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Management of the Cropping Pattern of Selected Crops in Afghanistan (Case Study: Nangarhar Province)

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ABSTRACT

Choosing the right cropping pattern is one of the main factors of increasing production productivity in agriculture. Optimum allocation of available production resources to the activities that bring the most profitability for farmers and determining the appropriate crops for each region to prevent excessive consumption of inputs are important and basic issues in agricultural management, neglecting which causes the inefficiency of the agricultural production system. In the present study, the optimal cropping pattern of Nangarhar province was determined by using the linear programming method. Modelling was done based on 45 functional constraints and 13 decision variables, and the information required for this research was obtained by completing 928 questionnaires on the cost of crop production in 16 districts of this province. Modelling and solving of this model was done using Lingo software version 19. The results of this study showed that by implementing the optimal linear cultivation model, the consumption of chemical fertilizers, agricultural pesticides, irrigation water and the total area under cultivation decreased by 4.33, 3.04, 2.09 and 2.32%, respectively. The amount of gross margin increased by 4.78% in the current model. Therefore, by optimizing the cropping pattern while increasing profitability for the farmers of the province, it is possible to help preserve and improve the environment by reducing the consumption of inputs. It is suggested that in future studies, other methods such as goal programming, gray programming, multi-objective fractional programming, multi-stage random programming, etc., should be used to determine the optimal cropping pattern of Nangarhar province and their results should be investigated.

Key words: Optimal cropping pattern, linear programming, optimization of input consumption, maximizing gross margin, Nangarhar province

INTRODUCTION

In order to increase agricultural production with limited resources, major technological advancements have been implemented throughout much of human history. However, a growing population along with climate change always poses a threat between food supply and demand. The world's population is estimated to reach 9 billion by 2050, which is about a 25% increase over the current population. However, population growth will be larger, mostly in emerging countries such as Mexico, India, China and others. Additionally, the urbanization trend is expected to accelerate in developing countries by 2050. Currently, 49% of the world's population lives in urban areas, which is expected to increase to 70% by 2050. Besides, since the living standard is expected to increase in the future, it will further increase food demand, particularly in emerging nations. Due to the continuous increase in the global population, one should be more cautious regarding nutritional values and food quality. To meet future food demands, food production should be doubled by 2050. In particular, grain crops and meat production should be increased from 2.1 to 3 billion tonnes, and 200 to 470 million tonnes, respectively, to meet the world food demand by 2050 (Khan *et al.*, 2021).

Since the main goal of economics is the allocation of scarce resources between competing activities, it is necessary to use methods and techniques that can achieve the aforementioned goals. So far, various methods such as genetic algorithm, game theory, dynamic programming, linear programming,

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non-linear programming etc. have been used to allocate optimal resources (Mirkarimi, 2019). However, the various modelling approaches have been applied to optimize the cropping pattern worldwide including the linear and non-linear optimization models, deterministic linear programming and chance-constrained linear programming models, the interactive fuzzy multi-objective optimization approach, the goal program approach, the multi-objective fractious. The various techniques for optimization have been developed for making the most efficient use of the available resources. Among these different models, linear programming has been found to be one of the best and simple techniques for optimizing an irrigated area where various crops are competing for a limited quantity of land and water resources (Juwono *et al.*, 2018). Joolaie *et al.* (2016) used the methods of linear programming and goal programming in the management model of agricultural products in Mazandaran province of Iran. In this study, 493 questionnaires were collected from 19 districts of this province.The results showed that in the case of applying linear and goal cultivation patterns, the gross margin will increase by 25 and 4% respectively, compared to the current pattern of the region. Neverthless, Soltani and Khajehpour (2020) used the linear program and resulted that in the optimal pattern of the region, the cultivated area of sesame, barley and saffron should be increased and the cultivated area of wheat and cumin should be decreased versus the status quo. In addition, the results of goal models in different scenarios showed significant changes in comparison to the current cropping pattern.

