Crop - Livestock Integration in Sudan
(A case of Gezira Irrigated Scheme)

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SUMMARY

Towards the end of the 1990's a significant decline in the areas sown to various crops and a sharp drop in productivity have been witnessed in Sudan's irrigated agriculture. At the same time feed shortages formed a main constraint on livestock production in the country. Under such a situation integration of fodder production activities within the existing crop rotations in irrigated agriculture seems plausible. Based on an optimization economic model, namely linear programming, this paper aims at investigating such prospects. The objective function in the basic model was to maximize farm returns. The analysis was based on primary data collected in the irrigated Gezira Scheme, generated through a comprehensive field survey in addition to supportive secondary data. The results showed the feasibility of introducing the fodder legume *Dolichos lablab* "*Lubia*" in the rotation for various reasons, such as no fertilizer needs and low demands for water and labour. A number of fodder-introducing scenarios analyses were conducted around the results of the basic model run. All scenarios demonstrated tangible increases in farm returns, indicating that fodder cultivation would be profitable. Farmers' income would be enhanced, either directly through fodder returns or indirectly by raising livestock products. Furthermore, fodder introduction would be conducive to reducing irrigation water requirements. Under the present and suggested changes in resource

availability tomato, sorghum and cotton production would yield superior profitability to that of wheat, groundnut and onions. With the optimal production plan returns were higher than in the present situation by about 24%, while water requirement was 32% less.

INTRODUCTION

Livestock plays an important role in human society and particularly in mixed farming. The animal gives multiple products in return such as meat; milk, eggs, income and fibers, while dung and urine are valuable to fertilize gardens, fields and fish ponds (Schiere and Kater, 2001). Many benefits can be gained from animal integration with other farming system components. For example, manure, which is an important component of livestock production (Harris, 1998), may contribute to as much as 35 % of the soil organic matter (Steinfeld *et al.,* 1996). Farmers throughout semi-arid Africa employ manure for crop

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production, save crop residues for feed, and use animals for cultivation and transport (McIntire et al., 1992). Livestock can also guarantee a daily source of income to the tenant, in addition to his annual income from field crops. Increased livestock production can improve the income position of low-income farmers and women, and in this way reduces malnutrition within this group (Singh, 2001).

In Sudan, livestock contributed almost 50% of the total agricultural sector GDP during the last decade (Sudan Bank, 2006). According to records of the Ministry of Animal Resources (2002), the livestock population has been steadily increasing during period 1997-2000 (Figure 1). From 2002 to 2005, the livestock population remained approximately constant. In 2005, the total animal population reached 131.6 million heads, composed of 38.30 (29.0 %) million heads of cattle, 48.0 (36.50%) million heads of sheep, 42.0 (32.0 %) million heads of goats and 3.30 (2.5%) million heads of camels **(Figure 1).** About 90% of the livestock production in the Sudan is produced under rainfed traditional farming system (Zaroug, 2006).

The most important constraints faced by livestock production in Sudan include technical constraints (e.g. lack of reliable statistics, poor health and genotypes, etc..), marketing constraints (e.g. lack of marketing facilities, improper infrastructure, etc..), financial and investment constraints (e.g. risk of financing the traditional pastoralists, because of endemic diseases, prevailing natural and environmental hazards, etc…), public sector involvement (e.g. impact of the liberalization policy on prices) and institutional constraints (e.g. deficiency in input supply and services, etc..).

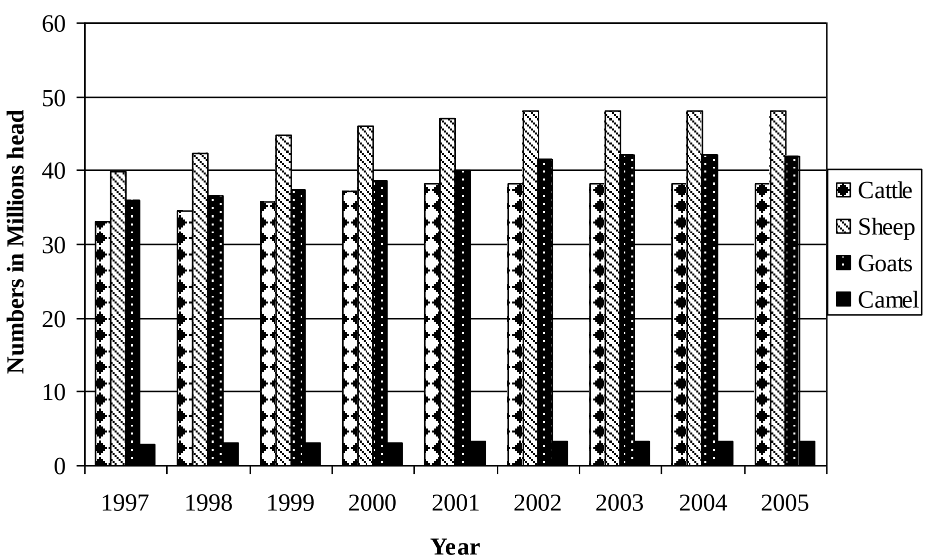

Figure 1: Trends in the livestock population in Sudan 1997/2005
Source: Various sources, Ministry of Animal Resources (2000), Sudan Bank (2001) and FAO (2005).

