Journal of Scientific Research & Reports
3(16): 2118-2130, 2014; Article no. JSRR.2014.16.001

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Optimization of Irrigation Water Utilization for Agricultural Production

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Authors' contributions

This work was carried out in collaboration between both authors. Author EAA designed the study, wrote the protocol. Author HHMF managed the final formatting of the study. Both authors read and approved the final manuscript.

Original Research Article

Received 9th March 2014
Accepted 7th May 2014
Published 5th July 2014

ABSTRACT

Optimization of scarce resources use is critical in agriculture production of Sudan. Since resources are economical inputs, the aim should be when optimizing resources use to obtain maximum production per unit. In Sudan, the tenants have compiled numerous crops in order to maximize production in an attempt to improve home food security and income. The field crops in North Sudan are commonly produced under pump irrigation from the River Nile. Production of these crops in the district faces numerous constraints, including inefficiency of water use, low level of productivity and high cost of production. This research aims to optimize the use of available irrigation water in food (i.e. wheat) and cash crops (i.e. faba bean). Primary data were collected by using structured questionnaires randomly. General Algebraic Modeling System (GAMS) by applying linear programming technique was used to assess the optimal combination of irrigation waterand other essential agricultural resources in field crops under study. The model revealed that tenants would get higher yield and returns by optimizing irrigation water and other resources use in food and cash crops production.Governments can seek to develop and stretching the modern irrigation systems for better management of water supply. Dissemination of irrigation water knowledge among the State farmers is needed to ensure the technical and economic irrigation water productivity as a tangible contribution to farm investment, returns, and food production.

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Keywords: Optimization of Irrigation water; yield improvement.

1. INTRODUCTION

Agricultural resources mainly water and land constitute the most important factors of agricultural production. Climate change, water supply limits, and continued population growth have intensified the search for measures to conserve water in irrigated agriculture, the world's largest water user. Policy measures that encourage adoption of water-conserving irrigation technologies are widely believed to make more water available for cities and the environment [1]. Sudan is rich agricultural resources that if properly managed can generate sufficient food for the region. Water from the River Nile and its tributaries as well as a from a network of numerous seasonal rivers and water courses, underground sources and impressive rainfall in the center and south enable cropping and herding at varying degrees. Of a total arable area of about 85 million ha, only 20% is currently under cultivation but with inter-seasonal variation [2]. Under the country's high dependence on crops and livestock for livelihoods, availability of and access to natural resources is paramount [3]. In North Sudan, their scarcity and importance rose due numerous resons such population pressure on land when compared to the rest of the country. The potential of irrigation for raising both food production and living standards of the rural poor has since long been recognized. Generally, a third of the current field crops production comes from the one-sixth of irrigated arable land. This reflects the improved reliability of crop production and the greater intensity of land-use follow in the removal of seasonal water supply constants. This paper focuses on the problem of how to balance demand and supply of irrigation water under these conditions. Thus the route lies in optimization of irrigation water utilization.

In Sudan, and some of the developing countries, the trend of the farmers towards diverse crop combination is a dominant practice as means of increasing efficiency of resources. This behavior might be earned by experience to avoid agricultural risk, such as pests and unfavorable climatic conditions (e.i. high temperature, low moisture and others). Many studies mentioned that the RNS has been assumed to have a comparative advantage with field cash and food crops production namely, wheat, faba bean, chick pea, dry bean, onion, vegetables, spices, sorghum, maize, potato and fodder beside some perennial crops.

All the mentioned field crops are grown in both private and public irrigated schemes of the state, but the public ones are regarded the main suppliers for these crops according to its areas and the highly number of tenants [4]. The production in the public schemes is based on payment of fixed water charges. The paper undertook Elzeidab public irrigated scheme as a case study to implement the study. The farm management is fully under the tenants' control, while the government is considered as a water seller besides the preparing for agricultural policies. Although, the research work is important to assess and recommend for the ideal crop combination, but in RNS a limited research has been conducted to establish resources combination level that maximize the tenants net returns [5]. North Sudan witnessed in the last three decades numerous of research work, they carried out through many organization programs such as International Center for Agricultural Research in the Dry Area (ICARDA) and International Fund for Agricultural Development (IFAD) with collaboration with Agricultural Research and Corporation (ARC), but the majority of their studies stressed on cereal and legume crops as pure stands and they provided information on production, productivity, breeding improvement, agronomy, microbiology, crop protection, technology transfer and others, but not on the cereal-legume combination particularly for winter season which is the main season in North Sudan. However, the optimum resource levels in the crop combinations that maximize the tenant' profits have not been adequately assessed. According to this fact, this study aimed to determine the optimal levels of farm resource combination namely, water, land, labor and capital, that might guide the tenants of the RNS as general and particularly the tenants of the public irrigated schemes of the State to make rational economic decision regarding efficient reallocation of the limited resources.

