Analysis of Factors Affecting Sorghum Production in the Gezira Scheme – Sudan and Implications on the Household Food Security

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Abstract:

The primary goal of this paper is threefold: firstly, to examine the influence of the conventional agricultural inputs on sorghum production levels in the Gezira scheme; secondly, to investigate the main factors behind tenants technical inefficiency and thirdly, to evaluate their implications on food security of the household level. Stochastic frontier production function was estimated using a sample of 100 tenants in the Gezira Scheme. The results show that credit, capital, hired labor, fertilizer and irrigation have a significant positive effects in sorghum production levels, while sorghum area shows a negative and significant effect. An average of technical efficiency of 67 percent for sorghum production is found, implying that room to increase sorghum yield through the better use of the tenants available resources is exist. Size of holding, education level, tenants experience, household size, contact with extension agents and farm location are significant in explaining tenants’ technical inefficiency.

Keywords: Gezira Scheme, Sorghum, Technical Efficiency, Stochastic Frontier.

1. Introduction

Sorghum is the most important staple food crops in the Sudan. Gezira scheme with an area of 2.1 million feddan (0.89 million ha) is the largest gravity irrigated farm in the world. The scheme contributes about 58, 46, 23 and 12 percent of the total cotton, wheat, groundnut and sorghum production in the Sudan, respectively (Ahmed, et al. 2004). Sorghum is produced as summer crop; it is mainly grown in June and harvested between November and December. Sorghum residues represent a major sources of animals’ feeds. Sorghum productivity in the Gezira scheme is low and fluctuating from one year to another and intra tenancies. Sorghum is not the most profitable crop compared with other crops produced in the scheme. Moreover, scheme’s tenants have to follow standard crop rotation. Within this standard rotation, the tenants are allowed to allocate 20 percent of their tenancy to sorghum production. However, the tenants increasing tendency to devote more area to sorghum production. Low and fluctuating sorghum production levels is one of the factors that encourage the tenants to expand sorghum area in the scheme. During the period 1992-2002, sorghum represented about 40 percent of the total area planted in the scheme. In the season of 2001/02, sorghum area represented 66 percent of the total area planted. Furthermore, the government policies of food self-sufficiency also encourage the tenants to allocate more area

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for food crops (wheat and sorghum). However, low and fluctuating sorghum yields are not seriously concerned as sorghum production is the responsibility of the tenants.

Reardon and Vosti, (1992) stated that as a result of rapid population growth with limited arable land substantial investment in agricultural productivity would be needed to meet growing demand. Household size growth as well as low and fluctuating sorghum production levels in the scheme are accompanied by allocating more area to sorghum production. Expanding or bringing more area in the scheme into sorghum production is restricted as it negatively influences area of cash crops and hence country exports of cotton and groundnut will be decreased. Increasing efficiency with which the tenants utilized the resources available would become so crucial to be investigated. Many studies in the scheme have tackled the problems of low and fluctuating productivity. However none of them has investigated the problem of technical efficiency differences among the tenants in depth enumerating the main factors behind the technical inefficiency.

Raising sorghum productivity will profoundly affect the income level and household food security for the majority of the tenants in the scheme as well as of the people living in the vicinity of the scheme. Moreover, it would increase scheme contribution to the total amount of the sorghum produced and positively affect food security at the national level. The primary goal of this paper is to examine the influence of the conventional input factors on sorghum production differences and to investigate the main tenant-specific factors behind tenants technical inefficiency. Implications on food security of the household in the Gezira scheme shall also be evaluated during the course of analysis.

This paper is organized as follow: in section two the analytical framework and data are presented. Empirical model is described in section three. The results are presented and discussed in section four and conclusions are highlighted in section five.

2. Analytical framework

The fundamental role of efficiency in increasing agricultural output has been widely recognized by the researchers and policy makers alike (Bavo-Utreta and Evenson, 1994). The importance of studying efficiency is that the farmer are not making efficient use of the present technology, then efforts designed to improve efficiency would be less expensive than introducing new technology as a mean of increasing agricultural production output (Belbase and Grabowski, 1985 and Shapiro, 1983).

