Cotton Production Constraints in Sudan: Economic Analysis Approaches

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Abstract

Sudan was traditionally one of the world's largest producers of long-stable cotton and medium producer of medium-stable cotton. The study area, Gezira Scheme (GS) contributes 58 % of cotton produced in Sudan. Cotton's contribution to export revenue had dropped from 45–65 % during the Seventies to 22 percent in 1995 and in 2001 it dropped below 3 %. During the period from 1987 to 2002 cotton area, production and yield dropped, on average, by 38, 48 and 18 percent, respectively. This study was intended to answer the following research questions: (1) How could cotton area, finance and marketing, tenants, and the scheme management aspects are interdependent and affect cotton production in the GS?; (2) Is the cotton yield variability among the tenants in the GS due to random variability or due to the tenants' technical inefficiency and the scheme management's specific factors?; (3) If it is due to tenant specific variability and scheme management factors, what are the variables which are significantly related to the tenants' technical inefficiency?; (4) If the tenants are free to choose what to produce, what are the crop combinations they will select and how close are they to the current crop combination, linear programming crop combinations and crop combinations under risk consideration?. The analytical techniques used in the study include stochastic production frontier analysis, linear programming, quadratic risk programming, sensitivity analysis, schematic analysis and descriptive statistics.

Keywords: Gezira Scheme, Sudan, Cotton, LP, Risk Analysis, Stochastic Frontier

1. Introduction

Agriculture is Sudan's most important economic sector in terms of its contribution to both GDP and employment. In 2001 agriculture directly accounted for 45.6 % of the GDP (Bank of Sudan, 2001). The sector also provides about 80 % of the country's exports (excluding petroleum) and contributes to the livelihood of 80 % of its population (EIU, 1998). The study area "Gezira scheme" with an area of 0.9 million hectare is largest irrigated scheme under one management in the world. During the period from 1987 to 2002, of the total production in the country, the scheme contributed 58 % of cotton, 46 % of wheat, 23 % of groundnuts and 12 % of sorghum. Sudan was traditionally one of the world's largest producers of long-stable cotton and medium producer of medium-stable cotton. In the Sudan cotton has been the most important cash crop and foreign-currency earner for the past 50 years. During the seventies and up to late eighties cotton alone contributed between 45 and 65 % of the total foreign-currency earnings (SCC, 1993). In addition, cotton is considered as a main source of income for about 13 % of the total labor-force. In spite of the economic importance of cotton for the Sudan economy big fluctuations in cotton area, production and yield occurred. During the period from 1987 to 2002 cotton area, production and yield dropped, on average, by 38, 48 and 18 %, respectively (Ahmed et al., 2004). On the other hand, cotton productivity is low compared to other cotton producing countries, best practice productivity and the productivity achievable in the research stations. Moreover, cotton yield in the Gezira Scheme varies between different administrative units (groups and blocks) and even between adjacent tenants. Cotton production fluctuation affect cotton's contribution to export revenue, as its contribution had dropped from 45–65 % during the Seventies to 22 % in 1995 and in 2000 and 2001 it dropped below 3 %. Cotton production fluctuation may be due to the cumulative effects of production problems such as tenants' technical inefficiency, scheme management inefficiency and centralized government and scheme management's decisions of area allocation between the different crops. Cotton production

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constraints in the Gezira scheme are interdependent and their solutions lie on their causes, only after these causes are examined can solutions be developed.

The main objective of this economic study is to identify, analyze and evaluate the major constraints of cotton production in the Gezira Scheme. More specifically the specific objectives of the study are to: (1) Elaborate and assess the interrelationships between the different causes of cotton production variability in the scheme; (2) Identify and evaluate tenants' technical efficiency and the scheme management's efficiency and to investigate the main factors behind tenants' technical inefficiency for cotton production; (3) Determine, compare, and evaluate the crop combination that will maximize returns to the tenants' available resources with (a) the current crop combination; (b) with crop combination from tenants' and the scheme management points of view if the tenants are free to allocate their resources between the different uses and (c) with the crop combination under risk considerations. The remainder of this paper consist of 3 sections. In section 2 the analytical techniques used are presented. In section 3, results are presented and discussed and in section 4 summary and conclusions are highlighted.

2. Analytical Techniques:

In this section the theoretical background, estimation procedures and the empirical models of the stochastic production frontier (SPF), linear programming (LP), quadratic risk programming and sensitivity analysis which were used to test the study hypotheses, are presented.

2.1. Stochastic Production Frontier Model (SPF)

Stochastic production frontier analysis is a method of estimating frontier functions involving the use of econometrics and thereby measuring the efficiency of production. Efficiency measurement received a considerable attention from both theoretical and applied economists (Bravo–Ureta, 1991). From a theoretical point of view there has been a spirited exchange about the relative importance of the various components of the firm efficiency (Leibenstein, 1966, 1978; Comanor and Leibenstein, 1969). From an applied perspective, measuring efficiency is important because it is the first step in a process which might eventually lead to substantial resource savings.

Farrel's (1957) proposed measure of firm efficiency consists of two components: technical efficiency, which reflects the ability of a firm to obtain the maximal output from a given set of inputs, and the allocative efficiency, which reflects the ability of the firm to use the inputs in optimal proportion, given their respective prices. These two measures are then combined to provide a measure of the total economic efficiency. Aigner and Chu (1968) considered the estimation of a parametric frontier production function of the Cobb-Douglas form using data on a sample of N firms. The model is defined by

$$\ln(y_i) = x_i \beta - u_i \quad , i = 1,2,....,N, \qquad (1)$$

Where

$\ln (y_i)$ is the logarithm of the (scalar) output of the i-th firm; xi is a (k+1) –row vector whose first element is "1" and the remaining elements are the logarithms of the K- input quantities used by the i- th firm; $\beta = (\beta_0, \beta_1 \ldots \beta_k)$, is a (K+1)- column vector of unknown parameters to be estimated; and the u_i is a non–negative random variable, associated with the technical inefficiency in production of firms in the industry involved.