In general, two main methods of livestock integration have been identified. The first is the situation in which crop and livestock production is combined under the same management (McIntire et al., 1992). The second is a situation in which the herders and crop produces are separate, but involved in an exchange contract based on the exchange of manure for crop residues and grazing with transhumance herders (Williams et al., 1995 and Powell et al., 1996). While the first is referred to as closely integrated farms, the second has been termed segregated integrated farms (Mc Crown et al., 1979).

Irrigated agriculture in Sudan is represented by many governmental Schemes. The Gezira Scheme is the most important one in terms of area, production and scale of management (World Bank, 2003). The call for animal integration within the rotation in the Gezira Scheme is not a new concept. It had been advocated since 1975 when full integration of both crop and animal production in the rotation constituted a major demand in the call for nationalization of the Scheme (Yousif, 1997).

Study Motivation:-

Faced with the liberalization policies and the subsequent liberalized economic atmosphere, which were implemented within the agricultural sector since the early 1990's (World Bank, 2000), farmers in the Gezira Scheme found themselves in a difficult situation, having to abide to a predetermined rotation and crop mix. Countenanced by this situation, many study teams and governmental committees investigated the problems of the Gezira Scheme. All of them urged the need for planning the cropping pattern of the Scheme taking into account the liberalized economic environment and emphasized the introduction of livestock production into the production system. However, although the latter may be favorable to rectify the odd cropping pattern (exclusively plant crop production), it poses additional problems, such as planning the livestock production activities along with the plant crop production activities.

Moreover, livestock had always been highly ignored and treated as a foreign body. It was not incorporated in the management concerns of the Scheme, and all the modifications that took place, were solely concerned with securing cotton production and increasing it's productivity (Yousif, 1997); i.e. in spite of the importance of crop-livestock integration in increasing household welfare, there are no opportunities for introducing livestock activities with crop activities

Objectives and Hypothesis:-

This paper uses an economical model (1) to investigate the prospect of livestock integration in irrigated agriculture in Sudan in terms of fodder and (2) to assess whether and how livestock may best be integrated into the Gezira Scheme's production system.

The specific objectives set to this study are:

- To determine the optimal crop combination including fodder within the current rotation.
- To introduce leguminous fodder crops in the current rotation.
- To satisfy the food and fodder requirements for human and animal consumption respectively and to satisfy the water requirements for food-feed production.

This study hypothesized that:

- Livestock – crop integration has a significant effect on farm profit and farmer's incomes and increases the total efficiency of the agricultural sector.
- Livestock – crop integration reduces the water requirements via the introduction of *labia* legume in the rotation
- Livestock –crop integration satisfies the animal feed requirements, directly increases animal production and indirectly enhances the farmers' income and hence circles out the poor tenants from the poverty sphere.

Research Methodologies:-

The study depends heavily on the primary data drawn from a farm survey conducted during the agricultural season 2001/2002, during the period February-October. Structural questionnaires were distributed among the target groups, which are mainly the Scheme's tenants and a personal interview was conducted.

With regard to sampling, multi-stage stratified random sampling technique was adopted as it gives more precise results because the variation within each stratum is less than the variation in the whole population. Gezira Scheme is comprised from Gezira main and Managil Extension regions.

These two main regions were considered as the basic strata as a first step in the employed procedure. The second step was to randomly select four Blocks from Gezira Main (sub-strata) and four Blocks from Managil Extension. The third step was to select four villages, one randomly selected village from each selected Block.

The sample size for this study is 120 farmers. Of those, 60 farmers were selected from Gezira Main and 60 from Managil Extension, which constituted about 3.2% and 1.3% of the total farmers in the surveyed villages in Gezira Main and Managil Extension, respectively. From each Block 15 farmers were selected randomly.

Data pertaining to crop activities, livestock activities and feeding types and regimes are collected.

Analytical Technique of Data Analysis:-

Linear Programming (LP) has been used to derive optimal farm plans and least cost feed mixes (Doll and Orazem, 1984). To achieve the stated objectives of this study the LP technique was used to determine the optimal plan or course of action for the production of livestock products and plant crops in the Gezira Scheme in a way that maximizes farmer's income and domestic consumption.