Many empirical studies of productivity analysis have centered on imperfect partial measurement of productivity, such as yield per hectare or per labor (Collei and Battese 1996). However, Farrel (1957) developed a method of measuring technical efficiency of the firms by estimating the production function of the firms that reflecting full efficiency.

Based on the pioneering work of Farrel, Aiger, Lovell and Schmidt (1977) and Meeusen, and Van den Broeck (1977) independently, proposed stochastic production frontier production function that involved two random components, one associated with the presence of technical inefficiency and the other being a traditional random error (Battese and Coelli 1992). Moreover, many subsequent works have been based on the Farrel’s idea (Bauer 1990, Greene 1993, Collei 1995a, Battese, 1992, etc). Stochastic frontier model permits the technical efficiency of the of individual producer to be estimated (Gimbol, et, al. 1997).

A number of empirical studies attempt to investigate the relationship between technical efficiency and the various socio-economic variables such as levels of education, age, family size, access to credit, extension services and experience (Bravo-Ureta and Pinheiro 1993, Coelli and Battese 1996). The level of technical efficiency of the farmers is influenced by socio-economic and demographic factors (Admassie 1999, Kalirajan and Shand 1989, Muller 1974, Parikh and Shah 1994, Timmer 1971). Technical inefficiency may arise primary due to managerial incompetence and therefore, efficiency differences could be explained in the
context of the management characteristics such as training, experience and motivation (Tyler, 1979).

3. Data and the Empirical Model

3.1. Data

Gezira scheme is divided into 18 administrative units called groups. These groups are divided into 114 small units called blocks. In each block there is about 1000 tenants. A sample of 100 tenants was interviewed from the Central and Northern groups of the scheme. From each group five blocks were randomly selected and from each block ten tenants were interviewed. Structural questionnaire was constructed to collect data from the tenants in the scheme during the growing season of 2002/2003. Data in the various variables were collected including tenants socioeconomic characteristics, such as age, family size, income, level of education and off-farm income. Data on the production inputs their amounts, prices, as well as, detailed costs of production for major crops produced in the scheme were collected. Moreover, Comprehensive data and information about the credit, extension services, labor and tenants resources were also gathered.

3.2. Empirical Model

The stochastic production frontier used in this study is based on analytical framework proposed by Battese (1992), Battese and Coelli (1995) and Battese and Hassan (1998). Frontier 4.1 computer program, developed by Coelli (1996), was used to estimate stochastic frontier production function, as well as, inefficiency model. In this study we assume that stochastic frontier production function in Cobb-Douglas form will specify the relationship between sorghum output of the tenants in the Gezira scheme and the explanatory variables. The model can be written as:

\[ y_i = f(CR_i, SA_i, K_i, FL_i, HL_i, FER_i, IRR_i, \beta) \exp(\nu_i - u_i) \]

in the log form the model can be written as:

\[ \ln y_i = \beta_0 + D_i \beta_1 \ln CR_i + \beta_2 \ln SA_i + \beta_3 \ln K_i + \beta_4 \ln FL_i + \beta_5 \ln HL_i + \beta_6 \ln FER_i + \beta_7 \ln IRR_i + \nu_i - u_i \]

where: \( \ln \) is natural logarithm; subscript i, denotes the ith tenant \( i = 1,2…100 \); \( y_i \), yield of sorghum in Kg per feddan; \( CR_i \), amount of the formal and informal credit received for sorghum production; \( D_i \), Dummy variable, which has a value of one, if the amount of credit is positive and zero if the credit amount is zero; \( SA \), sorghum area in feddan; \( K \), capital which represent the total amount of the expenditures on the production inputs (seeds, fertilizer, sacks and machinery); \( FL \), family labor (man-day/feddan\(^1\)); \( HL \), hired labor (man-day/feddan); \( FER \), amount of fertilizer in Kg/feddan and IRR is number of irrigations. \( \beta \)-coefficients are unknown parameter to be estimated.