The ratio of the observed output for the i-th firm, relative to the potential output defined by the frontier function, given the input vector x_i, is used to define the technical efficiency (TE_i) of the i-th firm :

$$TE_i = \frac{y_i}{\exp(x_i b)} = \frac{\exp(x_i b - u_i)}{\exp(x_i b)} = \exp(-u_i) \qquad (2)$$

The above stated measure of technical efficiency is output–oriented. Farrel's measure of technical efficiency (TE_i), takes a value between zero and one. It indicates the magnitude of the output of the i-th firm relative to the output that could be produced by a fully-efficient firm using the same input vectors.

Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977) independently proposed the stochastic frontier production function in which an additional random error, v_i, is added to the non-negative random variable, u_i, in equation (1) to provide:

$$\ln(y_i) = x_i \beta + v_i - u_i \qquad , i = 1,2,....,N, \qquad (3)$$

The random error, v_i, accounts for the measurement of error and the other random factors such as the effects of weather, strikes, luck, etc. on the value of the output variable, together with the combined effects of unspecified input variables in the production function. Aigner, Lovell and Schmidt (1977) assumed that the v_i's were independently and identically distributed (i.i.d.) normal random variables with zero mean and constant variance, δ_v^2, independent of the u_i's, which were assumed to be i.i.d. exponential or half-normal random variables. The model defined by equation (3) is called the stochastic frontier production function because the output values are bounded by the stochastic (random) variable $\exp(x_i \beta + v_i)$. The random error, v_i, can be positive or negative and so the stochastic frontier output varies from the deterministic part of the frontier model, $\exp(x_i \beta)$.

Aigner, Lovell and Schmidt (1977) derived the log likelihood function for the model, defined by equation (3), in which the u_i's are assumed to be i.i.d. $N(0, \delta^2)$ random variables, independent of the v_i's which are assumed to be $N(0, \delta_v^2)$. They also expressed the likelihood function in terms of two variance parameters, $\delta_s^2 = \delta^2 + \delta_v^2$. Battesand and Corra (1977) suggested that the parameter $\gamma = \delta^2/\delta_s^2$ be used because it has a value between zero and one, whereas the parameter γ could be of any non-negative value. A value of γ of zero indicates that the deviations from the frontier are entirely due to noise or uncontrollable factors, while a value of one would indicate that all deviations are due to the technical inefficiency.

Using stochastic production frontier four model were formulated. The first one is the tenant model, which includes the tenants' factors influencing the tenants technical efficiency. The second one includes the scheme management factors. The application of the best management practices for cotton production in the Gezira scheme is a responsibility of both the tenants and the scheme management as each one has certain tasks with respect to cotton production. As a result of that, the tenant and management models are combined to develop the third model, general model, in order to evaluate the influence of both the tenant specific factors and the scheme management factors on the tenants' technical efficiency. The fourth one is the inefficiency model which is used to identify the main factors behind tenant technical inefficiency.

Tenants, management and general models can be written as:

$$\ln y_i = b_0 + b_m^* D_m x_{im} + \sum_{j=m+1}^{n} b_j \ln x_{ij} + v_i - u_i \qquad (4)$$

where ln = the natural logarithm;

y_i = Yield of cotton in kantar/feddan (142 kg of seed cotton);

$D_m x_{im}$ = dummy variable (s), the subscript m indicate number of the dummy variables

N = Total number of variables in each model

The tenant's model variables include: $D_1 x_{i1}$ = dummy variable for sowing, which has a value of one if the sowing is done at the optimum time and zero, otherwise; x_2 , area grown by the other crops in feddan; x_3, number of irrigations; x_4, amount of labor per feddan in man days; x_5, number of weeding; x_6, number of harvestings and x_7, tenants' income from other sources used in agriculture during the season.

The management's model variables are: $D_1 x_1$, pest control dummy variable with a value of one if a tenancy is severely infested and zero, otherwise; x_2, difference between the cash advances paid to the tenants by the scheme management and the actual labor costs for weeding and harvesting cotton; x_3, number of delayed irrigations due to water distribution problems in the scheme and x_4, number of insufficient irrigations (less than recommended) due to the improper water distribution in the scheme. The general model factors include both the tenant's and management's model factors mentioned above.

b_1^* and b_j are unknown parameters to be estimated for the dummy and continuous variables, respectively.

v_i represents the statistical error and the other factors which are beyond the tenants' control such as weather, topography and others factors which are not included and may be either positive, negative or zero.

u_i is a non–negative random variable, associated with the tenants technical inefficiency in production and assumed to be independently distributed. For the technical inefficiency effect for the ith tenant, it will be obtained by truncation (at zero) of the normal distribution with mean, μ_i, and variance, δ^2. such that

$$m_i = d_0 + \sum_{s=1}^{7} d_s Z_{si} \qquad (5)$$

where:

Z_{1i} , tenant experience (number of years spent as a tenant); Z_{2i}, number of contacts with extension agents; Z_{3i}, difference between the cash advances from the Sudan Gezira Board (SGB) for cotton weeding and harvesting and their actual costs; Z_{4i}, dummy variable for credit, which has the value one if the tenant is not constraint by credit and zero, otherwise; Z_{5i}, years of tenant's formal education; Z_{6i}, total area grown with other crops and Z_{7i}, number of visits by the field inspector to the tenant during the season.

δ_s and δ_s^2 are unknown parameters to be estimated.

