5.422	4.358
Faming experience (Years)	13.017	11.928

Source: Kibirige (2013).

Results in Table 1 further suggests that the largest proportion of farmers had some education, mostly up to 5 years of primary school education (42%) although a handful did not have any education at all (28%) and very few had post-secondary education (1%). This implies that most household heads depend on the local language to access farm information especially through their fellow farmers. Education level of the farmer is crucial in sourcing for agricultural information and adoption of new technologies. Different farm reading materials, labels placed on input packages and conducting of trainings are presented using English. The household size averaged approximately 5 persons Household size in most rural villages of Sub-Saharan Africa is known to be a source of farm and off-farm labour (Kibirige *et al.,* 2010).

Most farmers (92%) interviewed considered farming as their major occupation, an indication of the endemic unemployment situation among the Qamata and Tyefu population. Data presented in Table 1 indicated that the average age of the household head among smallholder famers interviewed was about 61 years. This indicates that farmers at Qamata and Tyefu irrigation scheme areas may be less productive since their age is far above the youthful productive stage as defined by Ogundele and Okoruwa (2006). Increased number of farmers within this age bracket may be a reflection of more retrenched and retired formal employees who take on farming as their source of livelihood for survival (Kodua-Agyekum, 2009). According to Kibirige (2013), results indicated that the average farming experience of smallholder farmers was approximately 13 years. Although age and farm experience are considered to be interrelated, age in most cases is associated with increasing farm output in terms of energy for farm labour at a decreasing rate (Bagamba, 2007).

Input Use in Cabbage Production among Small-scale Farmers in the Study Area

Some of the major inputs used by small-scale farmers in the study area include land, irrigation water, seed, fertilizers and pesticides as presented in Table 2. On average, farmers grow cabbage on less than one hectare (0.16ha). They plant about 510g/ha of cabbage seed on average with approximately 41kg/ha of fertilizers and 1.38 litre/ha of pesticide, respectively. Cabbage can hardly survive both in winter and summer seasons without irrigation in the Eastern Cape Province of South Africa. Therefore, small-scale farmers irrigate their plots about 148 times/ha/season. Although results indicate that farmers' cabbage seed planting rate was within the recommended rate ranging from 0.50 to 2Kg/ha for direct seeding, they applied far less fertilizers than the recommended rate ranging between 500 and 1000Kg/ha in cabbage production (Allemann and Young, 2008).

Table 2. Input use in Cabbage production among Small-scale Farmers

Variables	**Average mean**	**Standard deviation**
land under cabbage production (ha)	0.16	0.23
Cabbage seeds planted per ha (Kg/ha)	0.51	1.12
Fertilizer applied per ha of cabbage (Kg/ha)	41.12	95.81
Pesticide applied per ha of cabbage (L/ha)	1.38	7.09
Number of irrigations/season/ha	147.68	308.32

Source: Kibirige (2013): ha = hectares, Kg = Kilograms, L = Litres.

Profitability of Cabbage Enterprises

The results presented in Table 3 indicated that the mean farmers' cabbage yields was about 974 with approximated average total revenue and total variable cost of production of R4431/ha and of R661/ha, respectively. The approximated average gross margins generated from cabbage production as reported by Kibirige (2013) were R3770/ha and only about 22% of cabbage produced is sold in the market.

Table 3. Profitability of Cabbage Enterprises among Smallholders (n = 158)

Variables	**Description**	**Mean**	**Standard deviation**
Cabbage yield	Heads/ha	974.09	2790.30
Total revenue from cabbage	Rand/ha	4431.245	15128.99
Total cost for cabbage production	Rand/ha	661.29	1684.24
Gross margins for cabbage	Rand/ha	3769.960	15022.47
Commercialization index for cabbage	Ratio	0.22	0.37

Source: Kibirige (2013). Where, ha = hectares, Commercialization index ratio = Quantity marketed of a given crop divided by total quantity harvested of the same crop.

According to Allemann and Young (2008), the recommended cabbage yield in terms of number of cabbage plants per hectare ranges between 40 000 and 45 000 heads/ha, however, findings in this study indicated that smallholder farmers were planting far less (about 974 heads/ha) than the recommended amount. This is probably because smallholder farmers in the Eastern Cape Province apply less agro-chemicals which are important for fertility, pesticides and weed control and hence resulting in low productivity. The less use of fertilizers, herbicides and pesticide may be due to lack of investment capital and lack of access to farmer friendly credit facilities to purchase these inputs.

