OPTIMAL CROPPING SEQUENCE OF SMALL-SCALE FARMS IN THE RAIN-FED SECTOR OF GADARIF STATE- SUDAN

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Abstract

The study aimed to examine the Optimal Cropping Sequence of the main crops grown under the rain-fed sector of *Gadarif state* - Sudan: such as sorghum, millet, sesame and groundnuts. The study used both primary and secondary data. Multistage random sampling technique was used to collect primary data on small-scale farms from three villages of the state by means of questionnaire as a sample farmer from 175 of *Gadarif State*, during 2017 -2018 season. Secondary data were collected from Central Bureau of Statistics and Federal Ministry of Agriculture. Linear programming technique was used to determine the optimal cropping sequence of small-scale farms (less than 210ha) in the rain-fed sector of *Gadarif state*. Spread sheet of the excel solver was used to run the analysis. The results revealed that the current cultural practices and crop sequence, in which sorghum do not come after sesame, was not the optimal one. Food-crops (sorghum and millet) did not enter the optimal cropping pattern under the current sequences and policy measures, with sesame dominated the total land. The crop sequence of groundnuts, sesame, sorghum and millet proved to be the optimal cropping pattern that improves farmer's returns. Under such sequence, the four crops entered the optimum plan and farmers' returns exceed of the current situation by 181.94%, but if this sequence is used with the recommended full package of technological improvement, then farmers' net returns will increase three times than the current practices. Small-scale farmers should be encouraged to adopt the crop sequence in which sorghum come after sesame. They should also be encouraged to change their mind to become commercially oriented (by following the crop sequences with greatest returns according to local and international demand and expected prices. Even if the subsistence crop is excluded).

Keywords

Gadarif state, sorghum, millet, sesame and groundnuts

المستخلص:

هدفت الدراسة لدراسة التعاقب المحصولي الأمثل للمحاصيل الرئيسية التي تزرع في ظل الزراعة المطرية بولاية القضارف – السودان الذرة الرفيعة والدخن والسمسم والفول السوداني. استخدمت الدراسة كلا من البيانات الأولية والثانوية. تم استخدام تقنية أخذ العينات العشوائية متعددة المراحل لجمع البيانات الأولية عن المزارع صغيرة الحجم من ثلاث قرى في الولاية عن طريق الاستبيان أخذت عينة من المزارعين(175 مزارع) من ولاية القضارف، خلال موسم 2017-2018. تم جمع البيانات الثانوية من الجهاز المركزي للإحصاء ووزارة الزراعة الاتحادية. تم استخدام تقنية البرمجة الخطية لتحديد التعاقب المحصولي الأمثل للمزارع الصغيرة (أقل من 210 هكتار) في القطاع المطري بولاية القضارف. تم استخدام خاصية التحليل(solver) من اكسيل لإجراء التحليل. أوضحت النتائج أن الممارسات الثقافية الحالية وتعاقب المحاصيل الذي لا يأتي فيه الذرة بعد السمسم، لم تكن المثلى. لم تدخل المحاصيل الغذائية (الذرة الرفيعة والدخن) نموذج الزراعة الأمثل في ظل التعاقب الحالي والتدابير السياسة، حيث سيطر السمسم على مجموع الأراضي. ثبت أن تعاقب المحاصيل (الفول السوداني والسمسم والذرة الرفيعة والدخن) هو نموذج المحاصيل الأمثل الذي يحسن عوائد المزارعين. تحت هذا التسلسل، دخلت المحاصيل الأربعة الخطة المثلى وعوائد المزارعين تجاوزت الوضع الحالي بنسبة 181.94 ٪، ولكن إذا تم استخدام هذا التعاقب مع الحزمة التقنية الكاملة الموصي بها فإن صافي عوائد المزارعين سيزيد ثلاث مرات عن الممارسات الحالية. يجب تشجيع صغار المزارعين على تبني تسلسل المحاصيل الذي يأتي فيه الذرة الرفيعة بعد السمسم. كما يجب تشجيعهم على تغيير رأيهم ليصبحوا ذوو توجه تجاري (من خلال اتباع تسلسل المحاصيل ذو العائد الأكبر وفقًا للطلب المحلي والدولي والأسعار المتوقعة). حتى وإن تم استبعاد محاصيل الإعاشة.

الكلمات المفتاحية:

مدينة القضارف، الذرة الرفيعة، الدخن، السمسم والفول السوداني

INTRODUCTION:

Sudan is one of the world's least developed nations, with 5.8 million people in need of some form of humanitarian assistance: Two million displaced people in Darfur, with an additional 775,000 in South Kordofan and Blue Nile (UNHCR,2011). Conflict and hunger in neighboring South Sudan has caused an influx in South Sudanese, with over 231,000 arriving since December 2013.