2.2. Linear programming (LP)

LP is a mathematical techniques for solving a problem that has certain characteristics. The essential characteristics of a LP problem are that, there is a function or objective to be maximized or minimized, there are limited resources to be used in the satisfaction of this objective and there are numerous means of using the resources available. Most resource allocation decisions faced by farm managers have these characteristics can be evaluated through linear programming. LP is a method of determining a profit maximization combination of the farm enterprises that is feasible with respect to a set of fixed farm constraints (Hazell and Norton, 1986)

LP has many advantages over other analytical techniques. It is appropriate to any resource allocation problem, handles more complex problems than budgeting and marginal analysis, provides information on the best or optimum way of allocating resources and the best production-marketing-financial plan and information concerning the value of various resources used in the plan. It can easily be used to evaluate how the result would change if changes occurred in product prices or technical efficiency and it handles the issue of opportunity cost easily (Boehlje and Eidman, 1984).

The objective of the tenants in the Gezira Scheme is to maximize the gross margin from the crops grown, namely, cotton, wheat, dura and groundnut. The tenants in the scheme are subjected to a set of constraints limiting the satisfaction of this objective. These constraints include land, family labor, amount of own capital and capital to be borrowed, amount of irrigation water and the institutional constraint in a form of a fixed crop rotation. The general algebraic notation of the linear programming used in the study is written as :

$$MaxGM = \sum_{j=1}^{n} c_j x_j \qquad (6)$$

subject to:

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i \quad \text{for } i = 1........m \qquad (7)$$

$$x_j \geq 0 \quad \text{for } j = 1.........n \qquad (8)$$

where: x_j, the level of the jth production process or activity, which represent the area of cotton , wheat, sorghum groundnut and vegetable; c_j , gross margin of the tenant's resources (b_i's) for the jth activity; a_{ij}, the amount of the ith resource required per unit of the jth activity i.e. the coefficients which represent the land and the monthly amount of family labor, capital and irrigation water required by the crops produced and b_i, the amount of the ith resource available on a monthly basis. Equation (6) identifies the objective function as the maximization of the sum of the gross margin (c_j) from the crops produced, namely cotton, wheat, sorghum, groundnut and vegetables times the number of feddans of each crop in the solution. Equation (7) specifies the restrictions on how many feddans of each crop can be produced. These restrictions are specified as the summation of resources required to produce one feddan of each crop (a_{ij}) times the number of feddans of each crop produced (x_j) may not exceed the resources available (b_i). Equation (8) reveals the practical reality and the mathematical necessity that the area of cotton, wheat, sorghum, groundnut and vegetable can not take on negative values.

2.3. Sensitivity Analysis

Sensitivity analysis is the investigation that deals with changes in the optimal solution due to the changes in the data (Gass, 1985). The aforementioned linear programming model was used to find the optimum crop combination mixes using different scenarios. 20 % change in the normal situation with respect to crop gross margins, capital available and production costs represent the scenarios used in the study

2.4. Quadratic Risk Programming Model: (Expected Income –Variance Concept)

When one solves many LP models one gets many plans and the question remains which plan should be used. In this case risk programming could help to select which plan to choose. Many different alternative decision rules and theories that have been developed in the literature are provided to help the farmers to rank farm plans on the basis of their income distribution and to select the farm plan that best meets his goals (Hazzel and Norton, 1986). Markowitz in his portfolio choice problem involves development of an "optimal" investment strategy. The variables indicate the amount of funds invested in each risky investment subject to a total funds constraint. He motivated the formulation by observing that investors only place a portion, not all, of their funds in the highest-yielding investment. This, he argued, indicated that a LP formulation is inappropriate since such an LP would reflect investment of all funds in the highest yielding alternative. This deviation between observed and modeled behavior led Markowitz to include a variance term resulting in the so-called expected value variance (E-V) model (McCarl and Spreen, 1997)

A quadratic utility function is subject to many usage limitations. It is characterized by an increasing absolute risk aversion and having a maximum value beyond which the marginal value of the income declines. Despite these limitations, it provides an excellent second order approximation to more desirable functions (Pratt, 1964, Levy and Makowitz, 1979).

If the (E-V) concept makes a choice equivalent to that of an expected utility function is debatable (Freund 1956, Tsiang 1972, 1974, Levy and Markowitz 1979, Kroll, et al. 1984; and Reid and Tew 1987, for review). However, the (E-V) concept has computational advantages. Moreover, it provides a set of efficient farm plans and the acceptability of any particular plan to an individual farmer will depend on his preference among the various expected income and associated variance levels. The (E-V) concept provides a set of optimal portfolios because it is possible to gain more income by accepting more risk.

The expected income –variance criterion assumes that farmers' preference among alternative farm plans are based on the expected income and associated income variance (Hazzel and Norton, 1986).

The model used in this study is based on Markowitz's original formulation of the E-V problem, which minimized variance subject to a given level of expected income. The empirical model is written as :

$$\min \quad V = \sum_j \sum_k x_j x_k d_{jk} \qquad 9$$

$$\sum \bar{c}_j x_j = ? \qquad 10$$

$$\sum a_{ij} x_j \leq b_i \quad \text{all} \quad i \qquad 11$$

$$x_j \geq 0 \quad \text{all} \quad j \qquad 12$$

Where V, represents the variance of the total gross margin from the crops grown (cotton, wheat, groundnut and sorghum) which is an aggregate of the variability of individual crop returns, and of the covariance relationship between them; X_j, Level of the jth farm activity, (cotton, wheat, sorghum and groundnut area); d_{jk}, Covariance of gross margins between the jth and kth activities (cotton, wheat, sorghum and groundnut), d_{jk} will be the variance when j=k and $\bar{c}_j$, Expected gross margin of the major crops produced in the scheme (cotton, wheat, sorghum and groundnut).

2.5. Data

for the purpose of this study both primary and secondary data were used. Structural questionnaires were used to collect data from both the tenants and the scheme management during the growing season of 2002/03. Gezira scheme is divided into 18 administrative units called groups , which further divided into 114 blocks each with about 1000 tenants. One hundred tenants from the Northern and Central groups were interviewed. Moreover, 30 field inspectors from different groups were also interviewed.