2. METHODOLOGY

This study was carried in Elzeidab public irrigated scheme of North Sudan. The crops are commonly produced under pump irrigation from the River Nile to some extend as well as from underground water. The farming system in North Sudan is characterized mainly as not full-mechanized system, the winter season is considered the main season for producing cereal and legume crops, recently, the State enlarged animal production activities and oil crops [5]. The study depend mainly on primary data which was collected by using structured questionnaires for seventy randomly selected respondents through probability proportional method from Elzeidab scheme public irrigated scheme as a case study. The sample size was determined according to the desired level of precision and availability of resources in terms of cost, time and other relevant facilities. Stratified random sampling proportional to size was used. Integrated analytical techniques comprising descriptive statistics, and linear programming (LP) are used to illustrate the potentiality and feasibility of field crops in area of the study. There are a number of tools that can be used to optimize resources use of which is Linear Programming technique (LP) through the General Algebraic Modeling System (GAMS) program was used to assess the optimally combining resources in prennial crops. LP is a mathematical technique for finding the best uses of a firm's limited resources as well as to get the best solutions to a problem involving limited resources. In this study, LP technique was used to achieve the optimal solution for field crops in the crop combination of the scheme farming system [5]. Reported that, from the collected data, the average farm resources, yield and gross margins by feddan were computed and entered in the General Algebraic Modeling System (GAMS) software program for optimization analysis. The model was specified with gross margins maximization as the objective function as:

$$\text{Max } Z = \sum_{j=1} Cj\,Xj \tag{1}$$

Such that:

$$\sum \alpha ij Xj \le bi, \text{all} = \overset{n}{\underset{j=1}{1}} \text{ to } m \tag{2}$$

And:

$$Xj \ge 0, \text{all } j = 1 \text{ to } n \tag{3}$$

Where:

- Z = Objective function value.
- Xj = Level of the jth the farm activity, such as the acreage of wheat grown. Let n denote the number of possible activities; the j=1 to n.
- Cj = Objective value, in this case the forecasted feddan) gross margin of a unit of the jth activity (SDD per feddan)
- Aij = Quantity of the ith resource available (i.e., days of labour or other required quantities of inputs) required to produce one unit of the jth activity

M = Denote the number of resources; then i= 1 to m
Bi = Amount of the i^{th} resource available (e.g. cubic meter of water, feddan of and, days of labour or other required quantities of inputs).

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

Equation (1) is the objective function, which maximizes the gross margins from one feddan of field crops. Equation (2) shows the limits on the levels of the available resources (i.e., cubic meter of water, feddan of land, days of labour or other required quantities of inputs) that tenant can apply to produce the mentioned crops. Equation (3) which is a non-negativity condition, states that all resources used in the production process and output must be equal to or greater than zero, meaning that negative use of resources and negative of production is impossible. The coefficients represent the average requirement of the i^{th} activity (enterprise), calculated on per feddan basis. The calculation of the crop water requirements (CWR) of any crop requires estimation of its crop coefficient (Kc). Kc values could be used for estimation of CWR as a product of Kc * ETo in different regions of Sudan. Pen-man equation (1948) for calculating evapotranspiration from free water surfaces was used in the calculation of crop factors (CF) by many scientists over the world. They were able to determine the CF of most filed and perennial crops in the world. Recently, FAO Penman-Monteith (PM) method was developed to estimate ETo values from a hypothetical reference crop that were more consistent with the actual CWR and has been recommended by FAO as the standard method for CWR calculation [5]. The reference crop evapotranspiration ETo was calculated from the daily whether data specifically the maximum and minimum temperature, relative humidity, wind speed at 2m height and sunshine duration by using Crop Wat4 windows program according to the recommended Penman- Monteith formula as follow:

$$ETo = C\ (WR_n + (1- W)\ f(u)\ (ea\text{-}ed)$$

Where:

W	=	weighting factors	R_n	=	net radiation
ea	=	saturation pressure	ed	=	perfumed water
f(u)	=	function in wind speed	C	=	error factor

3. RESULTS

3.1 Main Field Crops Production

Field crops in North Sudan are known by their satisfied profit. Unfortunately, the limitation of land, water, labor and capital affectachievement of decent benefits. Farmers' plotsor farms are averaged about 4.2 ha of area for cultivating field crops (see Fig. 1) as well as perennial crops. From Fig. 1, most of the land (48%) is allocated to cereals (wheat, sorghum and some maize) followed by legumes (faba bean, chickpea and dry beans) (22%). A diversity of vegetables, spices and fodder occupy small areas.