Dent *et al.,* (1986) stated that, in general, constraints on the free selection of activity levels can be grouped into six categories: land; labour; capital; husbandry; legal; institutional and marketing constraints; and personal factors. The constraints in the LP model in this study were land, irrigation water, labour, fertilizers, seed, feed and cash requirements. The activities used were the crops and vegetables activities (cotton, wheat, groundnut, sorghum, onions and tomatoes) in addition to the livestock activities (cattle, goats, and sheep). The basic data used for the construction of the matrix are the production capacities, the production activities and the input-output coefficients per cropped area and raised animal unit, in addition to the costs of variable inputs.

The justification of using the LP technique is that there are no clear rational plans for the Scheme with respect to crop rotations and feed supplementation. Additionally, the nutritional situation of livestock producers is characterized by the usage of different kinds of feed stuff, different quantities and levels of costs, for which the derivation of economically optimal levels is important.

Mathematical Statement of the LP Livestock-Crop Model:-

The LP livestock-crop model is written mathematically. The conventional statement of the LP model takes the following form (Boehlje and Eidman, 1984 and Hazell and Norton, 1986):

$$Max\ Z = \sum_{j=1}^{n} CjXi ------------------------------------- (1)$$

Such that:

$$\sum_{j=1}^{n} aij\ Xj \leq bi,\ all\ i = 1\ to\ m ----------------------------------- (2)$$

$$and\ Xj \geq 0\ all\ \ j = 1\ to\ n ------------------------------------ (3)$$

Where:

Z total gross margin.
X*j* level of the j[th] farm activity such as the area grown with field crops, vegetables or fodder or the type of animal held by tenants.
N the number of possible activities.
C*j* the objective value, in this case the forecasted gross margin of a unit of the j[th] activity ($ per feddan[4] or head).
a_{ij} quantity of the i[th] resource (land, water, feed etc…) required to produce one unit of the j[th] activity.
m the number of resources
b_i the available amount of the i[th] resource (feddan of land or days of labour or kg of nutritional value or kg of feed etc….).

The objective is to find the cropping system in the scheme (defined by a set of activities levels X_j, j = 1 to n) that has the highest possible total gross margin, Z, but does not violate any of the fixed resource constraints or involve any negative activity levels.

GAMS for Livestock-Crop Integration:-

The Linear Programming model was analyzed by using the GAMS (General Algebraic Modeling System) Software. GAMS is a software package to solve systems of equations and is constructed by GAMS Development Corporation (Dellink, et al., 2002). GAMS has it's origin in economics modeling. The general structure of a simple GAMS input file for this study contains the following elements:

A. Sets:-

Sets are fundamental building blocks in any GAMS model (Brooke *et al*., 1998). A set is a collection of elements or labels (Gotsch, 1993).

The sets used in the study model include the following:

- *Activities (j) and Inputs (i)*

Activities include the field crop production activities, vegetable production activities, crop and vegetables selling, consumption and buying activities, livestock production, selling and purchasing activities. Inputs correspond to constraints and include land, water,

[4] One Feddan= 0.42 ha. = 1.038 acres

labour, seeds, fertilizer quantities, cash and feed requirements, crops and animal balance[5] .

- *Nutritional values (n) and Feed (f)*

The basic information used in the LP model concerned with animal feed is the nutritional requirement for animals. The quality of various crop residues is determined by the protein content and energy or digestible dry matter (DDM) content (Shanhan *et al*., 2003). Nutritional requirements were defined in the model in terms of dry matter (DM), crude protein (CP), crude fiber (CF), ash, oil, calcium (Ca), phosphorus (P), and metabolism energy (ME). Metabolism energy values are expressed as MJ/kg. Daily dry matter consumed by various animals based on their body weight and animal unit are used.
The feed sets include crops residues, cakes and concentrates feed.

- *Period (t)*

Period illustrates the seasonality of some constraints (water, labour and land) from January to December. The letter (t) denotes the period of time, expressed in months.

B. Parameters:-

The parameters are denoted with C_jX_i (in equation 1) and b_i in equation (2). There is no formal procedure for estimating the parameters and coefficients within the LP approach, which can result in consistency problems (Bauer and Kasnakoglu, 1988). The parameters used in the study model are: Number of animals held by
tenants, number of animals sold, average price per animal sold in SD, price of feed per kg, gross margin of crop, vegetable and livestock activities (C_jX_i in equation 1), amount/level of constraints e.g. land, water, labour and feed (bi in equation 2), the right-hand side for animal balance, feed balance[6], milk balance[7], crop balance and vegetable balance[8] and the amount of nutritional contents per kg of feed, e.g. DM,CP, CF, ash, oil, calcium CA, P and ME.

C. Tables:-

The tables contain data arrays, which correspond to a_{ij} (equation 2), describing the amount of resources (i) required to produce activities (j). Different types of tables were introduced in the model. The first one shows the numbers of animals held by tenants and types of feed used. The second table is related to the technical coefficients used (land, water, seed, fertilizer and cash requirements). The third table pertains to crops and livestock balance.
Three specialized tables for livestock production are constructed to show (1) the monthly nutritional requirements for different animals, (2) the nutritional value of the different feed types and (3) feed characteristics. The other tables describe the seasonality of labour, water and land limits during the surveyed season.