3. Result and discussion

3.1. Schematic Analysis of Cotton Production Constraints

In figure 1 the main constraints of cotton production in the scheme are identified. In addition, interaction effects between cotton area, scheme management, Government policies, finance, productivity, crop rotation, irrigation and marketing on cotton production variation in the Gezira scheme are also illustrated.

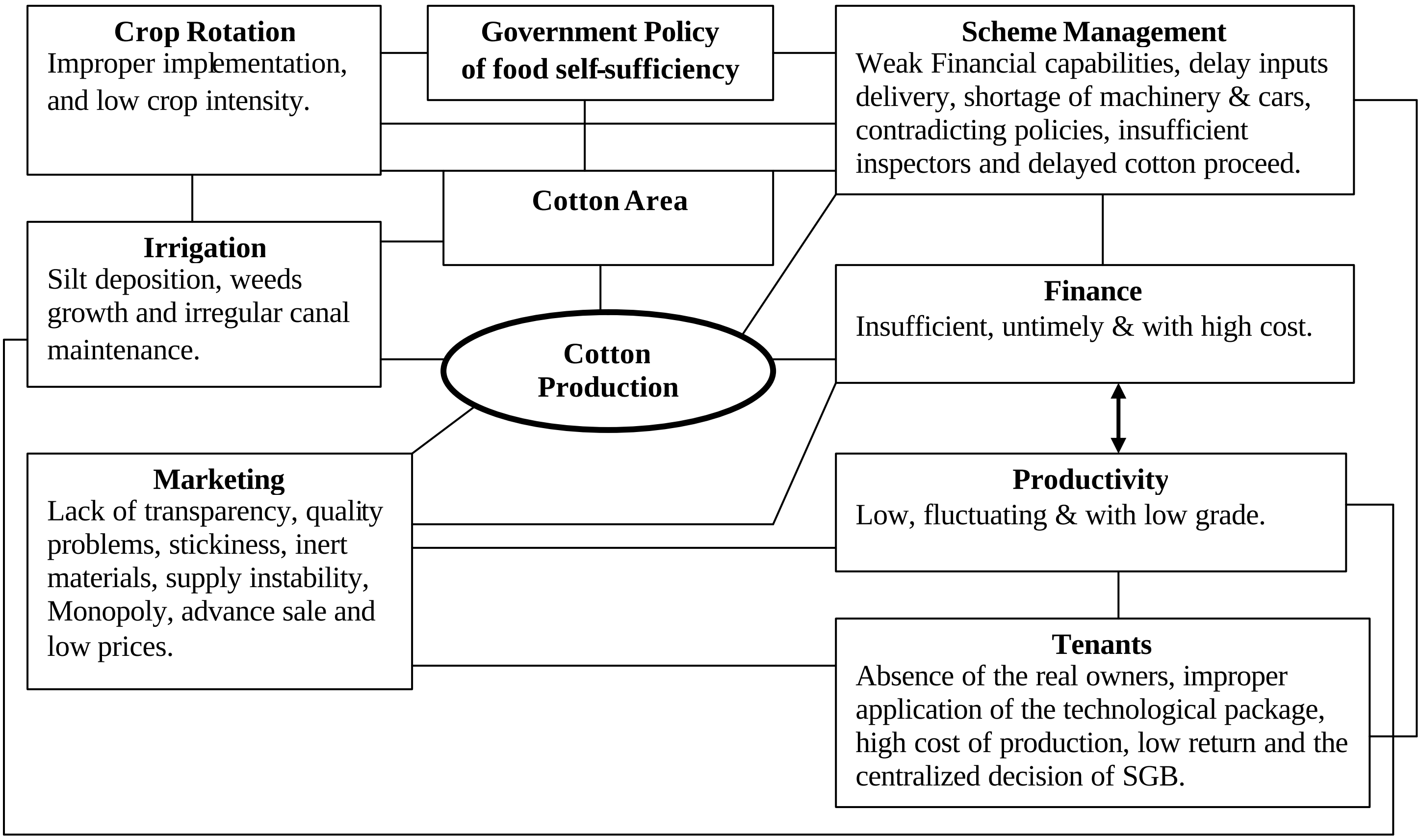

Figure 1. Schematic Diagram of Cotton Production Constraints in the Gezira Scheme

3.2. Stochastic Frontier Production Function Analysis

The four models, general, tenants, management and inefficiency, are estimated using the frontier 4.1 program (Coelli, 1996). The maximum–likelihood estimates (MLE) of the stochastic frontier for the general, tenant, the scheme management are present in Table 1 and inefficiency model is presented in Table 2. As shown in table 1, the mean technical efficiency of the tenants with respect to cotton production is 0.52 in the general model. This means that on average, the tenants in the scheme produced only 52 % of cotton yield attainable by the best practices. This result reveals that the tenants can increase their cotton output by 48 % using the current level of inputs if the tenants are technically efficient and the management carries out its tasks properly. This inefficiency in cotton production is shared between the management and the tenants as each of them has particular tasks to do concerning cotton production. By assessing the tenants' technical efficiency for tenants and management specific factors separately, the mean technical efficiency is 0.72 and 0.74 for tenants and scheme management factors, respectively. The variance parameter ? is significant and has a value of 0.99, in the general, tenants' and the scheme management's model, respectively. These results indicate that 99 % of cotton yield variability from the yield obtained by best practices is due to the combination of the tenants' and scheme management's specific factors, and only 92 % of the variability is due to tenant specific factors and 78 % due to scheme management specific factors. The significant estimates of ? and d_s^2 imply that the assumed distribution of u_i (truncated) and v_i (normally) is accepted (Kalirajan, 1981). Most of the estimated ß coefficients of the stochastic frontier in the general, tenants and the scheme management model have the expected signs. Cotton sowing has a negative sign in both the general and the tenants model. However, it is not significantly different from zero. The negative sign reflects the effect of late sowing on the cotton production level.