Besides, the study showed that the possibility of irrigating 5904.3 to 8051 ha of land at 80% by optimizing cropping patterns at irrigation efficiency of 48%. This could increase the yield by 108 to 153%, benefit by 153 to 208% and physical water productivity by 132 to 186% in economic water productivity by 205 to 241% of the actual values. In conclusion, the irrigated line in 2012-13 was below the optimal value and the irrigation water was mis-managed. Therefore, optimal crop planning in water management, the design commond area of 7000 ha could be irrigated. Finnaly, a study should be made to determine optimal levels of crop water defecate maximize water productivity (Birhanu *et al.*, 2015).

Shariati *et al.* (2021) discussed the optimization of the cropping pattern using the linear programming method in the plain of Dehglan, Kurdistan, Iran. In this study, seven scenarios were considered regarding the reduction of water consumption. The results show that the net interest ratio will increase between 7.92 and 400%. The results of a study in India showed that the linear programming approach was an efficient tool for optimizing the cropping pattern by considering the constraints of water, labour, fertilizer and seed consumption and with the aim of maximizing income (Shreedhar *et al.*, 2015).

Linear programming is an optimizing technique which is widely used to optimally allocate the resources in order to increase the production by a linear programming model for any agricultural farm to maximize the total gross margin by adopting crop rotation policy. The results of the study reveals that the income obtained by applying linear programming model is more than that obtained by binary crop rotation model (Bhatia and Bhat, 2020).

Also, in a study by Moulogianni (2022), she compared selected types of mathematical programming models for sustainable land management. The aim of this study was to compare three models of linear programming, positive mathematical programming (PMP) and weighted goal programming (WGP). For this purpose, 219 agricultural farms in Central Macedonia region in Greece were measured based on economic, social and environmental indicators. The results showed that each of the models had unique advantages and disadvantages that made it possible to use and implement them under specific conditions. According to the mentioned materials, in the present study, the linear programming method was used in order to investigate the optimal cultivation pattern of selected crops.

Afghanistan is a country where the economy and livelihood of most of the people is based on agriculture, so paying attention to this sector was considered a basic precondition for the economic development of this country. The agricultural sector accounts for 25% of GDP and 50% of employment in this country (Afghanistan Ministry of Agriculture, Irrigation and Livestock, 2016). Considering the vastness of Afghanistan's border region and the climatic diversity of different regions, it was an undeniable necessity to reach a suitable cultivation pattern for each province, from which the maximum exploitation of production factors can be obtained. Nangarhar is one of the 34 provinces of Afghanistan, which is located in the east of this country, and its center is the city of Jalalabad. The geographical coordinates of Nangarhar province are 70 degrees and 28 min east longitude and 34 degrees and 26 min north latitude. This province is 599 meters above sea level and its area is 7,916 square kilometers (Afghanistan Water Resources Department, 2018). Fig. 1 shows the geographical location of the study area.

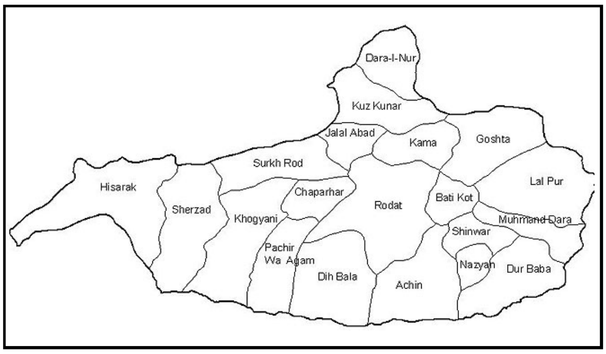

Fig. 1. Geographical location of Nangarhar province.

