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ORIGINAL ARTICLE

Optimizing the cropping mix in North Darfur State, Sudan: A study of Umkdada district

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Abstract This study shed light on the constraints of increasing farm-income in the traditional rain-fed sector of North Darfur State (NDS) through investigating the situation of crop production in Umkdada district. Linear programming (LP) technique was used to test optimality pattern. The results revealed that the optimal cropping pattern is different from the current farmers' production plans. In reality farmers are not producing optimally.

Family labor represented the main constraint of agricultural production in the study area. Application of recommended technologies, increasing output prices and lowering the production costs gave high support to the farm-income in the study area.

In order to achieve agricultural development and farmers' food security in the study area, the study recommended supplying farmers with agricultural inputs especially seeds through repayment in kind after harvesting and supporting agricultural extension to be more efficient and effective in transferring the recommended improved technologies. Resolution of Darfur security problems in addition to solution of other problems facing agricultural production such as pests, marketing, desertification, drinking water, and grazing are also essential.

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1. Introduction

Umkdada district lies between longitudes 25° 45′ and 27° 30′ east and latitudes 11° 45′ and 14° north (Elmangouri, 1985). The area of the district is about 23,000 square kilometers divided into three localities, Umkdada in the northern part, Ellait in the southern part and Twisha in between. The study area is one of the important agricultural regions in North Darfur State. It contributes to food production beside cash crops. However, agricultural production in Umkdada district

suffers from many economical, technological, environmental and social problems that hinder its development and success resulting in low yields and income. These problems are (a) shortage of agricultural credit, agricultural inputs, low farm-income and limited chances of off-farm income, (b) limited use of technology as a result of lack of technology and absence of know-how, (c) variability of rainfall in amount and distribution within the same year and from year to year (the coefficient of variation (CV) of rainfall for the years 1977–2006 in Alfashir recorded 34.12% (ITDG, 2000) and (d) Darfur conflict and its consequences of armed robbery and tribal conflicts that negatively affected agricultural production (Amin, 2008). The objectives of this paper were to identify the constraints of increasing farm-income in Umkdada district, determine the optimum cropping pattern and assess the impact of some policies on farm-income and resources use.

2. Background

2.1. Rainfall

The prevailing climate in Umkdada is a desert climate in the northern part while the southern part is semi poor savanna climate. Elmangouri (1985) stated that Umkdada district is an arid region whose rainfall is hardly reliable in amount and timing, the onset of wet seasons is a highly variable event as is the duration of wet season, an important agro-climatological parameter. In length, it varies appreciably from year to year. Table 1 shows rainfall in some years in the district.

2.2. Land

The average area holding of sandy soils in Umkdada, is about 24.10 hectare per farmer. In the district there are small pockets of clay soils not of significant importance and the farmers fundamentally depend on the sandy soils.

2.3. Crops grown and productivity

The main crops grown in the area in the agricultural season 2006/07 were millet, groundnuts and watermelon. The cropping pattern of the above mentioned season was different from that in the previous seasons (Table 2), due to insecurity conditions in the district and decrease in family labor participation (pupils) in the season 2006/07 due to change in the calendar of primary schools by the State Ministry of Education to start in Autumn (14 June) instead of summer.

Millet was grown as a food crop occupying most of the area (50%) and the remaining area was allocated to groundnuts and water melon as cash crops, Table 2.

The productivity of these crops in season 2006/07 was 219.57 (kg/hectare), 463.29 (kg/hectare), and zero for millet, groundnuts and melon seeds, respectively. The zero productivity of melon seed was due to pests and diseases in the first stages of plant growth. The average cultivated area of water melon in the winter season 2006/07 in Umkdada, was 16.14 hectare per farmer. On the other hand, the farmer on the average possessed 3.19 hectare of gum Arabic trees.

The variations of cultivated area during the agricultural seasons 2000/01–2004/05 were due to delay rainfall, variability of crops prices and security problems. While the variability of crops productivity during the above seasons is due to pests attack and plants diseases, shortage and variability of rainfall from year to year and within the same year and security problems.

3. Methodology

Cross sectional data on socioeconomic characteristics of farmers and inputs and outputs of crops grown in the study area (season 2006/07) were collected through personal interview survey of a random sample of 100 of farmers.

Linear programming was applied in the agricultural sector of Sudan by some researchers among them Abdelaziz (1999), Ahmed (1988), Brima (2004), Elbadwi (1999) and Ahmed (2005).