\( \nu_i \), is the stochastic disturbance term, which is distributed as \( N(0, \delta^2) \) and capture the random variability to uncontrollable factors. \( \nu_i \) account for the effect of measurement errors on the production variable \( y \), and the combined effect of the omitted explanatory variables (Gimbol, et al. 1995, Kaliraja 1981). The presence of the \( \nu_i \) indicate that the output vary randomly across the farms or over time for the same farm (Aiger, Lovell and Schmidt 1977), \( u_i \) represents the technical inefficiency term. It is a non-negative random variable associated with technical inefficiency of the tenants in the sample. It is assumed to be independently distributed by truncation at zero of the normal distribution with the mean \( \mu_i \) and the variance \( \delta^2 \).

\(^1\) Males man-day is equivalent to 8 hour per day. Female and child work are converted to male equivalent man-days based on the conversion rule that the female and child man-days are equivalent to 0.75 and 0.5 male man-day, respectively.
The empirical work on the issue of the explanation of the inefficiency has been investigated by many researchers (Kalirajan 1981, 1982, 1989, Kalirajan and Shand 1985, Battese and Broca, 1997) where two stage approaches are followed, firstly, stochastic frontier production function will specified and estimated. If technical inefficiency is predicted, then in the second stage, a regression for the level of inefficiency of the firm in term of the other explanatory variables will be specified (Battese and Coelli 1993). 

\[ \mu_i = \delta_0 + \delta_1 w_{1i} + \delta_2 w_{2i} + \delta_3 w_{3i} + \delta_4 w_{4i} + \delta_5 w_{5i} + \delta_6 w_{6i} + e_i \]

Where \( w_1 \) to \( w_6 \) are the tenants socio-economic factors and managerial characteristics which are expected to explain tenants technical inefficiency, \( W_1 \) size of holding in feddan; \( W_2 \) tenant’s Level of education, it represent the number of years of formal education; \( W_3 \), tenant experience, which is represented by the number of years the tenants engaged in agricultural production; \( W_4 \), household size; \( W_5 \), number of contact with extension agent; \( W_6 \), farm location with a value of one for the first 7 tenancies which are located at the head of the canal^2, and zero otherwise, respectively. 

\( \delta \)-coefficients are unknown parameter to be estimated. Technical efficiency of the ith tenants is defined as a ratio of the observed output to the output obtained by the fully efficient farmer, which uses best practices techniques in which the inefficiency effect is zero. The technical efficiency of the ith tenants can be defined by :

\[ TE_i = \exp(-U_i) \]

\( U_i \) is ranged between zero and one. If \( U_i \) is zero, then the technical efficiency is unity (100 percent). The density function of \( u_i \) and \( v_i \) can be estimated using the maximum likelihood method. The main advantage of the maximum likelihood approach is that the relative variability of \( u_i \) and \( v_i \) provide a mean to statistically examine the sources of the differences between tenants’ yield and that can be estimated by frontier (Kaliragan, 1981).

Battese and Corra (1977) calculated the value of the \( \gamma \) variance parameter as a ratio of the \( u_i \) variability to the total variability

\[ \gamma = \frac{\sigma_u^2}{\sigma^2} \quad \text{where} \quad \sigma^2 = \sigma_u^2 + \sigma_v^2 \]

\( 0 \leq \gamma = 1 \)

If \( \gamma \) has a value of one this will indicate that tenants yield differences from the maximum output estimated is mainly due to the technical inefficiency. A value of zero for \( \gamma \), indicates that the differences are mainly due to statistical errors (Kaliragan, 1981).

4. Results and Discussion:
4.1. Stochastic Frontier Production Function:
The maximum likelihood estimate of the parameters of the stochastic frontier production function (SFPF) with inefficiency model were presented in table 1.