MATERIALS AND METHODS

The statistical population of this research was all the farmers of Nangarhar province. In the last census conducted in the agricultural sector in 2021, the number of farmers in the agricultural sector of this province was reported to be 74,512 people. Kama and Rodat districts had the highest number of farmers with 13.82 and 10.07%, respectively, and Durbaba and Nazian districts had the lowest number of farmers with 1.69 and 2.28%, respectively. The information needed for this research was collected through the completion of 928 questionnaires in 16 districts of Nangarhar province, including Khewa (Kuz Kuanr), Kama, Surkhrod, Bihsud, Goshta, Bati Kot, Momand Dara, Achin, Spin Ghar, Rodat, Chaparhar, Darai Noor, Ghani Khel, Lalpora, Pachiragam, Kut and Khogyani. In the linear programming method, the best result can be achieved in special conditions and with special constraints. The solution to the problem, in addition to estimating the limitations of the model, must also estimate the optimal value of the objective function. The components of the linear programming model included the objective function, decision variables and constraints:

$$\text{Max } GM = \sum_{i=1}^{n} GM_i X_i \qquad ...(1)$$

Subject to:

$$\sum_{i=1}^{n} a_{ij} X_i \le b_j$$

$$X_i \ge 0 \text{ , } i = 1,2,..., n \quad J = 1,2,..., m$$

Where, GM: The objective function of the problem was to maximize the total gross margin of crops in Nangarhar province.

Xi: The decision variable was the i-th level of farm activity, which in this study showed the cultivated area of each of the studied crops.

GMi: The coefficient of the objective function showed the predicted gross margin for a unit of the i-th farm activity.

aij: The technical coefficient was the amount of use of the i-th activity from the j-th resource.

bj: The available value was the jth resource.

n: The number of activities, in this study (13 crops included were: wheat, corn, rice, potato, cauliflower, melon, watermelon, onion, spinach, cotton, okra, tomato and cabbage). It should be noted that these products cover a total of 96% of the current cultivated area of this province and other products had less than a thousand hectares.

m: The number of limiting sources, 45 constraints considered in this study were:

In the present study, linear programming model with 45 deterministic constraints and 13 decision variables was formulated for Nangarhar province. Definitive constraints included the constraints of cultivated area, types of fertilizers, types of poisons, seeds, labour, water consumption, machinery and capital. Machine, water and labour services were included in the model separately and for 12 months. Tables 1 and 2 show the indices and variables used in the model, respectively. Phosphate, urea and nitrogen are the three most used fertilizers in Nangarhar province of Afghanistan. In this study, to determine the technical coefficient of chemical fertilizer constraints, the amount of consumption of each of the above fertilizers in each product was checked. Also, to determine the amount on the right side of this constraint, the total of the mentioned chemical fertilizers was

Table 1. Crops indices

Proeuct name	Index	Product name	Index	Product name	Index
Wheat	i=1	Melon	i=6	Okra	i=11
Corn	i=2	Watermelon	i=7	Tomato	i=12
Paddy	i=3	Onion	i=8	Cabbage	i=13
Potato	i=4	Spinach	i=9		
Cauliflower	i=5	Cotton	i-10		

Table 2. Variables and parameters of the model

Variable name	Index	Variable name	Index
The cultivated area of the i-th crop	Xi	The amount of herbicide consumption of the i-th product	Hi
Gross margin of the i-th product	GMi	The amount of pesticide used in the i-th product	Ii
The amount of phosphate fertilizer of the i-th product	Pi	The amount of fungicide used in the i-th product	Fi
The amount of urea fertilizer used for the i-th product	Ui	The amount of water consumed by the i-th product	Wi
The amount of nitrogen fertilizer used for the i-th product	Ni	The rate of employment of the i-th product	L_i
The amount of seed consumption of the i-th crop	Si	The capital utilization rate of product i	C_i
The amount of machinery used for the i-th product	Mi		

considered according to the information published by the Ministry of Agriculture, Irrigation and Livestock of Afghanistan. In relations (2) to (4), Pi, Ui and Ni showed the technical coefficients of phosphate, urea and nitrogen fertilizers, respectively, and P_{Total}, U_{Total} and N_{Total} showed the availability of phosphate, urea, and nitrogen fertilizers in Nangarhar province, respectively.