Pest infestation has a negative sign in both the general and the scheme management model and is significant at 10% and 1% level of significance in the general model and the scheme management's model, respectively.

The area of the other crops, cultivated at the same time with cotton, has a negative sign in the general and in the tenant model but is not significantly different from zero. The number of irrigations is one of the main determinants of cotton productivity. Cotton in the Gezira scheme never receives the recommended number of irrigations, as cotton irrigation is confronted with various irrigation problems like silt sedimentation in the canals, weed growth, and lack of maintenance of the irrigation system in the scheme. The labor coefficient have a positive sign and are significantly different from zero at 5% significance level in the general and the tenants model. Labor is required to carry out cotton activities timely, particularly weeding and harvesting. Labor availability at the right time not only leads to the reduction of the tenants' cotton yield variability, but also to better cotton quality and hence higher tenants' income. The estimated coefficient of the number of cotton weeding is significantly different from zero in both, the general and the tenants' model. The coefficient of cotton harvesting is positive and significant in the general model and negative and not significant in the tenants model. This negative coefficient is contrary to expectation, since increasing the number of cotton harvestings, normally lead to higher cotton yields and better qualities. A possible explanation for this negative sign may be as fallow: SGB provides harvesting credit to the tenants. But some times the delivery of the harvesting credit delayed. Moreover, the tenants may use the credit in activities other than harvesting. In this case most of the harvesting burden will fall on the family labor and on small amount of hired labor. Depending only on the family labor and/or on a small amount of the hired labor for cotton harvesting increases the length of the harvesting period and the number of harvestings, but it negatively affects cotton yield and quality. The difference between the amount of credit from the Gezira scheme for weeding and harvesting and their actual costs reflects the sufficiency of the amount of credit. The coefficient of the difference is negative and significant. Increasing the difference adversely affects both weeding and harvesting, which in turn affect tenants' technical efficiency

Table 1: General, Tenant and Management Model: Maximum–likelihood Estimates for the Parameters of the Stochastic Frontier Production Function

Variable	Parameters	General	Tenant	Management
Constant	b_0	-3.78 * (2.75)	-12.02*** (2.77	2.21*** (0.259)
Sowing	b_1	-.087 (0.087)	-0.047 (0.073)	
Pest infestation	b_2	-0.12 * (0.078)		-0.69*** (0.107)
Area	b_3	-0.14 (0.12)	-0.72 (0.73)	
Irrigation	b_4	0.62 *** (0.22)	0.32* (0.21)	
Labor	b_5	0.12** (0.07)	0.324** (0.156)	
Weeding	b_6	0.28 *** (0.11)	0.22 ** (0.105)	
Harvesting	b_7	0.106 * (0.112)	-0.22 (0.15)	
Income	b_8	0.0025 (0.011)	0.0196** (0.0091)	
Difference	b_9	-0.014 * (0.01)		-0.092*** (0.0204)
Delayed number of irrigations	b_{10}	- 0.43 *** (0.074)		-0.13** (0.072)
Insufficient number of irrigations	b_{11}	0.0016 (0.081)		0.0055 (0.01
$d_s^2 = d_v^2 + d^2$	$d_s^2 = d_v^2 + d^2$	0.09*** (0.0163)	0.23*** (0.048)	0.22 ** (0.072)
$g = d^2 / d_s^2$	d^2 / d_s^2	0.99 ***	0.92 *** (0.057)	0.78 *** (0.197)
Mean efficiency		0.52	0.72	0.74

***,** and * asterisks on the value of the parameters indicates it is significant at 1, 5, and 10 % level of significance, respectively.

The estimated standard errors are presented in parenthesis below the corresponding parameter estimates

The coefficient of delayed number of irrigation is negative and significantly affects the cotton production level, in contrary to the coefficient of insufficient number of irrigations, which is positive and not significantly different from zero. A logical explanation of this result is that delaying cotton irrigation is critical and negatively affects cotton yield particularly during the period of boll formation. This period always coincides with bottlenecks of water supply, during which the four crops are established. Moreover, the tenants have to manage the four crops during the same time period. This may result in delayed irrigations. In most cases, insufficient irrigations or a less than the recommended number of irrigations may take place at the end of the season and hence has a smaller negative effect on cotton yield. This arises mainly in winter when there is less water available in the scheme than in the summer time.

Most of the tenants in the scheme have an off-farm income from other sources. Part of this income is used in agriculture. The estimated coefficient of the part of the off-farm income that is used in agriculture is not significantly different from zero in the general model and significant at 5% level of significance in the tenants model.

In the inefficiency model in table 2, the signs of all coefficients were as expected, except for the years of formal education. The years of formal education and the tenants' experience do not significantly affect the level of the tenants' inefficiency.

Table 2: Inefficiency model : Maximum–likelihood Estimates for the Parameters of the Stochastic Frontier Production Function

Variable	Parameters	Estimates
Constant	d_0	0.41 ** (0.20)
Experience (Z_1)	d_1	-0.0005 (0.0026)
Contact ((Z_2)	d_2	-0.015 *** (0.0025)
Difference (Z_3)	d_3	0.008 *** (0.001)
Credit(Z_4)	d_4	0.18 ** (0.07)
Education(Z_5)	d_5	0.083 (0.084)
Area(Z_6)	d_6	0.031** (0.015)
Visit(Z_7)	d_7	- 0.065*** (0.015)

***,** and * asterisks on the value of the parameters indicates it is significant at 1, 5, and 10 % level of significance, respectively.

The estimated standard errors are presented in parenthesis below the corresponding parameter estimates

The number of contacts with extension agents, the differences between the cash advances for cotton weeding and harvesting from the SGB and the actual cost of weeding and harvesting as well as the number of the visits by the field inspectors to the tenant during the season are highly significant (1%) in influencing the technical inefficiency of the tenants in the Gezira scheme. As the differences between the harvesting and weeding credit and their actual costs increase, the inefficiency increases.