The Famine Early Warning Systems (FEWS NET) estimated in March 2016 that 4 million people faced Crisis or more severe levels of food insecurity. By July 2016, FEWS NET estimates that more than 4.4 million people in Sudan could experience Crisis.

Amongst the many reasons responsible for the low productivity in Sudanese agriculture is the environmental factor. Moreover, inadequate land preparation, poor irrigation practices, moisture stress, late sowing, improper fertilization, aphid infestation, and weed and delayed harvest can be added to the major factors contributing to low yield in the Sudan (ICARDA Annual Report, 1989\90). Although future demand for food and cash crops will grow sharply, meeting this demand will still require the continued expansion of farmland, together with improvements in yield based on new plant varieties and farming technologies. all the above facts but the agricultural sector especially the rain fed sector in crisis situation so the only gate of this problem is the good planning of agricultural production. The traditional sub-sector is characterized by low productivity and limited resources. It is dominated by small producers who rely on their family labour and use primitive technology. Although the traditional sector involves the majority of the population, it does not receive the appropriate assistance and finance from government compared to another agricultural sector (Kabollo,1984). Constrain to food crops production in rain fed sector is the: climatic condition, financial problems to provide the required input at the required time leading to delayed cultural practices.

Farmers in the rain fed sub sector (traditional subsector) appear to pay much more attention to good farming practices than the investors in the mechanized subsector with a wider use of crop rotation, more frequent and timely sowing weeding, and higher sowing rates. These smaller farms regularly produce about 95 percent of the pearl millet, 38 percent of the sorghum, 67 percent of the groundnut and 38 percent of the sesame grown (FAO,2011).

As might be expected from the above description, crop production in the rain fed subsectors is characterized by high annual fluctuations owing to rainfall variation (FAO,2011).

Questions have been raised about all of these facts. Are there enough suitable inputs to expand the rain fed and irrigated area as much as will be needed, what the amount of this input can be used with each crop? What the optimum crop sequence for farmer to adopting? Is this approach of farming crop can increase the farmer returns?

One of the effective tools of agricultural planning is the linear programming approach, Several studies on developing countries applied LP to determine the optimum crop mix (Crop mix, is a crop planning system that involves “more than one crop being cultivated simultaneously during the same cropping period” (Mohamad& Said, 2011). A survey of literature revealed that LP is most widely used the technique to solve optimization problems that seek to determine the optimal crop mix, either by maximizing return or minimizing costs, subject to a set of constraints. In 1964, Heady and Egbert used LP to determine the efficient crop production plan for 122 regions in the United States for the year 1965. The objective of the model was to minimize costs, subject to a number of constraints, including land constraints, national requirement constraints, in addition to bounds on each crop for each region. In their paper, Heady and Egbert (1964) estimated the costs for the year 1965 based on projections of trends in technology and inputs for the period 1949 - 1959. They based their estimated for consumption on population and per capita income projections and on existing knowledge of price and income elasticity's of demand.

The aims of this study is to seeking of optimal cropping pattern for the small-scale farm in the rain fed sector *in Gadarif state* under different scenarios of policy measures with the objective of maximizing net return.

METHODOLOGY:

Both primary and secondary data were used to collect the required information, although primary field data from the basic source is the main data source. Farmers were interviewed by means of a structured questionnaire. Primary data on technical and economic aspects of different crops grown in Gadarif State and marketing were collected. These include, among others, agricultural practices for different crops grown in the study area, various factors of production and post-production costs, producer prices, technology levels, credit status and government incentives and supply. Secondary data on various types that serve the objectives of the study, including market prices and national production figures were collected from different institutional sources such as Ministry of Agriculture and Irrigation*, Gadarif State* Ministry of Agriculture and Forestry, Agricultural Bank, Ministry of Finance and Economic Planning, the Central Bureau of Statistics and the Central Bank of Sudan.

Multistage random sampling technique were used to collect data from 175 respondents distributed in three villages [Kajara (57 respondents), Janan (61 respondents) and Kassab (57 respondents)] of rain-fall area in *Gadarif state* by means of questionnaire. A relatively large sample size of 175 respondents will be collected, even though, homogenous population exists in the area.

Linear programming model was used to examine the optimal cropping-sequence (optimal cropping pattern) of the main crops grown under the rain-fed sector of Gadarif state: sorghum, millet, sesame and groundnuts. Based on different scenarios of technological improvement (Striga control, water harvesting) and policy measures (agricultural incentives and microfinance policies) were applied to see their effects on crop sequence and finance income.