$$\sum_{i=1}^{13} P_i X_i \leq P_{Total} \quad ...(2)$$

$$\sum_{i=1}^{13} U_i X_i \leq U_{Total} \quad ...(3)$$

$$\sum_{i=1}^{13} N_i X_i \leq N_{Total} \quad ...(4)$$

Herbicide, insecticide and fungicide are the three most widely used poisons in Nangarhar province of Afghanistan. In this study, to determine the technical coefficient of the constraints of poisons, the amount of consumption of each of the above poisons in each product was investigated. Also, to determine the amount on the right side of this constraint, the total amount of agricultural poisons mentioned was considered according to the information published by the Ministry of Agriculture, Irrigation and Livestock of Afghanistan. In relations (5) to (7), Hi, Ii and Fi, respectively, represented the technical coefficients of herbicides, insecticides and fungicides, and H_{Total}, F_{Total}, and I_{Total}, respectively, represented the inventory of herbicides, insecticides and fungicides in Nangarhar province.

$$\sum_{i=1}^{13} H_i X_i \leq H_{Total} \quad ...(5)$$

$$\sum_{i=1}^{13} I_i X_i \leq I_{Total} \quad ...(6)$$

$$\sum_{i=1}^{13} F_i X_i \leq F_{Total} \quad ...(7)$$

In this study, in order to determine the technical coefficient of the seed constraint, the amount of its consumption in each product was checked. Also, to determine the right side of this constraint, the total seed distributed in Nangarhar province was considered according to the information published by the Ministry of Agriculture, Irrigation and Livestock of Afghanistan. Equation (8) showed the seed limitation, where Si was the seed technical coefficient and S_{Total} was the seed stock in this province.

$$\sum_{i=1}^{13} S_i X_i \leq S_{Total} \quad ...(8)$$

In this study, to determine the technical coefficient of water constraint, the amount of water used in each product was examined. This required checking the water requirement of each crop, and the net requirement of water crops in Nangarhar province was extracted from CROPWAT and CLIMWAT software packages. Then, according to the number of times of irrigation, irrigation efficiency and agricultural calendar, the values of technical coefficients were calculated. Also, to determine the amount on the right side of this constraint, the amount of annual access for the agricultural sector of Nangarhar province was considered according to the information published by the Ministry of Agriculture, Irrigation and Livestock of Afghanistan. Equation (9) showed the monthly water constraint, where Wi and Wj were the technical coefficients and total water available in each month, respectively.

$$\sum_{i=1}^{13} W_i X_i \leq W_j \quad , \quad j = 1,2,....,12 \quad ...(9)$$

In this study, in order to determine the technical coefficient of labour constraint, the number of man-days required for the four stages of agricultural operations (preparation, planting, planting-harvesting and harvesting) was investigated for each product. Then, according to the agricultural calendar, the values of technical coefficients were calculated. Also, to determine the right side of this constraint, the entire working population in the agricultural sector of Nangarhar province was considered. Equation (10) showed the monthly constraint of the labour, where Li and Lj were the technical coefficients and the right-hand side value of the labour, respectively.

$$\sum_{i=1}^{13} L_i X_i \leq L_j \quad , \quad j = 1,2,....,12 \quad ...(10)$$

In this study, in order to determine the technical coefficient of machinery constraint, the cost of machinery services was analyzed by separating the four stages of agricultural operations (preparation, planting, planting-harvesting and harvesting) for each product. Considering that the cost of each hour of machinery was different according to the type of operation, in order to homogenize these costs, using the average price of one hour of machine operation in Nangarhar province, these costs were converted into hourly units per hectare and using the agricultural calendar, the technical coefficient of this the constraint was calculated. Also, to determine the right side of this limit, the total stock of machinery in the agricultural sector of this province and the average working hours of each of them were measured. Equation (11) showed the monthly limit of machinery, where Mi and Mj were the technical coefficients and the total working hours of machinery in each month, respectively.