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5 Crop balance means amount of consumption and production of crops. Animal balance means number of animal purchased and sold during surveyed year.

6 Feed balance means difference between amounts of feed produced from filed, amount purchased from market and amount consumed by animal.

7 Milk balance means difference between amount of milk produced and consumed by tenants.

8 Vegetables balance means differences between amount of vegetables selling, consumption and production.

D. Variables:-

The variables to be estimated in the model include the revenue from animal sales, level of crop and livestock activities (j), nutritional requirements for feeding animals and total gross margin (Z, the objective function of the model in equation 1). The model maximizes gross margin, while adopting positive values for activities (j), including x animal (j), x crop (j), x animal sold (j), x feed (j) x animal held (j), x nutritional value (N), where the letter x denotes the name of the activity.

E. Equations:

Equations are a key to specify the types of equations included in the model. For example, resources (i) denote constraints or resources available to produce the corresponding crops yields or animal products. Equations are written through two steps: firstly, the equation must be declared and secondly, the equation itself must be written in the equation definition section. The main written equations to be estimated in the model are the following:

- ***Objective function of crop and livestock production*** (equation 1)
- ***Resources constraint equation*** (equation 2)

Two types of constraints equations were introduced in the model: The first equation estimates the technical coefficients of inputs (available amounts of land, labour, water, seed, fertilizer…etc). The second equation estimates the available amount of feed provided for different species of animal.

- ***Labour balance equation***

The 218 limit is the available amount of labour (mandays) used during the season for the different crops per feddans in the scheme. This limit of labour is introduced in the model to estimate the labour balance[9] equation in the scheme.

- ***Land limit equation***

This equation illustrates the land occupied by different crops in feddan per month during the surveyed season, implying that the crops occupy the land for certain periods during the season and not all a year-round. The total size of tenancy in the scheme is 20 feddans.

- ***Water limit equation***

The annual crop water requirement for the different crops activities in the scheme was introduced in the model. The total water available in the scheme is 27613 m^3.

- ***Nutritional balance equation***

This equation illustrates the nutritional value of feed provided to animals in the scheme throughout the surveyed season.

- ***Returns from animal sold equation***

This equation illustrates the returns gained from cattle (calves, cows and bulls), goats and sheep sold during the surveyed season in the scheme.

Scenarios Analysis Technique:-

A counter-factual analysis is done. Dellink *et al.,* (2002) divided the counter-factual analyses in two types, the scenario analysis and sensitivity analysis. The former tries to answer questions of the type "What happens if one or more elements in the model change", while the sensitivity analysis tries to answer "What is the consequence of miss-specification

9 Labour balance means differences between hired and family labour.

of some parameter values”. In this study some parameter values in the model or equation specifications are changed, the changed model is run and the new results are compared to the reference results.

In a scenarios analysis, several alternative model specifications are compared to each other. These scenarios may differ due to differences in parameter values, but also due to differences in the model equations. In principle, each of the scenarios specified may be equally viable. The input matrix contains activities and consists mainly

of the present, five-course rotation (Cotton-Wheat- Sorghum - Groundnut/Vegetable - Fallow).

Three main scenarios were adopted in the study as follows:

- ***In the first scenario*** vegetables were completely removed from the rotation, as they are risky for tenants.

- ***In the second scenario*** *lubia* (Dolichos lablab) was introduced in the rotation. The *lubia* legume is introduced in the rotation for various reasons. It needs no fertilizer and low amount of water and labour. It is cultivated in the winter season when only wheat and some other vegetables are grown. Moreover, it increases soil fertility and hence adds an additional improvement to the soil for the next crop in the rotation (e.g. cotton) leading to higher cotton productivity.

In the third scenario the *lubia* legume was introduced in vegetable land. Based on the extra vegetables are cultivated in the private farms and neighboring gardens.

A change of technical coefficients (land, water, labour, seeds, fertilizers and cash requirements) are compared between the basic solution and the scenarios.

Furthermore other types of scenario analysis were implemented. A multiple changing of data or bounds in second scenario was implemented to observe the change of optimal solution with the fodder integration.

RESULTS AND DISCUSSIONS

The information obtained from the LP analysis includes the objective function value (returns), optimal crop and animal combination, nutritional value of feed, resources used and their respective marginal productivities.

Cropping Pattern and Optimal Returns:-

From **Table 1** it is clear that for cotton, sorghum and tomatoes there are big differences between the actual land cultivated and the optimal allocation. Wheat, groundnut and onion did not appear in the optimal plan. The optimal land areas for cotton, sorghum and tomatoes are 5.08, 7.57 and 5.29 feddans, respectively. The actual returns from crop production were $ 511.2, while the optimal returns are $826.2, which is 23.6% more than the actual returns.