Tenants technical efficiency for sorghum production in the Gezira scheme is ranged between 30 and 98 percent with mean efficiency of 67. Mean technical efficiency of is 67 percent, indicating that production, on average, is about 33 percent below the frontier. This mean that considerable amount of sorghum production, on average, is foregone due to the tenants technical inefficiency.

All the coefficients of SFPF have theoretically the accepted signs of influence on the sorghum production. The sign of the coefficients, of credit, capital, hired labor, fertilizer and irrigation

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^2 Tenancies in the Gezira scheme are aggregated into 90 feddan administrative unit called number. Each number is aggregate of 15-22 tenancies and irrigated by a canal called “Abuxx”. Each number is planted by one crop. In this study farm location implies the location of the tenancy from irrigation canal (Abuxx). The first 7 tenancies represent the head of the canal and the other tenancies represent the tail of the canal.
are positive and significant. Indicating that they contribute positively to sorghum production in the scheme. Sorghum area coefficient is negative and significant whereas, family labor coefficient is found not be significantly different from zero.

The coefficients of credit, capital, hired labor, fertilizer and irrigation are 0.203, 0.23, 0.166, 0.628 and 0.203, respectively. Whereas, the sorghum area is negative and with a value of – 0.397. These coefficients can be interpreted as follow: one percent increase in credit, capital, hired labor, hired labor, fertilizer and number of irrigation will lead to 0.203, 0.23, 0.166, 0.628 , 0.203 percent increase in sorghum yield, respectively. While 1 percent increase in sorghum area will lead to 0.397 percent decrease in the sorghum yield.

Capital, which represents total expenditure on the production inputs (fertilizer, seeds, sacks and machinery) is positive and highly significant at (1 % level). It could be noticed that the costs of irrigation, weeding and harvesting are excluded, because the costs of weeding and harvesting are implicitly included in the number of labor used. For the irrigation water charge, scheme’s management applies a constant irrigation water costs irrespective to the number of irrigations.

Family labor coefficient is not significantly different from zero, while hired labor coefficient is significant at 5 percent level of significance. This result indicates that the tenants who rely heavily on family labor are expected to have low yield compared with those who depend on the hired labor. Depending only on the family labor for operations such as weeding required long time span to accomplish the operation. Moreover, weeding period is very critical due to the rainy season, so inappropriate weeding time will negatively influence sorghum yield.

Table 1. Maximum likelihood estimates of the parameters of the stochastic frontier Production function with inefficiency model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>$\beta_0$</td>
<td>0.891</td>
<td>0.888</td>
<td>1.003 N.S.</td>
</tr>
<tr>
<td>Credit</td>
<td>$\beta_1$</td>
<td>0.203</td>
<td>0.086</td>
<td>2.366***</td>
</tr>
<tr>
<td>Sorghum Area</td>
<td>$\beta_2$</td>
<td>-0.397</td>
<td>0.168</td>
<td>-2.363**</td>
</tr>
<tr>
<td>Capital</td>
<td>$\beta_3$</td>
<td>0.230</td>
<td>0.016</td>
<td>14.375***</td>
</tr>
<tr>
<td>Family labour</td>
<td>$\beta_4$</td>
<td>0.017</td>
<td>0.089</td>
<td>0.191 N.S.</td>
</tr>
<tr>
<td>Hired labour</td>
<td>$\beta_5$</td>
<td>0.166</td>
<td>0.093</td>
<td>1.784**</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>$\beta_6$</td>
<td>0.628</td>
<td>0.322</td>
<td>1.950**</td>
</tr>
<tr>
<td>Irrigation</td>
<td>$\beta_7$</td>
<td>0.203</td>
<td>0.134</td>
<td>1.515*</td>
</tr>
</tbody>
</table>