The algebraic expression of the linear programming model used as given below:

$$\begin{aligned}
&\text{Max } \pi = C_1X_1 + C_2X_2 + \cdots + C_nX_n \text{ objective function}\\
&\text{Subject to } a_{11}X_1 + a_{12}X_2 + \cdots + a_{1n}Xn \le b_1 \text{ constraints}\\
&\qquad a_{21}X_1 + a_{22}X_2 + \cdots + a_{2n}X_n \le b_2\\
&\qquad \vdots \qquad\quad \vdots \qquad\qquad \vdots \quad \vdots\\
&\qquad a_{m1}X_1 + a_{m2}X_2 + \cdots + a_{mn}X_n \le b_m
\end{aligned}$$

And $X_1, X_2, \cdots, X_n \ge 0$ non negativity constraintswhere:

π = the objective function value.
C_j = the coefficients of decision variables ($j = 1, 2, \ldots, n$).
X_j = decision variables ($j = 1, 2, \ldots, n$).
a_{ij} = technological coefficients ($i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$).
b_j = available units of productive capacity in the production line i,

for production of n products ($i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$).

Table 1 Rainfall (mm) in the years 2000–2006: Umkdadda district.

Locality	Year						
	2000	2001	2002	2003	2004	2005	2006
Allait	547.5	621.5	530	712	368	622	652.5
Tiwisha	196.7	269.2	371.8	568.4	198.4	457.2	476.1
Umkdada	210	102	161.7	308.2	NA	155.4	233.7

Source: State Ministry of Agriculture, Animal Wealth and Irrigation, North Darfur State (2000/01–2005/06).
NA, not available.

Table 2 Average cultivated area (hectare/household) and crops yield (kg/hectare) in the agricultural seasons 2000/01–2004/05.

Agricultural Season	Millet		Groundnuts		Sorghum		Melon seed		Sesame		Karkdai	
	Area	Yield	Area	Yield	Area	Yield	Area	Yield	Area	Yield	Area	Yield
2000/01	5.04	219.57	1.36	650.17	0.29	290.48	5.22	298.57	0.80	95.24	0.11	149.79
2001/02	5.24	58.05	1.50	884.05	0.14	169.05	0.03	0.00	0.05	41.90	0.02	43.07
2002/03	5.30	171.62	0.74	517.00	0.51	335.71	3.11	240.67	0.08	89.52	0.24	135.00
2003/04	5.57	159.00	1.26	628.90	0.03	0.00	0.10	0.00	0.03	93.33	0.15	105.43
2004/05	2.48	280.14	0.67	500.21	NA	NA	0.49	213.52	NA	NA	NA	NA
Average	4.73	177.68	1.11	636.07	0.24	198.81	1.79	150.55	0.06	80.00	0.20	108.32

Source: State Ministry of Agriculture, Animal Wealth and Irrigation, North Darfur State (2001/02–2004/05).
NA, not available.

3.1. Technical coefficient matrix

A tableau of the model's technical input–output coefficients and resources are presented in Table 3.

The objective of farming practice in the study area is profit maximization after household food security of millet and sorghum. Below, are the variables that constitute the objective function values in the district as revealed from the survey.

3.1.1. Production cost

The total production cost (SDG/hectare) represents the total production cost for specific crop (Table 4) excluding the hired labor cost which was dealt with separately.

3.1.2. Labor hiring activity

The average wage rate during the agricultural season 2006/07 was SDG-30.36 in Umkdada. The wage rates were constant throughout the season.

3.1.3. Capital transfer activity

Capital transfer from one period to another did not affect the objective function values since it does not involve money transactions.

3.1.4. Crops sales activity

The average prices per kg of the crops during the harvest season in Umkdada, were SDG-0.56 and -0.42 for millet and groundnuts, respectively.

3.1.5. Millet consumption

Millet produced for consumption takes zero value in the objective function while the values of the crops purchased from the market affected the objective function negatively by the price per kg The price of consumed millet was SDG-0.60 per kg.

3.2. Constraints

3.2.1. Land

The average holding size in Umkdada region was 24.10 hectare in sandy soils.

3.2.2. Family labor (FL)

Family labor represented is by the available mandays per family that can be employed in crop production during the agricultural season 2006/07. The available mandays per family in the district were 190, 209.11, 153.68 and 32.60 for land clearance, planting, weeding and harvesting operations, respectively. Table 5 shows agricultural the main crops' labor requirements in Umkdada district for season 2006/07.