Resources Use and Seasonal Constraints:-

The total land used in the optimal plan solution is 17.24 feddans, which is 89.7 % of the total land used in the actual scenario **(Table 1).**

Table 1: Optimal crop production plan per tenancy of 20 feddans area

Item	Actual	Optimal	Units
Cropping pattern:			
- Cotton	4	5.08	Feddan
- Wheat	4	-	Feddan
- Sorghum	4	7.57	Feddan
- Groundnut	4	-	Feddan
- Tomatoes	2	5.29	Feddan
- Onions	2	-	Feddan
Resource use:			
- Total land	20	17.24	Feddan
- Total labour	218	218	Mandays
- Total water	36766.3	24183.7	M^3
- Seed	62.55	34.67	Kg
- Fertilizer	650	650	Kg
- Cash 1	60	38.91	$
- Cash 2	55	33.82	$
- Cash 3	55	44.00	$
- Cash 4	75	54.81	$
Returns: Objective function value	511.2	826.2	$

Source: Model results, 2001/2002.

Seasonality is a major determinant of comparative advantage in most agricultural systems (Gotsch, 1993). Hazell and Notron (1986) stated that, introducing seasonality in the model would further restrict the model solution and will likely lead to lower values of the objective function. It is clear that in the optimal plan all labour available (218 mandays) was used. There are two peaks of labour. The first peak is during July and August, when land preparation, sowing and weeding needs to be done. The second peak is from December to February,

which coincides with the harvesting period for sorghum, groundnut and first and second periods of cotton picking.

The water use dropped from 36766.3 m^3 (in the actual solution) to 24183.4 m^3 (in the optimal solution). This means that because of introducing the fodder crop in the rotation the water requirement

decreased by 32%. The peaks of water used are during July, September and October, coinciding with the sowing of most of cotton, sorghum, groundnut and summer tomatoes.

Optimal Livestock Production:-

The optimal composition of the cattle herd is 2.4 heifers, 1.2 bulls, 1.2 mature cows and 3.3 calves **(Table 2).** The optimal structure of the sheep herd is 0.06 ewes, 0.01 rams and 0.031 lambs, while that of the goat herd is 0.06 does, 0.04 bucks and 0.96 kids. The optimal number of milking animals was 7.3 milking cows and 0.2 milking sheep.

Many lambs sold during the surveyed season, due to the occasion of the various ceremonies. Most of the tenants who owned sheep during the surveyed season had

purchased them for resale after fattening. But the optimal solution indicates that the optimal numbers of sheep sold was 1.0 sheep per tenant. While the optimal numbers of cows, calves and goats are 1.0 cow, 1.0 calve, and 1.0 goat per tenant;
respectively. The optimal total animal unit (AU) held per tenant was 26.07 AU **(Table 2).** The LP result shows that, the optimal value from animal sales was $1162.7.

Optimal Feed Mix and Nutritional Value-

The model results show that the optimal level of feed mix used were 207 kg of sorghum stalks and 850 kg of cakes feed and 1299 kg of fresh fodder per month per herd **(Table 3).** Comparing the model results with the actual feed quantity and quality, the maximum number of animals that can be raised on the optimal level of feed can be determined.

All nutritional ingredients appeared in the basic solution, expect for phosphorus. The optimal dry matter and crude fiber were more than the other ingredients, which is due to the high quantities of groundnut hay in the ration **(Table 3).** Even though the groundnut crop disappearance from the optimal solution the tenants fill gap of groundnut hay feed from the market. In the scheme majority of the tenants are failure to harvest the groundnut seeds and they harvest only the groundnut residue (hay). Beside the cheaper cost of the groundnut

Table 2: Optimal solution of livestock level held by tenant.

Animal composition	Actual level in head	Optimal level in head
A) Cattle		
Heifers	3.5	2.4
Bulls	2	1.2
Mature cows	1.7	1.2
Calves	2.8	3.3
Milking cows	7	7.3
Cows sold	2.0	1.0
Calves sold	2.8	1.0
Subtotal in AUA*	21.8 X 1.0 AU= 21.8 AU	17.4 X1.0 AU = 17.4 AU
B) Sheep		
Milking sheep	16	0.2
Ewes	14	0. 6
Rams	2.7	0. 1
Lambs	11.6	0. 31
Sheep sold	6.8	1.0
Subtotal in AU	51.1 X 0.15 AU = 7.7 AU	1.2 X 0.15 AU = 0.18 AU
C) Goats		
Milking goats	23	0.3
Does	13.5	0. 6
Bucks	5.4	0. 4
Kids	9.2	0.9
Goats sold	6.2	1.0

Subtotal in AU	57.3 X 0.10 AU= 3.73 AU	2.2 X 0.10 AU=0.22 AU
D) Transportation animal Female donkey Male donkey Horses	1.5 1.4 1.0	2.8 2.5 1.5
Subtotal in AU	2.9X 1.05 AU+1.0X 1.80 AU = 4.05 AU	5.3X 1.05AU+1.5 X 1.80 AU = 8.27 AU
D) Total in AU	**37.28 AU**	**26.07 AU**

*Source: Model results, 2001/2002. *AU = Animal unit.*

hay the Scheme tenants prefer to feed their animal with extra groundnut hay and believe that it's more beneficial for animal in contrast with other types of feed.