Inefficiency Model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>$\delta_0$</td>
<td>0.767</td>
<td>0.744</td>
<td>1.031</td>
</tr>
<tr>
<td>Size of Holding</td>
<td>$\delta_1$</td>
<td>-0.07</td>
<td>0.05</td>
<td>-1.400 **</td>
</tr>
<tr>
<td>Education</td>
<td>$\delta_2$</td>
<td>-0.166</td>
<td>0.077</td>
<td>-2.155 **</td>
</tr>
<tr>
<td>Experience</td>
<td>$\delta_3$</td>
<td>0.007</td>
<td>0.004</td>
<td>1.750 **</td>
</tr>
<tr>
<td>Household size</td>
<td>$\delta_4$</td>
<td>-0.485</td>
<td>0.205</td>
<td>-2.366 **</td>
</tr>
<tr>
<td>Extension</td>
<td>$\delta_5$</td>
<td>-0.130</td>
<td>0.073</td>
<td>-1.780 **</td>
</tr>
<tr>
<td>Farm location</td>
<td>$\delta_6$</td>
<td>-0.043</td>
<td>0.008</td>
<td>-5.375***</td>
</tr>
<tr>
<td>$\delta_s^2=\delta^2+\delta^2$</td>
<td>0.177</td>
<td>0.029</td>
<td></td>
<td>6.103***</td>
</tr>
<tr>
<td>$\gamma=\delta^2/\delta_s^2$</td>
<td>0.995</td>
<td>0.031</td>
<td></td>
<td>32.096***</td>
</tr>
</tbody>
</table>

The frequency distribution of the tenants technical efficiency show a wide variation in efficiency level ranging between 30 and 98 percent. This result provide information for decision makers and help them to investigate the main factors behind tenants technical inefficiency and to design policies to improve tenants technical efficiency and hence household food security. The histogram of the tenants technical inefficiency is displayed in
figure 1, it is clear from the histogram that 37 percent of the sampled tenants are operating at technical efficiency below 60 percent. Only 29 percent of the tenants have technical efficiency in the range between 80 and 100 percent.

The variance parameter, $\gamma$, with a value of 0.995 is significant component in explaining the variability of sorghum production level in the Gezira scheme. This relatively high value of the variance parameter, implies that substantial proportion, 99 percent, of the sorghum production total variability is mainly associated with tenants technical inefficiency of production. The estimate of the variance parameter $\gamma$, is significantly different from zero, indicating that the inefficiencies are significant in determining the level of the variability of sorghum yield in the Gezira scheme (Sharma, et al. 1999). Tenants low technical efficiencies are consistence with relatively high ($\gamma$) variance of tenants effects which indicate that the stochastic frontier and the average production function are expected to be quite different. The variance of the random effects ($v_i$) was not a significant components of the sorghum yield variability.

![Figure 1. Efficiency distribution frequency](image)

**Figure 1. Efficiency distribution frequency**

### 4.2. Inefficiency model

The results of the factors affecting tenants’ technical inefficiency were presented in table in the bottom of table 1. Tenant-specifics factors which are significant in describing sorghum yield variability were size of holding, level of education, experience, household size, number of contact with extension agents and farm location.

Size of holding has a negative and significant effect on the inefficiency level, indicating that tenants technical efficiency increase with decrease in the size of tenancy. Less inefficiency among the small tenants may be attributed to the facts that tenants with small sorghum area perform the cultural operations timely. Moreover, they try to secure their food from the area grown. Large size of holding is expected to influence technical inefficiency negatively, if the tenancy size is large enough to enable the tenants to achieve economy of the scale, however, maximum size of the tenancy is scheme is 40 feddan and it divided in five plots (Hawasha) each with 8 feddan. Each plot of five plots is located in the a different number\(^3\) in the scheme. Tenants who produce less area of sorghum are expected to be less technically inefficient than those who grow large areas. small farmers are more technically efficient than the large farmers. The positive association found between efficiency, experience and farm size has been documented by Kalirajan and Flinn (1983), Huang and Bagi (1984), Belbase and Grabowski (1985), and Lingard, Castillo and Jayasyriya (1983).