The Structure of The Linear Programming (Lp) Model

Here an account on the LP model is given. The parameters and coefficients of the LP model, method of estimation and assumption employed are discussed.

The objective function

The objective function of this model was to maximize framers' net returns from crop production. The mathematical form of the model followed the general maximization function (Dent et al. 1986; Hazel, 1986):

$$\text{Max} \quad Z = \sum_{t-1}^{n} R_j x_j$$

SUBJECT TO:

1) Constrainers of the form: $\sum_{t-1}^{n} a_{ij} x_j \leq b_i$
2) And non-negativity constrainers: X j ≥ 0, j= 1, 2, …, n

Where:

Z= Objective function value

X j = productivity of the main crops produced under the rain-fed sector of *Gadarif state*. The crops were (sorghum, millet, sesame and groundnuts).

R j = net return/Feddan of the j activity,

n = number of restrictions in the model.

a_{ij}= the cost of the i.th resource required to produce one unit of the jth activity.

b_i= vector of resources availability.

One and only one of the symbols ≥, =, ≤ holds for each of the bi constrainer's equation. Both the objective function and constrains must be linear equations.

Technical coefficients of the model

Results and Discussion

A simplified tableau of the model technical coefficients is presented in Table (1). The first row of the model represents the activities set, which is equal to the actual area allotted for each crop cultivated in the study area. The maximum area of activity set must be less than or equal to the average area/farmer (Fadden). The second row represents the productivity in Kg/Fed. The third row represents the price in SDG/Kg. The fourth row represents return per Fadden for each of the four crops under consideration. The fifth, sixth and seventh rows represent the costs of inputs. Row eight to twenty represents the labor man day hours/season which should be equal or less than the constraint of the right-hand side. Row 21 to 24 represents the operational costs (land, labor and machine costs SDG), they should equal or less than their equivalent right-hand side. Row 25 to 26 represents the capital at hand at the begging of the season, which should be equal or less than 500SDG.

Table (1) Tableau of the linear programming model

Activity set	Crops						
	Sorghum (X1)	Millet (X2)	Sesame (X3)	Groundnuts (X4)			
Area							
Productivity (Kg/Fadden)	Kg1	Kg2	Kg3	Kg4			
Price (SDG/Kg)	P1	P2	P3	P4			
Returns	P1Kg1	P2Kg2	P3Kg3	P4Kg4	P1Kg1+ P2Kg2+ P3Kg3+ P4Kg4		
Input costs (SDG/Fadden):							
Seed	5.9	20	10	20	5.9Kg1+20Kg2+10Kg3+20Kg4	≤	5000
Chemicals (Fertilizers and Pesticides)	16.53	20	27	0	16.5Kg1+20Kg2+27Kg3+ 0Kg4	≤	
Labour constraints (man-day hours):							
16-30 July	600	360	600	360	600Kg1+ 360Kg2+ 600Kg3+ 360Kg4	≤	2400
1-15 August	360	480	480	360	360Kg1+480Kg2+480Kg3+ 360Kg4	≤	1800
16-31 August	240	360	480	240	240Kg1+ 360Kg2+480Kg3+240Kg4	≤	1800
1-15 September	240	240	240	120	240Kg1+240Kg2+240Kg3+120Kg4	≤	960
16-30 September	120	120	120	120	120Kg1+120Kg2+120Kg3+ 120Kg4	≤	1200
1-15 October	240	600	240	480	240Kg1+ 600Kg2+240Kg3+480Kg4	≤	1200
16-30 October	120	120	600	360	120Kg1+120Kg2+600Kg3+360Kg4	≤	1800
1-15 November	600	360	0	120	600Kg1+ 360Kg2+ 0Kg3+120Kg4	≤	1200
16-30 November	240	360	0	0	240Kg1+ 360Kg2+ 0Kg3+ 0Kg4	≤	960
1-15 December	240	240	0	0	240Kg1+240Kg2+ 0Kg3+ 0Kg4	≤	960
16-30 December	240	360	0	0	240Kg1+ 360Kg2+ 0Kg3+ 0Kg4	≤	960
Operational costs:							
land preparations	43.67	62.08	65.36	43.7	43.7Kg1+62.08Kg2+65.4Kg3+43.7Kg4	≤	5000
Labour cost	170	117	123.8	174.8	1700Kg1+117Kg2+123.8Kg3+174.8Kg4	≤	885
Machine cost	63.44	59.5	35.8	93.84	63.4Kg1+59.5Kg2+ 35.8Kg3+93.8Kg4	≤	600
Other constraints							
Capital at hand	1	1	1	1	1Kg1+1Kg2+1Kg3+1Kg4	≤	500

Policy analysis scenarios

Scenarios were developed from the technological improvement and changing its parameters. They were developed from the model in order to reflect a range of technological improvement (crop sequence) and policy choices (increasing microfinance accessibility and quantity). Increasing microfinance will increase farmer's ability to increase his limiting factors by various degrees.