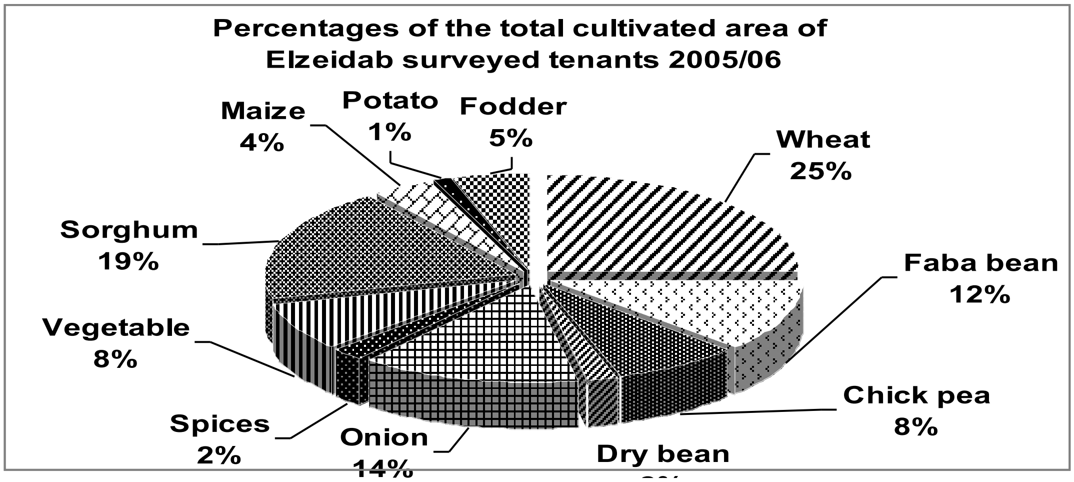

Fig. 1. Allocation of Total Cultivated Area to Different Crops in the Scheme

In northern Sudan, there are mainly two distinct seasons, winter season (October to March), and summer season (May to September). The majority of these crops are cultivated as winter crops with exceptional cases for some crops that could be produced in seasons, namely maize, fodder, and vegetables. Furthermore, the sorghum crop is usually sown at the end of the summer season (September) to be harvested at the middle of the winter season (January). The harvested crops are used either for domestic consumption and/or as cash crops as shown in Fig. 1. From Fig. 1 the distribution of field crops in 2006 was such that 25% of the total land was devoted to wheat, followed by 19% for sorghum and 14% for onion, while the lowest percentage (1%) was allocated to potato. The other crops were ranked as 2%, 2%, 4%, 5%, 8%, 8%, and 12% occupied by spices, dry bean, maize, fodder, vegetables, chick pea, and faba bean, respectively.

Although most of the crops grown in the State are mostly highly profitable, limitations on land, water, labour and capital hinder attainment of adequate benefits. Most of the land (48%) is allocated to cereals followed by legumes (22%). A diversity of vegetables, spices and fodder crops occupy small areas. Crop yields were much lower than research yields. Yield gaps of 47% and 81% were derived for dry beans and vegetables, respectively, indicating high potential to boost yields [6]. According to [7], every 10% increase in crop yield reduces the number of income-poor by an average 7.2% in Sub-Saharan Africa.

Variables cost of production play a unique role in producing annual crops where material-input costs largely influence earned profits [8]. The survey focused on 15 components constitutes most of the production cost. The majority of respondents suffered of high cost of production due to high prices of production inputs. The research revealed the Irrigation water resource is considered as the single most expensive component due to the high cost of water pumping from the River Nile (RN). However, sampled farmers invariably over-irrigated their field crops, with crop water requirements exceeded annually by 60%. This result reflects high potential for irrigation water use once effective water-use is applied [6]. Stated that labour is also an important resource, but tenants tended to avoid using hired labour to reduce production costs. On average, tenants employed two family members; however (for example), 10 and 34 work-days of hired labours are recruited for chickpea and potato production, respectively. After land, water and labour, the fourth pillar of production is capital.