Table 3: Optimal solution of the nutritional balance and feed used by tenants in optimal plan.

Feed type	**Optimal level in kg per month per herd**	**Nutrient value**	**Optimal**	**Unit**
Sorghum stalks	207	DM	970	MJ/kg
Sorghum grain	-	CP	56.700	G/kg
Groundnut hay	-	CF	642.200	G/kg
Wheat straw	-	Ash	63.200	G/kg
Wheat bran	-	CA	5.400	G/kg
Concentrates	-	P	-	G/kg
Cakes feed	850	Oil	26.600	G/kg
Fresh fodder	1299	ME	7.23	G/kg

Source: Model results, 2001/2002.

Marginal Productivities of the Activities and Constraints:

The Marginal Value Product (MVP) of a resource is its shadow price. For farm situation, MVPs indicate the increase in the objective function value that would be obtained if a particular resource is expanded by one unit. A negative value of marginal productivity indicates a reduction in the objective function if an additional unit of resource is introduced.

From **Table 4,** it is clear that labour has the highest marginal value productivity; reaching $ 1.432 per season, explaining why tenants are always giving it more care. The marginal value product of feed varied from $ 0.06 to $ 0.36 **(Table 4).** The optimal returns reduced by $ -32.45 when an additional feddan of land was cultivated by groundnut (Table 4).

Scenarios Result:-

- ***In the first scenario*** the result shows that the optimal returns were $ 675.688, which is 10 % less than the basic solution, while the optimal land was increased by 8%. Water and labour used were remained as the same as in the basic solution. Wheat and groundnut disappeared from the optimal solution **(Table 5).** The optimal crop combination in this scenario was 10 feddans of cotton and 10 feddans of sorghum **(Table 6).**

Table 4: Shadow prices for limiting resources.

Resources	Shadow price in $
Wheat land	-0.00583
Groundnut land	-32.4562
Onions land	-0.01395
Labour	1.432
Fertilizer	0.580216
Cash 3	0.00474
Sorghum consumption	0.004
Cakes feed	0.1018
Sorghum stalks	0.36
Concentrates	0.36
Sorghum grain	0.16
Wheat straw	0.16
Wheat bran	0.16
Fresh fodder	0.06

Source: Model results, 2001/2002.

Table 5: Comparative Analysis between Basic Solution and Various Scenarios**.**

Optimal resource used	Basic solution	Scenario I	Scenario II	Scenario III
Total land (feddan)	17.24	20	12.69	13.23
Total water (M^3)	24183.73	24130.0	12421.21	12241.30
Total labour (Mandays)	218	218.50	97.12	99.86
Fertilizer (Kg)	650	441.28	45.93	18.66
Returns:				
Objective function value ($)	826.19	675.68	1179.67	1161.64

Source: Computed [10].

- ***In the second scenario*** the optimal return was found to be $1179.67 **(Table 5),** which is 17.6% more than the basic solution. Land, water and labour used were reduced by 15%, 32% and 38%; respectively. The optimal crop combination in this scenario was 0.306 feddans of tomatoes and 12.38 feddans of lubia legume (Table 6). Husson *et al.,* (2003) stated that when introduced the livestock- crop in the rotation the whole farming system benefits from this integration, food (Omolehin *et al.,* 2003) and feed systems performances are increased, while use of the farm resources are optimized.

Furthermore, Fakoya (2007) verified that utilization of crop-livestock was enhanced income through sales, sustain food production and enhancing soil fertility (Hoffmann, 2002) and help to exploiting the by products and residues from crop.

Table 6: Optimal crop combination for the various scenarios.

Item	**First scenario**	**Second scenario**	**Third scenario**
Cotton	10 feddans	-	0.93 feddans
Wheat	-	-	-
Sorghum	10 feddans	-	-
Groundnut	-	-	-
Onions	-	-	-
Tomatoes	-	0.306 feddans	-
Lubia	-	12.3 feddans	12.3 feddans

Source: Computed[10].

- ***In the third scenario*** the optimal return was found to be $ 1161.64 which is 16.8% more than the basic solution **(Table 5).** The optimal crop combination for this scenario was 0.93 feddans of cotton and 12.3 feddans of *lubia* **(Table 6).** Land, water and labour used were reduced by 13%, 33% and 37%, respectively.