The inspectors in the scheme visit the tenants during the whole season to supervise the proper and timely application of the cultural practices. The inspectors in the scheme act as extension agents as they give advice to the tenant on the proper application of the cultural practices, and answer their immediate questions and inquiries during their daily supervision of the scheme. Some of the tenants receive more visits by the inspectors than others. According to this fact it can concluded that, as the number of the visit by the inspector to the tenant increases, the inefficiency of the tenants decreases. Credit, and the area of other crops grown by the tenants, influence tenants' technical inefficiency at 5% level of significance. This result indicates that the tenants who are not constraint by credit are more technically efficient than those who are. The tenants who cultivate a large area with other crops than cotton tend to be less technically efficient than those who cultivate small areas.

Equation 13 and 14 were used to decomposed tenants technical inefficiency in the general model between tenant and scheme management factors:

$$\text{Tenants factors} = \frac{\text{1-MTEG}}{\text{(1-MTET)+(1-MTEM)}} * (1-\text{MTET}) = \frac{1-0.52}{(1-0.72)+(1-0.74)} * (1-0.72) = 0.25 = 25\ \text{percent} \quad (13)$$

$$\text{Management factors} = \frac{\text{1-MTEG}}{\text{(1-MTET)+(1-MTEM)}} * (1-\text{MTEM}) = \frac{1-0.52}{(1-0.72)+(1-0.74)} * (1-0.74) = 0.23 = 23\ \text{percent} \quad (14)$$

Where:

MTEG = Mean technical efficiency in the general model
MTET = Mean technical efficiency in the tenant model
MTEM = Mean technical efficiency in the management model
The results reveal that 25 % of the tenants' technical efficiency in the general model is due to tenant specific factors and 23 is due to the management's specific factors.

3.3. Linear Programming

In this section of the study different crop combination scenarios are developed and compared. These scenarios include (1) Field survey crop combination (sc1.); (2) Crop combination from the tenants' point of view if they are free to allocate their resources between the different uses (Sc2); (3) Crop combination from the scheme management point of view (Sc3); (4) Linear programming crop combination with vegetables (Sc4); (5) Linear programming crop combination without vegetables (Sc5); (6) Linear programming crop combination with vegetables and assuming tenants are technically efficient for cotton production (Sc6) and (7) Linear programming crop combination without vegetables and assuming tenants are technically efficient for cotton production (Sc7). As depicted in Table 3, each crop area is represented as a percentage of the total area in the corresponding scenario. The field survey crop combination is expected to be as close as possible to the crop combination from the tenants and the scheme management point of view as well as to the linear programming crop combinations. However, the result shows, tenants', scheme management's and linear programming crop combinations differ from the field survey crop combination. This result indicates the impact of the scheme management's centralized decision on the tenants preference, i.e., the tenants have to follow a certain crop rotation.

In the linear programming crop combination (Sc4 to Sc7), land use intensity ranges between 40 to 60 %. In scenarios Sc4 and Sc5 there is no significant difference with respect to cotton, wheat and sorghum area percentages. However, as vegetables are introduced in the model, the groundnut area decreases to zero. The crop combinations from the tenants' and scheme management's points of view have the highest land use intensity compared to other scenarios.

Table 3: Different Scenarios of Crop Combinations in the Gezira Scheme (In % unless otherwise indicated)

Scenario	C	W	S	GN	Vegt.	Z (000 SD)	Total Area (Feddan)
Gross Margin (000' SD)	23	7.5	12.3	8.8	82		
Sc1: Field survey	34	7.6	42	11	5	241.55	13.39
Sc2: Management	30	0	30	30	9	346.14	16.50
Sc3: Tenants	30	0	30	30	9	346.14	16.50
Sc4: LP with vegetables	38	22	29	0	11	259.38	10.78
Sc5: LP without vegetables.	39	24	25	12	0	149.46	9.74
Sc6: LP,TE[3] with vegetables	74	20	0	0	6	390.34	9.44
Sc7: LP,TE Without Vegetables	70	30	0	0	0	261.12	7.24

C= cotton, w = wheat, S = sorghum, GN=groundnut, Vegt.=Vegetables and Z = value of the objective function

Introducing technical efficiency in the model as in scenarios Sc6 and Sc7 is done by using cotton gross margin for the tenants who have a technical efficiency above 80 % (48,383.8 SD/ feddan) in the model instead of the average gross margin. In Sc6 and Sc7 land use intensity decreased to 52 and 40 % compared to the field survey result (Sc1). The higher gross margin of cotton of the technically efficient tenants will cause the tenants to reallocate their resources between the different crops. Introducing tenants' technical efficiency for cotton production in the model results in allocating 74 (Sc6) and 70 (Sc7) percent of the area grown to cotton production with no sorghum and groundnut. However, the income at the tenant and scheme levels increases by 129 and 100 %, respectively, compared to field survey income.

Table 4: Gezira Scheme and its Tenants: Income under the Different Scenarios of Crop Combination

Scenario	Z (000SD)	Total Area (fd)	Income/fd (000's SD)	Land use intensity	Tenants income (000's SD) (15 fd.)	Scheme Income (Mill. SD)	Income change (%)[4]
Sc1: Field survey	241.55	13.4	18	74	271	30894	0
Sc2: Management	346.14	16.5	21	92	315	35869	17
Sc3 : Tenants	346.14	16.5	21	92	315	35869	17
Sc4 : LP with vegetables	259.38	10.8	24	60	361	41151	34
Sc 5: LP without vegetables	149.46	9.7	15	54	230	26221	-15
Sc 6: LP,TE, with vegetables	390.34	9.4	41	52	620	70701	129
Sc7: LP,TE Without Vegetables	261.12	7.2	36	40	541	61677	100

As shown in Table 4, per feddan income of the different scenarios is higher than the income of the situation of the centralized decision of the area allocation between the different crops (Sc1), except Sc5. Per feddan income is 17, 34, 129, 100 percent higher than the real situation (Sc1) for Sc2 and Sc3, Sc4, Sc5 and Sc6 scenarios, respectively. These results illustrate the impact of the centralized decision in area allocation on the income at the tenant as well as at the national level.