The formal financial system provides only a small part of the credit used by farmers and 93% of the surveyed tenants depended on their own resources, while informal sources such as village merchants contributed only 2.8%.

3.2 Cost of Field Crops Production in the Scheme

Production economics play a unique role in farm management [8]. The dominant conception of production cost in the area of study is known as the cost of material inputs, labor force, services, and the management used in producing a certain goods or/and crops. Many studies showed that the cost of production overall the North Sudan has leaded to the low profit. The high cost of production attributed to high cost of numerous of production inputs, but absolutely, the irrigation water cost is considered as the most agricultural constraint and that might refer to the high cost pumping water from the River Nile and this is justified strict allocation among the different crops grown. The coming elaboration of the survey results in Fig. 2 discerned the cost items as the sequence of the seasonal crop production operations.

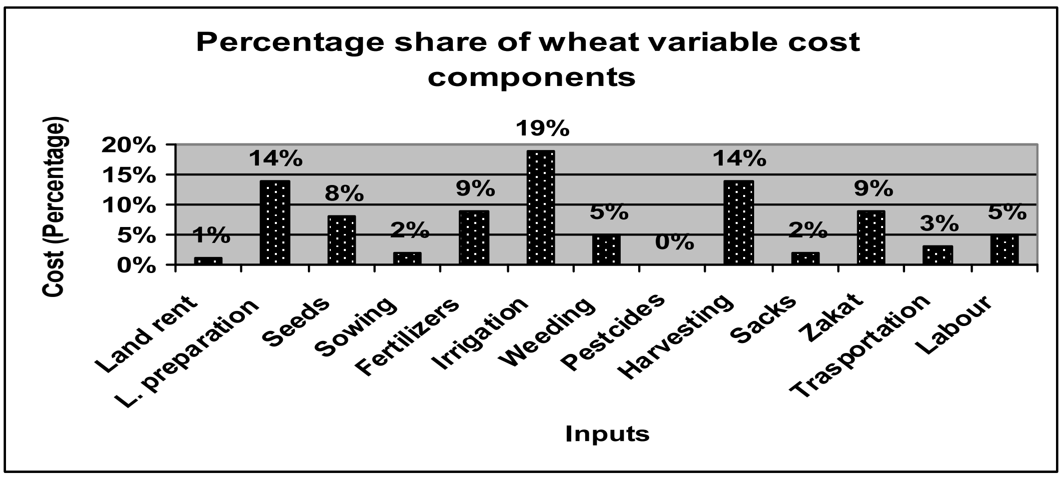

Fig. 2. Percentages share of variable cost components for field crops of the scheme

The paper detected that mainly about 13 cost components as mentioned in the earlier figure; they constitute the cost of production and they accounted SDD 70054.2 equal about US $ 300. Irrigation cost component achieved the highest cost item as 19% of total production cost. The wheat growers in Elzeidab scheme pay the cost of this item as a fixed rate for the scheme administration at the end of the season. The research also revealed that the average variable cost of potatoes was the highest one at 167800 SDD/fed, followed by vegetables and onion at 156271 and 121212 SDD/fed, respectively, while Abu70 forage was found to be 30200 SDD/fed as the lowest average cost.

3.3 Food Crops Productivity in the Scheme

The profitability of adopting new irrigation technologies depends on the level of productivity improvement [9]. The crop combination adopted by the scheme's tenants as well as the average area distribution of the mentioned crops is shown by Table 1 [5]. Mentioned that crop yields achieved by Elzeidab surveyed tenants were generally low when compared by research yields reported by the Agricultural Research Corporation (ARC). Yield gaps of 47%

and 81% apply for dry bean and vegetable crops, respectively, indicated that much potential gap exists to increase the scheme's yields of all field crops except for spices due to lack of information.