3.2.3. Capital

The available cash during the agricultural season 2006/07 was 3694.14, 0, 375 and 0 for land clearance, planting, weeding and harvesting, respectively. The farmers in the study area obtained the operating capital by themselves and through relatives assistance. The formal and informal credits were not recorded.

3.2.4. Consumption activity

The average annual household consumption (kg) of millet in Umkdada in the season 2006/07 was about 1351.5.

3.2.5. Crop balance activity

This constraint means that what is produced is equal to what is consumed and/or sold.

3.2.5.1. Activities.

1. Production: These activities in Umkdada, represent the production of millet and groundnuts.
2. Selling: Selling activities represent the selling of the crops that are produced.
3. Labor hiring: It represents labor hiring to add to the available family labor to be utilized in production activities.
4. Consumption and buying: Millet is produced to meet farmers households consumption requirements. When the farmers' own production of the crop is not sufficient to meet their consumption requirements, it will be supplemented by purchasing from the market (through buying activities).
5. Transferring: These activities ensure that the surplus operating capital can move from one period to another.

4. Results and disscussion

4.1. The basic linear programming model solution

4.1.1. Cropping pattern

The only crop produced by the basic run is millet by about 11.67 hectare. This allocated area produce more than household consumption requirements of millet (1351.5 kg/household), the rest about 1211.58 kg goes to the market for selling.

Table 3 LP tableau of a representative farm in Umkdada district in north Darfur state.

Activities		Producing				Selling				Hired labor				Borrowing				Ttransferring			Consum.		Buying					
		CR1	CR2	CR3	CR4	Q1			Q	HL1 I			HL4 IV	Br1 1			Br4 IV	1 II	II III	III IV	Mil.	Sor.	Mil.	Sor.	Cap. Rep.	End Cap.		
Obj.fu notion		−C	−C	−C	−C	C	C	C	C	−C	−C	−c	−c	−C	−C	−C	−C	0	0	0	0	0	−C	−C	0	0		
Constraints	Unit																										Dir	RHS
T clay land	Hectare	1	1																								⩽	B1
T. sandy land	Hectare			1	1																						⩽	Bi
CM clay land	Hectare	1																									⩾	0
Cr2 land clay	Hectare		1																								⩾	0
Cr3sandy land	Hectare			1																							⩾	0
Cr4 sandyland	Hectare				1																						⩾	0
FL period 1	M.D	C	c	c	c					−1																	⩽	Bi
FL period II	M.D	C	c	c	c						−1																⩽	Bi
FL period III	M.D	c	c	c	c							−1															⩽	Bi
FL period IV	M.D	c	c	c	c								−1														⩽	Bi
oc period 1	SDG	c	c	c	c					c				−1				1									⩽	Bi
oc period II		c	c	c	c						c				−1			−1	1								⩽	Bi
oc period III	SDG	c	c	c	c							c				−1			−1	1							⩽	Bi
oc period IV	SDG	c	c	c	c	−c	−c	−c	−c				c				−1			−1							⩽	Bi
Cap. rep	SDG													c	c	c	c										⩽	Bi
End cap.	SDG																									1	⩾	BI
CM prod	Sack	−c				1																1		−1			⩽	0
	Sack		−c																		1		−1				⩽	0
By prod	Sack				c				1																		⩽	0
Millet con.	Sack																				1						=	Bi
Sorghum con.	Sack																					1					=	Bi

Table 4 Cost (SDG/hectare) of millet and groundnuts production in the agricultural season 2006/07 in Umkdada district.

Operation	Millet	Groundnuts	Total
Land clearance	18.29	19.55	37.83
Planting	19.17	61.79	80.95
Weeding	11.88	18.52	30.40
Harvesting	21.17	42.02	63.19
Total	70.50	141.88	212.38

Source: Field survey, 2007.

Table 5 Crops labor (mandays/hectare) requirements in Umkdada district, in the agricultural season 2006/07.

Operation	Millet	G/nuts	Total
Land clearance	4.26	5.60	9.86
Planting	2.71	9.79	12.50
Weeding	13.17	19.57	32.74
Harvesting	5.40	26.50	31.90
Total	25.55	61.45	96.33

Source: Field survey, 2007.

Table 6 Cropping pattern and objective function: basic model solution and reality.