3.4. Sensitivity Analysis

Six scenarios are developed to perform sensitivity analysis. Crop gross margins, capital available and costs of production in the scenario of the crop combination with vegetable (Sc4) are increased and decreased, respectively, by 20 %. Table 5, shows the effect of each scenario on the crop combinations, the land utilization and the value of the objective function (Z). The range of values

[3] Tenants assumed to be technically efficient for cotton production

[4] Percentage change in per feddan income, tenants income and the scheme income

for an objective function (Z) for which the optimal solution remains the same is called the range of optimality. Within the range of optimality, the optimal values of the solution variables will not change (Van Soest, 2002). A 20 % increase and decrease in the gross margin of the crops grown show no effect on crop areas. However, it leads to a 20 % increase and decrease in the value of the total gross margin (Z) from the crops grown, respectively.

Capital is the most restricting constraint in the model. Land, family labor and irrigation water are nonbinding constraints with the given level of capital. This section examines how a 20 % increase and decrease in the amount of capital available to the tenants (RHS) affect area allocation between the different crops. A 20 % increase and decrease in the amount of the capital available to the tenants lead to the same increase and decrease in percent in the crop areas. A 20 % increase in the capital available, results in a 47 % increase in total gross margin. However, a 20 % decrease in the capital available leads to a 2 % decrease in the total gross margin.

Table 5: Sensitivity Analysis: Impact of the Different Scenarios on the Crop Combination, Land Utilization and Total Gross Margin

	Cotton	wheat	Sorghum	GN	Vegeta-bles	Total area	Z (000, SD)
S0 Normal Situation (area Feddan)	4.061	2.346	3.135	0	1.233		259.38
S1 20% increase GM	0	0	0	0	0	0	20
S2 20% decrease GM	0	0	0	0	0	0	-20
S3 20% increase in capital	20	20	20	0	20	20	47
S4 20% decrease in capital	-20	-20	-20	0	-20	-20	-2
S5 20% increase in production costs	-28	-13	-13	3.5[5]	-26	14	-13
S6 20% decrease in production costs	25	25	25	0	25	25	25

A 20 % increase in the production costs results in decreasing the cotton area by 28 %, and wheat, sorghum and total gross margin by 13 %. However, a 20 increase in the production costs, introduces groundnut into the crop mix with an area of 3.5 feddan. As a consequence total land utilization increased by 14 % compared to the actual situation (see Table 5). A 20 % decrease in the production cost of the crop produced, will result in 25 % increase in cotton, wheat, sorghum and vegetables areas. It also leads to a 25 % increase in the total area and tenant's total gross margin.

3.5. Quadratic Risk Programming Model

Before discussing the gross margin variance and covariance of the major field crops in the scheme, risk sources of the major field crops have been elaborated. The gross margin variance and covariance of the major crop in the scheme are affected by the variability in the crop yields, costs of production and output prices. To know whether the source of risk in each crop is due to yield, output prices and cost of production variability or due to combined effects of these factors, yield, output prices and costs of production variance of the major field crops are calculated (see Table 6).

Sorghum has a high yield variance followed by cotton, wheat and GN. Sorghum ranked third and fourth with respect to output prices and costs variance, respectively. Sorghum is a riskier crop, compared to the other crops, mainly because of yield variability, followed by output price and production costs variability. Cotton has the highest output price variance and cost variance compared to the other crops, produced in the scheme. Moreover, cotton ranked the second after sorghum with respect to yield variability. Groundnut gross margin variability is mainly due to the

[5] Groundnut area in feddan

production costs followed by yield and output price variability. The main sources of risk for wheat production in the Gezira Scheme are output prices followed by the input prices variability and yield variability

Table 6: Gezira Scheme: Yield, Output Price and Production Costs Variance for the Major Crops Grown (1987-2002)

Variance	Cotton	Wheat	GN	Sorghum
Yield[6]	0.53	0.03	0.02	0.71
Output price (000)[7]	0.779	0.141	0.101	0.133
Cost (00000)[8]	0.23382	0.11051	0.14267	0.05861

As depicted in Table 7, sorghum is a high-variance crop in the scheme followed by groundnut, cotton and wheat. The sorghum crop is riskier in terms of its own variance of gross margins. However, it still proves attractive to the tenants as its gross margins are negatively covariate with cotton which will result in a more stable aggregate gross margin (Hazell and Norton, 1986). Moreover, sorghum production is a very important crop for the tenants in the Gezira Scheme. It represents the main staple food crop for the majority of the tenants in the scheme, and sorghum residues are used as fodder for tenants' animals. As a result, the tenants in scheme insist and continue to grow sorghum irrespective to its prices and yield variability.

Groundnut with a gross margin variance of 17,552 ranked second after sorghum (Table 7). Moreover, GN has the lowest yield variance compared to cotton, wheat and sorghum, and a lower output price variance than wheat and sorghum. Nevertheless, the tenants preferred to reduce groundnut area, rather than sorghum. This may be attributed to the fact that groundnut production is optional and requires more labor than sorghum.

Wheat is a low–variance crop in the scheme (Table 7). Wheat output price variance is higher than that of GN and sorghum and has a higher cost variance than sorghum. As mentioned before, the tenants in the scheme ceased to produce wheat because of its high cost of production and low gross margin compared to the other crops produced in the scheme.