From this scenario analysis it is clear that the introduction of fodder in the rotation increases farm returns and reduces water requirements. This result agreed with study performed by Abdelmagid in 1986 in the mechanized irrigated Scheme in Sudan.

The second scenario was used as the basic solution for the other types of scenarios analysis because in second scenario the fodder were introduced in the rotation and the objective value was more than two other scenarios.

First Scenario with Fodder Integration (SF_1): The gross margins of cotton, wheat, sorghum, groundnut and onions were increased by 25% subject to the potential of higher yields with improved technology use as well as the possibility of subsidy provision to inputs, which matches WTO concessions to Least Developed Countries (WTO, 1995) .The optimal solution was found to be 10.95 feddans of sorghum, 2.87 feddans of tomatoes and 4.51 feddans of *lubia*. Land utilization was increased by 10%. The optimal return was $ 1197.17 **(Table 7).**

[10] The optimal crop combination in first scenario was 10 feddans of cotton and 10 feddans of sorghum (no fodder introduced in this scenario). Introduction of *lubia* in second and third scenarios shows the profitability of this fodder.

Second Scenario with Fodder Integration (SF_2): Based on the fact that tenants face marketing problems with *lubia* and tomatoes in the scheme, gross margins of these two crops were reduced by 25%, while those of cotton, wheat, sorghum, groundnut and onions were increased by 25%. The optimal solution was found to be 1.95, 11.98, 2.47 and 3.59 feddans of cotton, sorghum, tomatoes and *lubia*; respectively. The optimal resources used were 19.99 feddans of land, 26939 m^3 of water and 221 mandays of labour. The optimal return was $ 1012.86 **(Table 7).**

Third Scenario with Fodder Integration (SF_3): Wheat is currently grown by farmers and in areas where productivity potential is high and its profitability is reasonable. Accordingly, the gross margin of wheat was increased by 75% and that of *lubia* was decreased by 25% where wheat straw and wheat bran form partial substitutes to *lubia*. The optimal solution was found to be 2.0 feddans of cotton, 2.0 feddans of wheat, 4.20 feddans of sorghum, 3.21 feddans of tomatoes and 5.52 feddans of *lubia*. The optimal resources used were 16.89 feddans of land, 25846 m^3 of water and 213 mandays of labour. The optimal return was $ 1132.30 **(Table 7).**

Fourth Scenario with Fodder Integration (SF_4): The wheat crop was totally removed from the rotation because of risks of high temperatures and its low returns. The optimal solution was found to be 0.30 and 12.4 feddans of tomatoes and *lubia*, respectively. The optimal resources used were 12.6 feddans of land, 12421m^3 of water and 97.13 mandays of labour. The optimal return was $ 179.67 **(Table 7).**

Table 7: Optimal crop combination of the various scenarios analysis under the situation of the fodder integration.

Item	**Basic Solution (Second scenario)**	**SF_1**	**SF_2**	**SF_3**	**SF_4**	**SF_5**	**SF_6**
Cotton (in feddan.)	-	-	1.95	2.0	-	-	10
Wheat (in feddan)	-	-	-	2.0	-	-	-
Sorghum (in feddan)	-	10.95	11.98	4.20	-	3.9	-
Groundnut (in feddan)	-	-	-	-	-	-	-
Onions l (in feddan)	-	-	-	-	-	-	-
Tomatoes (in feddan)	0.306	2.87	2.47	3.21	0.30	3.8	4.2
Lubia (in feddan)	12.38	4.51	3.59	5.52	12.4	6.4	8.6
Resources use:							
Land (in fedda)	12.69	18.33	19.99	16.89	12.6	14.10	13.8
Water (in M^3)	12421.21	26091	26939	25846	12421	25221	26434
Labour(in man days)	97.12	205.95	221	213	97.13	201	218
Objective Function ($)	1179.67	1197.17	1012.86	1132.30	1179.67	1121.84	1261.65

Source: Computed11.

[11] The farm return was increased in SF_1 and remains unchanged in SF_4. *Lubia* legume was appeared in all *lubia* scenarios while it reached it highest level in SF_4. Reduction in water use in all *lubia* scenarios were notes in comparison with the basic solution, while land allocation was increased comparing with the basic solution.

Fifth Scenario with Fodder Integration (SF_5): The total labour available was increased by 25%. This is based on the labour deficits faced by the scheme due to successive migration from rural to urban areas. Therefore the optimal solution was found to be 3.9 feddans of sorghum, 3.8 feddans of tomatoes and 6.4 feddans of *lubia*. The optimal resources used were 14.10 feddans of land, 25221 m^3 of water and 201 mandays of labour. The optimal return was $ 1121.84 **(Table 7).**

Sixth Scenario with Fodder Integration (SF_6): Under the possibility that financial facilities could improve through credit provision for agricultural practices, the available cash was increased by 25%. The optimal solution was found to be 1.0 feddan of cotton, 4.2 feddans of

tomatoes and 8.6 feddans of *lubia*. The optimal resources used were 13.8 feddans of land, 26434.51 m^3 of water and 218 mandays of labour. The optimal return was $ 1261.65 (Table 7).