Education denotes tenant’s year of the formal education. The coefficient of the education level significantly negative associated with technical inefficiency. Indicating that tenants with

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\(^3\) 90 feddan area in which a tenant possess a single plot (Hawasha)
more education are more efficient than those with low education level. Positive association between the education level and technical efficiency is well documented in the literature (Lockheed, Jamison and Lau 1980). Better educated tenants are assumed to have less inefficiency, due to their better skills and access to information (Llewelyn and Williams, 1996). More schooling years has a significant association with technical inefficiency. However, the eliminatory education of 4-5 years of schooling does not have much effect on agricultural productivity (Lockheed, Jasmison and Lau 1981, Moock 1985, Lipton 1985, and Philipp and Marble 1986). Weak association between efficiency, education and extension has been also reported by Antiporta (1978), Cotlear (1986) and Azhar (1991).

Number of years the tenant engaged in agricultural production is used as proxy of the tenant experience. Tenants experience show a positive association with tenants’ technical inefficiency, indicating that the technical inefficiency increases with increasing number of years the tenant engaged in agricultural production. This unexpected coefficient sign can be attributed to the fact that, tenant with relatively high number of years as a tenants are expected to be relatively old. Old tenants may be less educated, as well as, they are more conservative to adopt the newly technology and hence expected to more inefficient. This finding is not in conformity with findings of Herdt and Mantac (1981), Rahman (2002) and Kalirajan (1984). They found a negative association between the technical inefficiency and farmer experience.

Household size is negative and significantly associated with inefficiency level, implying tenants technical efficiency increase with increase in the household size. Sorghum demand by tenants’ with large household size is more than those with small size, thus household size is assumed to influence technical efficiency positively. It is expected that as the household size increase the number of the member who participate in farming activities increase, however, the family labor shows no significant influence on the sorghum yield in the scheme (Table 1).

The coefficient of the of the number of contact of the tenants with extension agent is found to be negatively associated with the tenants technical inefficiency. Indicating the tenants technical inefficiency will decrease with increase in number of contact between the extension agent and the tenants. It could be concluded that limitations to extensions agents activities is one of the factors that negatively influence sorghum yield in the Gezira scheme.

Farms’ distance from the water-supply sources unfavorably affect the availability of irrigation water to plant growth and accordingly crop yields (Faki, 1982). Tenancy location with respect to irrigation canal is assumed to be one of the tenants’ socioeconomic factors that influence tenants technical efficiency for sorghum production. The results of the study reveal that the tenants whose tenancies are located at the head of the irrigation canal, are more efficient than those who are located at tail of the canal. The tenancies which are located at head of the canal are expected to receive the first irrigation within the range of the recommended sowing date, while those which are located at tail of the canal are expected to be delayed. Moreover, the tenants who are located at head of the canal received more number of irrigations than who are located at the tail. The result of this study is in line with Faki (1981) which stated that, there is a significant decreasing yield with increasing distances from field-outlet pipes in the Gezira scheme.

5. Conclusion:

In this paper stochastic frontier production function was used to derive the influence of the agricultural inputs on sorghum production and estimate individual tenant technical efficiency. Moreover, Tenant’s specific-factors affecting tenant efficiency were examined and analyzed. An average of technical efficiency of 67 percent for sorghum production in the Gezira scheme is found, implying that room to increase sorghum yield and to reduces yield variability through the better use of the tenants available resources is exist. The tenants in the scheme are not producing maximum amount of sorghum which could be produced given the available resources and technology. The result reveal that there is a significant technical inefficiency
effects in sorghum production in the Gezira scheme. It has been found that 99 percent of the sorghum yield total variability is mainly associated with tenants technical inefficiency. Size of holding, education level, experience, household size, extension contact and farm location had significant influence of the estimated tenants technical efficiency.

Gezira scheme contribution to the total sorghum production in Sudan could be increased by 6 percent if tenants technical inefficiency effects are eliminated. On the other hand, on average, current sorghum area could be reduced by 33 percent and at the same achieving the current sorghum production level if inefficiency effects are eliminated. As a consequences of the sorghum area reduction, cash crops areas are expected to increase resulting high income for tenant and hence food security at the household level will improved.

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