Table 1. Area, yield and production of crops of tenants compared to ARC yields

Crops	Area (fed)	Yield (kg/fed)	Production (kg)	ARC yield (kg/fed)	Yield Gap %
Wheat	3.67	676	2481	2000	66
Faba bean	3.73	489	1823	1500	67
Chick pea	0.85	414	352	1250	67
Dry bean	2	54	1080	12000	55
Onions	2.12	2880	6106	1200	76
Spices	3	63	1890	Na	Na
Vegetables	2.6	1853	481	10000	81
Sorghum	5.57	1005	56	1700	41
Maize	2.2	855	1881	1700	50
Potato	1	4000	4000	10000	60
Fodder	6	4000	24000	2000	80

Source: field survey 2006, ARTC and MAS report for Investment Book 2006

3.4 Contribution of Field Crops to Tenants Food Security

Since food security is a multi-dimensional issue, food security policy should include specific measures to promote food security at different stages of the food chain, i.e. production, marketing and consumption [10]. Agriculture provides employment and livelihood to about 65 % of the labor force and their families. Thanks to its huge natural resources, favorable climatic conditions and experienced labor, Sudan enjoys self-sufficiency in most basic food items. Beside traded items, Sudan enjoys self-sufficiency in most basic food items. Beside traded items, Sudanese agriculture furnishes a wealth of non-trade functions, which have many valuable uses and deserve to be maintained and further developed Those functions include climatic, social and cultural aspects as well as employment and food security [11]. Field crops, especially wheat, sorghum, food legumes and vegetables are generally considered the main sources of food crops. Moreover, they play an important role in sustaining the production of the farming systems. Decisions on marketable surplus quantities and the timing of their sale depend on the type of crop. Given limited infrastructure, this leads to high levels of sales immediately after harvest; however, some is withheld for disposal over the rest of the year. 88% of the produce was sold (83% immediately after harvest and 17% for future sales), with the remaining 12% going to storage. About 32% of the stored quantities were for next season's seeds and 68% for household consumption[6]. Of individual crops, grains and legumes are partly sold after harvest and partly stored, while vegetables, spices and potatoes are sold immediately due to lack of appropriate storage infrastructure and inadequate markets as illustrated in Table 2.

Table 2. Distribution of annual crop quantities

Crop distribution	Sale (88%)		Storage (12%)	
Disposal crop Quantities	After harvest sale (83%)	Future sale (17%)	Seeds of next season (32%)	H.H consumption (68%)

Source: Field survey, 2006

Many research mentioned multi sources of income is important for farm sustainability. Integrating trees and shrubs with the other enterprises on a farm can create additional sources of income, spread farm labor throughout the year, and increase the productivity of the other enterprises, while protecting soil, water, and wildlife [12]. While [6] reported that the main off-farm sources in the area are remittances and contributions of family members, formal employment, trade, and other off-farm private activities. About 37% of the tenants earned off-farm income beside their farm income, while 63% relied only on farm returns. Most of the farm income accrues from perennial crops (78%). The majority of tenants (63%) diversified by growing several crops at one time, often having both livestock and annual crops, and sometimes value-adding enterprises. Enterprise diversification makes it easier for households to be more self-sufficient in terms of nutrition, livestock feed, soil organic matter and energy.

3.5 North SudanModel for Optimizing Food Crops Production

Water indeed a precious commodity; it needs to be quantified by drops. Water saving can add the prosperity to life. It can style mentally as well as physically. With the developing world, it is needed to plan for the optimum use of water and ensure its supply on the basis of demand [13].

[14] stated that the integrated modelling approach was useful for linking biophysical and socio-economic factors influencing decision making on small-holder farms and evaluating trade-offs for resource use in terms of nutrient balances, labour use, food sufficiency and cash balance. The agricultural resources that endowed North Sudan tenants are promising in term of investing in field and perennial farms as well as in animal breeding. Effective use of these resources might improve the farm system and livelihood of people in the country. [10] stated that Adoption of policies and actions is needed for efficient and socially desirable management of land, water fisheries and forest resources. Considering the multifunctional character of agriculture, interventions should enhance its positive and mitigate its negative impacts on the environment and natural resources. The paper revealed numerous results pertaining resources use in North Sudan. The running of the model provides a valuble information regard objective function value or returns, the optimality of crop combination, and resources use accompanied by their respective marginal value productivities. The model indicated that the available land should be devoted food legume crops as an optimal use due to their high returns when compared to other field crops in the scheme.SD 399,487.28 is the actual returns of crop production, while the optimal returns were found to be SD 811,596.73 (a 103% increase on current as shown in Table 1. The Table also illustrates the resources-use and constraints that the most important season in the Northern Region of Sudan are winter, hence the tenants pursue the best crop combination to achieve satisfaction returns. According to the importance of the winter season, the resources-use and availability might be described as fully utilized during this season. Introducing seasonality in the model as a known technique would further restrict the model solution and will likely lead to lower value of the objective function. The actual and optimal levels of the resources are depicted in Table 3 per season; the average tenant had up to 10 feddans of land, 28,573 m^3 water, 191 work-days of labour and SD 179,532 (about US$ 870) as capital available for the cropping season.