Conclusions and Policy Implications:-

- Although wheat and groundnut represented 50% of the total cultivated land in the present rotation, they have almost disappeared from the rotation in the optimal production plan. This indicates that they were unprofitable. Tomatoes and cotton areas were increased by 11% in the basic solution, while sorghum increased by 31%. This was due to large areas cultivated with hybrid sorghum crop in the sampled area. The total land size decreased from 20 feddans to 17.4 feddans. Cotton, tomatoes and sorghum under the present system in the Gezira Scheme were comparatively most profitable. For cotton crop the scheme management usually finances this crop during various stages of production (as cash crop) furthermore, the sorghum is cultivated in this area are hybrid type (high productivity crop) and also tenants prefer to cultivated sorghum crop because its the main food staff of the tenants in the Scheme. The total farm returns in the optimal solution is high than the actual situation by 23.6%.
- No significant increase were recorded in the number of milking cows in the optimal solution (7.3 cows), while the number of milking sheep was reduced from 16 to 0.2 heads and the milking goats were reduced from 23 to 0.3 heads. The ruminant animals in the Scheme are highly ignorable, lacking of the veterinary services and feed is the main factor affecting the milk yield of those animal.
- Sorghum grain, wheat straw, wheat bran and concentrates disappeared from the optimal plan. The percentage of crude fiber was higher than the other components of the different ingredients. This because of the high content of groundnut hay in the rations. Phosphorus also disappeared from the optimal solution. From this result the study concluded that there are feed insufficiency for animals in the Scheme, particularly the milking animals and no economic feed were cultivated in the scheme.
- When introducing the irrigated fodder crop in the Scheme rotation the farm return is increased and resources use was reduced.
- The Gezira Scheme management still appears to accord much higher priority to crop production than livestock production.

- Cotton and tomatoes crops are linked to fodder crop. When fodder integrated in the rotation these two crops are appeared in the optimal solution and lead to enhance the farm returns and reduction in the inputs resources (e.g. water, labour and land). Further more when no fodder integrated in the rotation reasoned for low farm returns.

Suggestions and recommendations based on the results and analysis of this study can be summarized as follows:

- Effort should be made by appropriate government institutions to sensitize livestock integration to be applied in all irrigation schemes in the Sudan on account of its multi-dimensional benefits.
- Fodder crops must be quickly incorporated into the farm structure of those tenants who have dairy animals to avoid farmer-pastoral conflicts. Such conflicts can only be avoided if the linkage between the two systems is well understood and accepted.
- A cropping pattern that incorporates a combination of two feddans of cotton, 12 feddans of sorghum, 2.5 feddans of groundnut or vegetables and 3.5 feddans of fodder should be promoted.

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ملخص البحث:

شهدت الفترة الأخيرة في التسعينيات انخفاضاً ملحوظاً في المساحات المزروعة والإنتاجية للمحاصيل المختلفة في المشاريع المروية في السودان وفى نفس الوقت شكل نقص غذاء الحيوان عائقا رئيسياً للمنتجات الحيوانية في القطر وفي ظل هذه الظروف يعتبر إدخال إنتاج الأعلاف مع الدورة المحصولية الحالية في الزراعة المروية أمراً في غاية الأهمية . وبناءاً علي تعظيم النموذج الاقتصادي (البرمجة الخطية) تهدف هذه الورقة إلي اختبار هذه التقنية. وتهدف دالة الهدف في ذلك النموذج إلي تعظيم إيرادات المزرعة. اعتمد التحليل علي جمع البيانات الأولية باستخدام المسح الميداني الشامل في مشروع الجزيرة المروي بالإضافة إلي البيانات الثانوية.

وقد أظهرت النتائج إمكانية إدخال الأعلاف البقولية (اللوبيا) في الدورة الزراعية لعدة مواسم لأنها لا تحتاج لسماد وقليل من الماء والعمالة . عدد من السيناريوهات لإدخال الأعلاف طبق حول النموذج الأصلي . وقد أوضحت كل السيناريوهات زيادة ملموسة في إيرادات المزرعة وهذا يدل علي أن زراعة الأعلاف مربحة للمزارع مباشرة من إيرادات الأعلاف أو بطريقة غير مباشرة بواسطة المنتجات الحيوانية. كما يؤدي إدخال الأعلاف إلي نقصان مياه الري . وفي ظل هذه التغيرات نجد أن التركيبة المحصولية المختلفة (الطماطم، الذرة والقطن) مربحة ما عدا القمح والفول السوداني. وقد أدي استخدام التركيبة المحصولية الجديدة إلي زيادة الإيرادات بـــ 24% ونقصان متطلبات المياه بــ32%.