Table 7: Gezira Scheme: Variance and Covariance of the Major Crops Grown (1987-2002)

	Cotton	Wheat	Groundnut	Sorghum
Cotton	**9305**	3401	4366	-8012
Wheat	3401	**6572**	7117	9338
Groundnut	4366	7117	**17552**	5942
Sorghum	-8012	9338	5942	**47198**

Cotton ranked third after sorghum and GN with respect to the gross margin variance (Table 7). However, it has the highest gross margin of the major crops produced in the scheme.

In Risk programming model, eight expected income levels (Scenarios) were used in order to estimate the crop combinations and the expected income variances up to the maximum amount of the expected income that can be achieved under the available resources. Scenario 2 to 6 are based on the field survey crop combinations income, as well as, on the crop combinations income generated by linear programming. These scenarios include the following income: (1).Starting target income (500 US $); (2) Linear programming crop combination without vegetables (573 US $); (3) Field survey crop combination (925 US $); (4). Linear programming crop combination with

[6] Average yield for the major crops during the period 1987-2002
[7] Average output price for the major crops produced during the period 1992-2002
[8] Average costs (Input prices) for the major field crops during the period 1987-2002

vegetables (994 US $) (5) Linear programming crop combination without vegetables and assuming tenants are technically efficient for cotton production (1000 US $); (6) Crop combination from the tenants point of view (1,326 US $); (7). Linear programming crop combination with vegetables and assuming tenants are technically efficient for cotton production (1,456 US $) and (8) Maximum amount of the expected income that can be achieved under the available resource (Table 8)

As depicted in Table 8, as target income increases, its variance increases, which says that achieving higher income means bearing more risk. There is a strong positive correlation between the income and the land use intensity. As target income increases crop areas increase. Land use intensity is only 27 % when the target income is 500 US $. With target income of 1,500 US $ the land use intensity approaches 81 %.

Table 4.31.(8) Gezira Scheme: Crop Combination, Land Use Intensity, Tenant and the Scheme Income under E-V concept

Scenario	1	2	3	4	5	6	7	8
Target income (U.S.$)	500	573	925	994	1000	1326	1456	1500
Variance (000's)	118	155	488	655	671	2277	3385	3940
Cotton	74	74	50	41	40	4	0	0
Wheat	0	0	0	0	0	13	13	12
Groundnut	2	2	23	31	31	51	43	38
Sorghum	24	24	27	28	28	32	44	50
Total Area	4.8	7.9	8.8	9.5	9.6	13.2	14.3	14.6
Land use Intensity	27	44	49	53	53	73	80	81
Tenant Income *	1567	1567	1569	1570	1570	1509	1524	1538
Scheme Income (Mill. US $)	175.5	175.5	175.8	175.8	175.8	169	173.7	172.2

With low target income more area will be allocated to cotton production. When the target income is only 500 US $, a 74 % of the area allocated to cotton production and 24 % to sorghum. Increasing target income results in decreasing area allocated to cotton and at the same time increasing sorghum and groundnut area. With an expected income variance of 2,277,000, cotton area represents only 4 % of the total area grown and then after cotton area approaches zero. As we move from scenario 1 up to scenario 5 wheat is removed from the crop combination. However, from scenario 6 to scenario 8 the wheat area represents 12.5 % of the total area grown. Increasing target income results in more area allocated to sorghum. With a target income of 1,500 US $, sorghum area represents 50 % of the area planted i.e. a 26 % increase compared to the starting income (500 US $). Comparing the results of the quadratic risk programming with crop combination from the tenants' and the scheme management's points of view, scenario 4 is the crop combination closest to the tenants' and the scheme management's preference. Reasons are:

- It yields crop combination which is closer to the crop combination under the tenants' centralized decision of area allocation between the different crops. Moreover, the value of the objective function is also closer to the income targeted by the tenants if they are free to select what to produce.
- Land use intensity is 53 % which is almost the same as the current average land use intensity in the scheme (57 %). This means that this crop combination is achievable even under the prevailing irrigation conditions in the scheme .
- Wheat area is zero, as in the crop combination from the tenants' and scheme management's points of view.

* If 15 feddan are utilized

- It has the highest income at the tenant, as well as, at the scheme level.
- The amount of sorghum produced in this scenario, exceeds the average amount of sorghum, consumed by the tenants in the scheme.

4. Summary and Conclusions

The main objective of this study is to identify, analyze and evaluate the major constraints of cotton production in the Gezira Scheme(GZ), Sudan (GS). The primary data were collected using structural questionnaires. One hundred tenants and 30 field inspectors were interviewed. The analytical techniques used in the study include stochastic production frontier analysis (SPFA), linear programming (LP), quadratic risk programming, sensitivity analysis, schematic analysis and descriptive statistics. A combination of factors are negatively affect cotton production in the GS. These, among others, are insufficient and untimely finance, centralized decision of area allocation by the scheme management, shortage of machinery and improper implementation of the crop rotation. Cotton marketing constraints include lack of market transparency, marketing monopoly, delayed payments of cotton proceeds, cotton supply instability and cotton quality problems. SPFA results reveal that 48 % of cotton yield variability is due to tenant and scheme management specific factors. 25 % of this variability is due to the tenants' technical inefficiency and 23 % is due to the scheme management's inefficiency. Tenants, scheme management and the LP crop combinations are highly differ from the current crop combination. Moreover, they yield higher income at the tenant and scheme level than current crop combination. Sorghum is riskiest (a high–variance) crop in the scheme followed by groundnut, cotton and wheat. The tenants in the GS behave risk averse way. Ensuring the availability of timely and sufficient credit is the first best way to reduce or eliminate the negative effects on cotton production caused by the tenants, scheme management, government, crop rotation and cotton marketing. Making better use of the existing cultural practices and input levels in the GS can increase the cotton yield substantially. The level of the decision making should be completely decentralized and the tenants should be the chief decision makers concerning resources allocation. The role of the government and the scheme management should be concentrated on the irrigation, credit, marketing systems, extension services and infrastructural development.

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