Table 3. Optimal resources use and cropping pattern plan for the scheme tenancy

Item	Actual	Optimal	Units
Resources use			
Total land	10	10	Fed[1]
Total irrigation water	28573	15384.42	Cubic meter (m^3)
Total labour	191	124	Man-day
Total capital	179532	122236.61	SDD[3]
Returns: objfn[2] value (Z)	399487.28	811,596.73	SDD
Cropping pattern			
Wheat	1.1	-	Fed
Faba bean	1.1	-	Fed
Chick pea	0.3	8.62	Fed
Dry bean	0.6	1.38	Fed
Onions	0.6	-	Fed
Spices	0.9	-	Fed
Vegetables	0.8	-	Fed
Sorghum	1.7	-	Fed
Maize	0.7	-	Fed
Potato	0.4	-	Fed
Fodder	1.8		Fed

[1] Fed= Feddan = 4200 m^2, [2]objfn = Objective function and SDD[3]= Sudanese Dinar= $0.30
Source: Model results

The levels at which these mentioned resources were used in food legumes were attained. Based on these results provided by the system are reflecting that, the rest of the annual crops could be listed as unfeasible crops unless improvements are achieved. However, most of these crops are considered as strategic crops, due to their importance for household food consumption and returns, so encouragement for the scheme tenants is needed to make them more profitable.

Although there are some annual crops that were mentioned as strategic crops particularly for food security and poverty reduction, these crops did not appear in the optimal plan. To ensure the importance of these crops for farm sustainability, the research designed a scenario based on the model solution. The new model was assumed that, a decline in prices is happen for two of the food legumes crops namely, chick pea and dry beans as a frequent phenomenon in the River Nile State markets. Variation of seasonal prices of annual crops is a normal feature of agricultural products in the State: price of food crops in general follows a common seasonal pattern. The new model predicted that the decrease of prices for both chickpea and dry bean would lower gross margins, but the margin would remain positive.

Table 4 illustrates the results of the new model solution. The achieved scenario analysis here provides the changes of both chickpea and dry bean prices in the optimal solution. The research revealed that the optimal return was SD 845,495.61, it is clear that, the returns here is greater than the basic solution by 112%. 10 feddans reflects all the available land as included in the optimal levels of the resources used as well as 17,644.94 m^3 of water, 133 work-days of labour and SD 202,608.4 of cash capital are less than the actual quantities in the basic solution. The allocation of the cultivated area per feddan was diverse, implying all crops except maize (Table 4). The study concluded that the achieved results pointed to a conviction point that quick crucial solution is needed to conserve the available agricultural resources of State to improve tenants' living standard, nutrition, household returns, and farm sustainability. Staple agricultural food systems will remain the essential sources of food supply, and rational farm activities are more dependable sources of household income, diversified crop combination that offers higher returns from available resources investment.

Table 4. Impact of low prices of chickpea and dry beans

Item	Actual	Optimal	Units
Resource use:			
Total land	10	10	fed[1]
Total irrigation water	28,573	17,644.94	Cubic meter (m^3)
Total labour	191	133	Man-day
Total capital	267,118	202,608.4	SDD
Returns: objfn[2] value (Z)	399,487.28	845,495.61	SDD
Cropping pattern:			
Wheat	1.1	1.0	fed
Faba bean	1.1	0.0	fed
Chick pea	0.3	1.0	fed
Dry bean	0.6	1.0	fed
Onion	0.6	1.0	fed
Spices	0.9	0.5	fed
Vegetables	0.8	1.5	fed
Sorghum	1.7	1.7	fed
Maize	0.7	-	fed
Potato	0.4	1.3	fed
Fodder	1.8	1.0	fed

[1] Fed= Feddan = 4200 m^2 and [2]objfn = Objective function
Source: Model results

3.6 Marginal Productivities of The Resources Used in the Scheme

Marginal value product (MVP) of a factor of production can be directly computed from its elasticity of production when output is measured in value terms. The MVP of a resource could be calculated from the equation:

$$MVP_{xi} = eiY/X_i$$

Where: MVP_{xi}: the marginal value of resource Xi, ei: input elasticity of production for Xi, Y: the geometric mean of gross value of farm production and X_i : the geometric mean resource Xi.