Item	Unit	Model	Actual
Millet	Hectare	11.69	7.90
Groundnuts	Hectare	0	4.54
Melon seed	Hectare	0	3.46
Objective function	SDG	+115.97	−2189.04

4.1.2. Optimum return

In Umkdada region, the model plan gained a profit of SDG-115.97 after satisfying household consumption requirement of millet while the actual farmer practice scored high loss SDG-2189.04 (Table 6). The variation between objective function in reality (loss) and basic run can be attributed to some reasons:

- Farmers in reality resorted to diversification and risk avoidance by planting groundnut in an area of 4.54 hectare while it did not enter in the plan and the crop produced was millet.
- Farmers in reality allocated only 7.64 hectare to millet while the optimal plan allocated 11.67 hectare of millet (53% increase).

4.1.3. Resource use

The total land exploited by the basic model in Umkdada district, was about 11.67 hectare (48%) while in the actual practices it was about 17.90 hectare (66%).

The labor employed in the basic model solution was (mandays) 49.74, 31.68, 153.68 and 63.08 during land preparation, planting, weeding and harvesting, respectively. The employed labor revealed two peaks of labor demand in the third and fourth periods. These results were consistent with reality because they represented the periods of weeding and harvesting. The labor employed in basic run solutions was the family labor and hired labor was not employed.

4.1.4. Marginal value productivities (MVPs)

Family labor represented a constraint in the weeding period and recorded SDG-5.66 while the other periods recorded zero indicating that no additional profit can be gained by increasing family mandays during these periods. These results are consistent with theories confirming that labor in the developing countries is abundant and some times with negative marginal productivity but still there are times when labor may become a constraining factor of production during the time of weeding, harvesting and such operations that demand large amount of labor during limited times (Elfeil, 1993).

The results revealed that the operating capital in the study area, was not a constraint in all periods of production i.e. MVP was zero, this result may be attributed to the surplus of operating capital in Umkdada, due to the failure of the cultivated watermelon in season 2006/07.

4.2. Policy scenarios

The study tested some scenarios through sensitivity analysis. The scenarios were based on solving some problems facing the agricultural production in the study area. These scenarios can be used by the farmers, planners and policy makers to develop the traditional rainfed agriculture in Umkdada district. These scenarios were:

Scenario I: Participation of school boys in agricultural operations.
Scenario II: Restriction of the cropped areas of millet and groundnuts to the levels practiced by the farmers.
Scenario III: Prices prevailing after three months from the harvest time.
Scenario IV: Reducing the production cost by 25% and 50%.
Scenario V: Increasing the operating capital by 25% and 50%.
Scenario VI: Adoption of improved technologies.
Scenario VII: High productivity achieved by some farmers.

4.2.1. Scenario I: Participation of school boys in agricultural operations

In school year 2006/07, the calendar of basic school was changed and the new calendar starts on 14th June and ends on 15th February. Therefore most of the school period falls within the farming period which restricted participation of school boys in the agricultural work. The scenario of old calendar was tested giving the results below (Table 7).

The result of participation of school boys increased millet area by about 4.77 hectare and all other crops did not enter the plan.

The objective function value increased from SDG-115.97 to -471 (307%) due to pupils' participations.

4.2.2. Scenario II: Restriction of the cropped areas of millet and groundnuts to the levels practiced by the farmers

Farmers tend to avoid the natural and market risks by diversification and this scenario was based on the practice of the farmers who plant on average 7.90 hectare of millet and 4.54 hectare of groundnuts (Table 7).

Table 7 Cropping pattern and objective function: participation of school boys in the agricultural operations.

Scenario	Item	Unit	Scenario values	Basic
Scenario I	Millet	Hectare	16.44	11.67
	Groundnuts	Hectare	0	0
	Objective function	SDG	+471.48	+115.97
Scenario II	Millet	Hectare	7.90	11.67
	Groundnuts	Hectare	0	0
	Objective function	SDG	−165.29	+115.97
Scenario III	Millet	Hectare	6.13	11.67
	Groundnuts	Hectare	3.73	0
	Objective function	SDG	+2144.04	+115.97

Table 8 Cropping pattern and objective function: reduction of production cost by 25% and 50%.

Item	Unit	25%	50%	Basic
Millet	Hectare	11.67	11.67	11.67
Groundnuts	Hectare	0	0	0
Objective function	SDG	+321.62	+526.37	+115.79

Table 9 Cropping pattern and objective function: capital increased by 25% and 50%.