The scenario is based on the crop sequences and provision of microfinance:

1. The first crop sequence: it is the current agricultural practices of crop sequence in which sorghum did not come after sesame in the cropping rotation.
2. The second cropping sequences: Groundnuts– Sesame– Sorghum– Millet. Here sorghum comes after sesame. This sequence plays a great role in controlling the major pest threating sorghum (Striga) thus increases sorghum productivity by 150%.

Under each of these scenarios three level of technological improvement were used. These are:

a. Using the current agricultural practices and technological improvement

For the first scenario: this is the first run of the model.

For the second scenario: Adopting this sequence will increase sorghum yield by 100%, other crops remain unchanged.

b. Adoption of 50% of the technological improvement:
For the first scenario: all crops increased by 50%.
For the second scenario: Here it is assumed that the total returns of the sorghum crops increased by 200%, sesame increased by75%, groundnuts increased by 75% and millet increased by 75%.

c. Adoption of 100% of the technological improvement:
For the first scenario: Here all crops are assumed to be increased by 200%.
For the second scenario: Here it is assumed that the total returns of the sorghum crops increased by 400% (Yousif and Babiker, 2015), sesame increased by 150%, groundnuts increased by 150% and millet increased by 150%.

Sensitivity analysis was also carried out to assess farmer's returns under adverse conditions for the optimal cropping sequence under different technological improvements:

1. Reducing crops-prices by 10%.
2. Reducing crops-prices by 25%.
3. Increasing input costs by 10%.
4. Increasing input costs by 25%

Optimal Cropping Pattern of The Small-Scale Farms in The Rain-Fed Sector of Gadarif State

Results of the linear programming model, which was used to determine the optimal cropping sequences of the small-scale farms in rain-fed sector of Gadarif state, were validated by comparing them with the current net returns/crops in season12/2013andpresented thereafter:

Current agricultural practices and crop sequences (sorghum not coming after sesame)

Net returns and optimal cropping pattern under the current agricultural practices of the small-scale farms in the rain-fed sector of *Gadarif state* are discussed here.

Net returns under the current and optimal agricultural practices and crop sequences (Sorghum not come after sesame).

The results of the linear programming net returns is presented in Table (2).

Table (2) Farmers' net returns (optimal and actual value) under the current agricultural practices and technological improvement (SDG/Feddan)

	Net Returns under the current agricultural practices
Initial value	3619.40
Optimal	4005.13
% increase	110.70

Source: field survey.

It is clear from Table (2) that, the optimal net return from the main crops produced under the current farmers practices (crop sequence) were greater than the actual one by 110.7%. However it is worth mentioning here that, farmers used three quarters of their land only. But in case of the relaxation of the binding constraints farmers net returns reached up to SDG 4244, that is increase by more than 117%. This variation could be attributed to the fact that producers actually prefer to assign most of their area to sorghum cultivation.

Optimum Cropping Pattern for The Rain-Fed Sector of Gadarif State (Under the Current Agricultural Practices and Crop Sequences)

The optimum cropping pattern (current agricultural practices) of the rain-fed sector of Gadarif State, compared to the actual one are presented in Table (3).

Table (3): Cropping pattern for the rain-fed sector of Gadarif State (actual and optimal) (%)

Crops	Actual	Optimum
Sorghum	1.39	0.00
Millet	1.00	0.13
Groundnuts	0.40	2.00
Sesame	1.17	0.77

Source: field survey.

From Table (3), it is very clear that sorghum did not enter the optimum cropping under the current cultural practices, crop sequence and technological improvement. On the other hand, groundnuts dominated the area.

NET RETURNS AND OPTIMAL CROPPING PATTERNS UNDER THE RECOMMENDED CROP SEQUENCES (SORGHUM COME AFTER SESAME).

The optimum net returns and cropping pattern of the recommended crop sequence is presented in Table (4).

Table (4) Farmer's net returns (optimal and actual value- SDG/ Feddan) under the current agricultural practices and technological improvement

	Net Returns (SDG)
Current agricultural practices	3619.4
Optimal	4296.75
% increase	119%

Source: field survey

It is clear that the optimal crop plan under the current agricultural practices (crop sequence) increase small-scale farm net returns by more than 119%. Accordingly, it is very important to enlighten the small-scale farms about the optimal crop plan.