Estimating the Production Efficiency of Cabbage Enterprise by DEA

A study carried out by Kibirige (2013) generated results using the *DEAP (Version 2.1)* statistical software as displayed in Table 4. The Variable Returns to Scale (VRS) scores of smallholders under study indicated that all are technically efficiency in cabbage production at 98% level. Further, results suggest that smallholders' scale efficiency and the CRS indices were low at 0.49 and 0.47, respectively, and closely related. The relatively correlated scores of both the scale efficiency and CRS seem to suggest that farms under study were not operating at the same optimal scale/frontier. Thus, this qualifies the VRS scores as the viable estimate to consider in such situations. Results further indicate that there are approximately 98.7% of farmers operating at increasing returns to scale, respectively.

Farmers' technical, allocative and economic efficiency scores were generated using available data related to amounts of cabbage seeds planted in Kg/ha, fertilizer in Kg/ha and litres (Kg) of pesticides applied per hectare. According to Kibirige (2013), generated results revealed the mean allocative, technical and economic efficiency scores were approximately 0.72, 0.94 and 0.77, respectively. Based on the allocative efficiency scores, for profit maximization at least input cost combination, farmers had to reduce on costs incurred in the use of cabbage seed, fertilizer and pesticide by 28%. In order to maximize output using the same available inputs and technology, smallholder irrigators have to increase on their technical efficiency by about 6%.

Table 4. Estimating Farmers' Cabbage Production Efficiency: DEA

Variables	**Mean**	**Standard deviation**
Variable returns to scale (VRS) technical efficiency	0.981	0.081
Scale technical efficiency	0.485	0.158
Constant returns to scale technical efficiency	0.469	0.133
Allocative efficiency (A.E)	0.719	0.300
Technical efficiency (T.E)	0.939	0.158
Economic efficiency (E.E)	0.765	0.318

Source: Kibirige (2013).

4. Conclusions and Recommendations

On average, statistics in this article indicate most farmers are aged about 61 years old with as low as approximately 5 years of formal education. This implies that there are very few youth aged farmers. The low youth participation in farming may result in increased loss of sustainable indigenous knowledge and skills in farming, increased unemployment rates and increased food insecurity and hence leading to skyrocketing and wide spread poverty levels in the Eastern Cape Province. This calls for more innovations and initiatives that attracts youths and equip them with formal education and financial support to ease their participation in farming.

Farmers in the selected study area seem to allocate a few acres of land and apply far less fertilizers and pesticides in cabbage production compared to the recommended amounts. Thus, given the availability of cabbage markets and increasing demand for the same produce, farmers need to be encouraged to expand individual acreage under cabbage production through more appropriate and feasible pro-poor rural land reforms. Further, there is need to improve on farmers' easy access to farm inputs including fertilizers and pesticides through improved subsidies and input credits, and improved distribution of input dealers nearer to farms. Improved access to inputs may also call for improved networking between farmers, agricultural input dealers and finance institutions like banks, micro-finance and Savings and Credit Cooperatives (SACCOs), and revolving group funds.

The major sources of water for crop production among farmers understudy were reported as direct rainwater and dam water converged from rivers. Since most farmers interviewed are resource-poor, direct rainwater was viewed as the cheapest means of watering their crops in addition to communal dams. This is an indication that farmers lacked rainwater harvest technologies and less irrigation equipment necessary to store and transport water to their gardens, respectively. Therefore, it is of great importance that the government and other support organisations to fund projects that promote sustainable water use and establishment of rainwater harvest technologies and irrigation schemes.

The findings of this study indicated that farmers earn low net gross margins from cabbage production. The findings further indicated that farmers were generally technically efficient, although allocatively and economically inefficient. For farmers' efficient utilization of irrigation water, results indicate that they were technically inefficiently. Thus, for more profitable cabbage production, farmers should retain the same technologies with exception of water utilization and consider accurate application of purchased inputs in terms of amounts of fertilizers and pesticides applied. To improve on the accurate amounts of inputs applied, more agronomic extension service trainings need to be emphasised, and farmers trained in business management skills for improved participation in markets and hence increased household incomes, allocative and economic efficiency. These trainings can be provided by the government, NGOs and internal social networks.

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