Item	Unit	25%	50%	Basic
Millet	Hectare	11.67	11.67	11.67
Groundnuts	Hectare	0	0	0
Objective function	SDG	+115.97	+115.97	+115.97

The results of this scenario decreased millet area by about 3.77 hectare and all other crops did not enter the plan. The value of the objective function showed a loss (SDG−165.29) while the basic model was profitable (SDG−115.97).

4.2.3. Scenario III: Prices after harvest time

Farmers of the study area usually sell their products immediately after crop harvest and usually the product prices increase later in the season. The prices usually increase from February and reach the highest levels during May and June. The prices in Umkdada, increased from SDG-59.17 to -72 (increased by 22%) and from SDG-22 to -47 (114%) after the harvest in agricultural season 2006/07 for millet and groundnuts. The following results were obtained:

Millet area decreased and groundnut area was 3.72 hectare (Table 7). The net farm income increased from SDG 115.97 to 2144 (126%) due to prices increase.

4.2.4. Scenario IV: Reduction of production cost by 25% and 50%

This scenario of reducing the production cost by 25%and 50% was based on the assumption that the government subsidized some inputs and reduced taxes (Table 8).

Reduction of production cost by 25% and 50% did not change the cropping pattern and the value of the objective function increased from SDG-115.97 to -321 (177%) and 526.37 (354%) due to cost reduction by 25% and 50%, respectively.

4.2.5. Scenario V: Increasing the operating capital by 25% and 50%

The scenario assumes the operating capital increased by 25% and 50% through providing farmers with credit. The results obtained were as follow (Table 9):

Increasing the operating capital by 25% and 50% did not affect the cropping pattern in the two cases, millet was the only crop produced by 11.67 hectare.

Increasing the operating capital by 25% and 50% did not change the objective function in the two cases; the objective function was SDG-115.97.

4.2.6. Scenario VI: Improved technology

Modern technology contributes to rational exploitation of resources, improving efficiency and quality of production (Amin, 2002).The efficiency of an economy in doing its job depends on technical and economical efficiencies. A dynamic contribution of economic development from the agricultural sector and significant improvement in rural welfare depends upon the modernization of agriculture through technological change (Mellor, 1966). There are recommended technological packages by the Agricultural Research Corporation for rain-fed crops. Due to adoption of the above described packages, the productivity of millet and groundnuts increased. The scenario of the improved technology was tested giving the results below (Table 10).

Millet area decreased by about 4.70 hectare and groundnuts did not enter the plan. Adoption of technological packages led to an improvement and increased the objective function in Umkdada, from SDG-115.97 to -2044.79 (by 1663%).

4.2.7. Scenario VII: High productivity achieved by some farmers

The study found that there were some farmers in the district with higher productivity kg/hectare) compared to other farmers. In comparing the productivity of some farmers to others,

Table 10 Cropping pattern and objective function: improved technology.

Item	Unit	Scenario	Basic
Millet	Hectare	6.97	11.67
Groundnuts	Hectare	0	0
Objective function	SDG	+2044.79	+115.97

Table 11 Cropping pattern and objective function: high productivity achieved by some farmers.

Item	Unit	Scenario	Basic
Millet	Hectare	5.04	11.67
Groundnuts	Hectare	0	0
Objective function	SDG	+2152.25	+115.97

millet productivity (kg/hectare) ranged from 291.57 to 1160.95 while groundnuts productivity ranged from 463.29 to 1342.86 per hectare.

The scenario of the difference in productivity was tested giving the results below (Table 11). Millet area decreased by about 6.63 hectare and groundnuts did not enter the plan. The objective function increased from SDG-115.97 to -2152.25 (1755%).

5. Conclusions

According to the above LP analysis, we can conclude that the results of the model were different from the real practices of the farmers. The value of the objective function in the basic model was positive while in reality farmers incurred losses. Family labor was the main constraint to agricultural production during weeding and harvesting periods. The results are consistent with theories confirming that labors in developing countries are abundant but still there are times they become a constraining factor of production during the time of weeding and harvesting (Elfeil, 1993).The results of the scenarios revealed that the scenarios of changing schools calendar, reduction of production cost, improved technology and increase prices of crops improved the situation and increased the income of the farmers.

In order to improve agricultural production in the area, the study recommended the following:

1. Change of the calendar of schools so that boys can participate in agricultural operations.
2. Reduction of production cost by removal of some direct and indirect taxes.
3. Supporting agricultural extension to be more efficient and effective in transferring the recommended improved technologies.
4. Supplying farmers with credit to avoid selling their crops immediately after harvest.

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