To find the efficiency index of a resource, MVP is related to its marginal factor cost (MFC). Mathematically, the expression below gives the efficiency index (IEXi) of a particular resource:

$$IEXi = MVP_{xi} / MFC_{xi}$$

Efficient resource use is reached when the expected value of IEXi is positive, in other words, a resource can be expanded until its MVP is exactly equal to its MFC. A comparison will give an insight into the differences in efficiency of resource use within a district and between districts. Economically, MVP is the shadow price of the resource used.

Table 5. Shadow prices for essential resources in the scheme

Resource	Shadow price in SDD
Land (per fed)	67339.141
Capital of November (per SDD)	8.579

Source: Model results, 2008

Table 5 shows the shadow prices of land and capital in November in optimal plan. The shadow prices for both mentioned resources had a positive sign, and this indicates the possibility of increasing the gross margin or the objective function value by increasing land and capital. The Table also shows that land has the greatest marginal value productivity (SDD 67339.141 per fed); thus explaining land scarcity in the study area. The capital devoted for November was found to be SDD 8.579 per SDD, indicating limitation of financial resources particularly in November, which is regarded the peak period for capital requirements.

4. DISCUSSION

The research demonstrates that River Nile State has the opportunity to take a lead in annual food crop production due to its stable and high-quality natural resources. This paper explores some of the findings of the field survey, and it describes the resources utilisation for agricultural production in term of food security and livelihood. We are able to draw the following conclusions:

(1) The farming system is dominated by wheat production which occupies 25% of the farm land.
(2) The study reveals the low productivity of the annual food crops that form promising strategic crops.
(3) Surface irrigation system– the dominant one in the State – is regarded as conventional, low efficient and expensive.
(4) Food production in the State consider as a challenge. This might attributed to the high cost of numerous of food crops production inputs, but irrigation water is considered as the most expensive resource.
(5) The irrigation cost item of annual crops production was 19% of the total cost of production – the largest overall the variable cost items.
(6) Annual crops in the North Sudan are diversified and economically important products.
(7) Reallocation of available resources is needed because most of the tenants of the scheme were not optimally allocating the agricultural resources and they devoted only small portions of their farmland to the most profitable crops, especially food legume crops.

Eventually and based on the above conclusion and findings, the study pointed that:

- The potential of both food and cash crops production in the State are quite promising due to the endowed agricultural resources. The agricultural policies of the State should design the relevant optimal use of the scarce resources to raise farm returns, conserve the available resources particularly soil fertility and stabilize farm sustainability.

- While the expected contribution of food crops to household nutrition can be improved by choosing the optimal crop combination and improving farm productivity, lower the cost of production, raising households' market surplus for increasing income will be a route to effective resource use that contribute to hunger and poverty alleviation. Thus, government intervention and developing tenants' awareness are essential to achieve this goal. Because lack of public investment are consider as the most chronic hindrance facing agricultural development in the State, hence, infrastructures investment are needed.
- [6] reported that, the RNS model detected that the tenants considered the misuse of resources as a cost issue, while they ignored the dimension of negative environmental consequences. So, it is very important to raise the tenants' awareness of environmental issues through an efficient mechanism that can be applied by the extension system. The study revealed that most of the annual crops under study were considered as low-value crops. Incentives should be provided to make these crops more profitable due to their importance for food security. Relevant policies may include reducing production costs or interventions to purchase them at reasonable prices.
- Designing of suitable resources combination (land, water, labour and capital) for food and cash annual crops production in Northern Sudan is very important to conserve the available resources and environment.

5. CONCLUSION

This research illustrates numerous findings of the field survey, and it emphasises on optimization of one of the most essential resources in agricultural sector namely, irrigation water in the North region of Sudan. Based on the study findings the research concluded that, low productivity of the annual field crops indicating their low value particularly the strategic ones such as wheat, thus, encouragement to farmers in the region is needed to improve the profitability of these crops. State policies are important to reduce the cost of irrigation water. The predominant of conventional irrigation systems such assurface irrigation system, led to low efficiency of irrigation water use, hence, to a noticeable technological gab between the actual applied on-farm water and the crop water requirements. However, government intervention is required to modernize irrigation-water systems so as raise water-use efficiency.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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