Recommended Crop Sequence: Net Returns and Optimal Cropping Pattern of Small-Scale Farms Under the Different Technological Improvements

Here two levels of technological improvement were tested: 50% and 100% adoption of technological improvement. The basic idea of these scenarios is based on the provision of microfinance for small-scale farmers coupled with strong extension programs.

Results revealed that, the four main crops, produced under the rain-fed sector of Gadarif state (sorghum, sesame, millet and groundnuts), entered the optimal cropping pattern under optimum crop sequences. The area allotted for the four crops were almost equal. On the other hand, small-scale farms returns increased substantially, by more than 131%, 214% and 369% %, from the actual farmer returns, if they used the recommended crop sequences, adopt technological improvement by 50% and 100%, respectively.

Results also revealed that food crops, both sorghum and millet, dominated the area in case of 50% adoption of technology. But in case of 100% adoption of technology, millet alone occupied the largest land. These results confirmed the findings of farmers used improper cultural production and used traditional methods. It also showed the importance of microfinance in solving farmers' problems poor saving stable (5).

Table (5): Framers' net returns (SDG/Feddan) and optimal cropping pattern of the recommended crop sequence under different scenario of technological improvement (50% and 100% technology adoption)

	Optimal Crop sequence: recommended practices		50% adoption of technological improvement		100% adoption of technological improvement	
	Area	Net returns	Area	Net returns	Area	Net returns
Sorghum	1.00	4738.16	1.50	7760.77	0.19	13359.03
Sesame	0.90		0.30		0.54	
Millet	1.00		1.30		1.81	
Groundnuts	1.00		0.40		0.76	
Total	3.90		3.50		3.80	
% increase from actual farmers returns		131%		214%		369%

Source: field survey.

*In these table the program entered the sorghum area (because the farmer doesn't accept a crop sequence that excludes the subsistence crop(sorghum)).

Table (6): Sensitivity analysis for the recommended crop sequence under different scenarios of technological improvements and adverse condition changes in prices of crops and cost of inputs.

	Optimal crop sequence	Adoption of 50% technological improvements					Adoption of 100% technological improvements				
		Optimal	10% price decrease	25% price decrease	10% costs increase	25% costs increase	Optimal	10% price decrease	25% price decrease	10% costs increase	25% costs increase
Areas(fed)											
Sorghum	1.14	1.50	0.70	1.14	0.186	0.86	0.50	1.01	0.50	0.00	1.50
Sesame	0.80	0.30	0.50	0.80	0.54	1.00	0.70	0.00	0.70	0.00	0.30
Millet	1.09	1.30	1.20	1.09	1.81	1.10	1.46	1.20	1.46	1.70	1.30
Groundnuts	0.90	0.40	0.97	1.80	0.70	0.50	0.86	0.90	0.86	0.90	0.40
Net (SDG) returns	4244.15	7760.78	4452.93	3536.76	13339.134	4386.6	11109.25	12993.82	9547.3	11163.19	7760.78
% changes				-25.35	181.50	-7.42	134.46	17423	101.49	135.58	63.79

Source: field survey.

SENSITIVITY ANALYSIS

Test of sensitivity analysis was carried out to assess small-scale farms' returns under adverse conditions by reducing crops-prices by 10% and 25 from one hand and increasing input costs by 10% and 25% on the other hand. Results of the sensitivity analysis results revealed that, if small-scale farms adopt the improved technologies, their net returns would be far greater than the current practices, under all adverse conditions. The sensitivity analysis revealed that all crops were very sensitive to variation in inputs and output prices, except millet.

CONCLUSIONS

Results of the linear programming technique revealed that the current cultural practices and crop sequence, in which sorghum does not come after sesame, was not the optimal one. Food-crops (sorghum and millet) did not enter the optimal cropping pattern under the current sequences and policy measures, with sesame dominated the total land. The crop sequence of groundnuts, sesame, sorghum and millet proved to be the optimal cropping pattern that improves returns. Under such sequence, the four crops entered the optimum plan and farmers' returns exceeds the current situation by 181.94%, but if full technical packages were adopted farmers returns doubled three times.

- The sensitivity analysis revealed that sorghum was very sensitive to increase the costs of inputs and sesame is very sensitive to change in output prices.

RECOMMENDATIONS:

Small-scale farmers should be encouraged to adopt the crop sequence in which sorghum coming after sesame. They should also be encouraged to change their mind to become commercially oriented. This could be done through provision of microfinance, extension programs and subsidized inputs. Likewise, the government should purchase their products during adverse conditions of price drop.

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