$$\sum_{i=1}^{13} M_i X_i \leq M_j \quad , \quad j = 1,2,....,12 \quad ...(11)$$

In this study, to determine the technical coefficient of capital constraint, the annual variable cost of each crop in Nangarhar province was considered. The value on the right was also calculated through calibration. Equation (12) showed the capital limitation, where Ci and C_{Total} were the technical coefficients and capital stock, respectively.

$$\sum_{i=1}^{13} C_i X_i \leq C_{Total} \quad ...(12)$$

In this study, in order to control the total cultivated area of crops in the framework of arable land, the land constraint was also considered. Equation (13) showed the land constraint, where Xi and X_{Total} were the decision variable and the total cultivated area of Nangarhar province, respectively.

$$\sum_{i=1}^{13} 1 \cdot X_i \leq X_{Total} \quad ...(13)$$

RESULTS AND DISCUSSION

The present research model was estimated with the help of Lingo 19.0 software and the results are shown in Table 3.

In the current cropping pattern of Nangarhar province, wheat and corn occupied the largest cultivated area with 55.72 and 19.30%, respectively. Also, the total cultivated area of the 13 crops studied in this province in 2021 was about 124 thousand hectares and its gross margin was equal to 7852.7 million Afghani. By implementing the optimal linear cultivation model and in the direction of maximizing the profit of the farmers of the

Table 3. The cultivated area of crops in Nangarhar province estimated based on the results of the model

Product name	Cultivation pattern (ha)		Comparison of cultivation patterns	
	Current region	Linear optimization	Amount of changes (ha)	Changes rate (%)
Wheat	69262	68866	-396	-0.57
Corn	23990	23255	-735	-3.06
Paddy	14216	13925	-291	-2.05
Potato	2416	0	-2416	-100
Cauliflower	2292	3077	+785	+34.26
Melon	2250	3389	+1139	+50.64
Watermelon	1840	0	-1840	-100.00
Onion	1770	0	-1770	-100.00
Spinach	1342	0	-1342	-100.00
Cotton	1294	1204	-90	-6.94
Okra	1566	1647	+81	+5.15
Tomato	1008	5439	+4431	+439.58
Cabbage	1048	611	-437	-41.72
Total cultivated area	124294	121413	-2881	-2.32
Gross margin (million Afghani)	7852.7	8227.8	375.1	4.78

region, despite the decrease of 2.32% of the total cultivated area of crops, the amount of gross margin increased by 4.78%. Therefore, in this province, it was possible to increase profits without the intervention of external factors and only through changing the cropping pattern. Also, the findings indicated that if we grouped the 13 products examined in this study; so that wheat, corn and paddy were in the cereal group; cotton was in the industrial products group, potatoes, cauliflower, onions, spinach, okra, tomatoes and cabbage were in the vegetable group, and melons and watermelons were in the jalizi products group. Then, according to Table 1, the current cultivated area of cereals, industrial products, vegetables and Jalizi products in the current cultivation pattern was 107.47, 1.29, 11.44 and 4.09 thousand hectares, respectively, which in the optimal linear cropping pattern. They were reduced to 106.05, 1.20, 10.77 and 3.39 thousand hectares. The results indicated that the highest decrease with 17.13% belonged to the group of jalizi products and the lowest decrease was 1.32% belonging to the group of cereals. Next, Fig. 2 shows the amount of changes in the cultivated area of crops in Nangarhar province based on the current and linear cultivation patterns.

In the linear optimal cropping pattern, cultivation diversity was reduced and potato, watermelon, onion and spinach products were removed from the cultivation pattern (Table 3). Also, the cultivated area of wheat was 396 ha (0.57%), corn 735 ha (3.06%), rice 291 ha

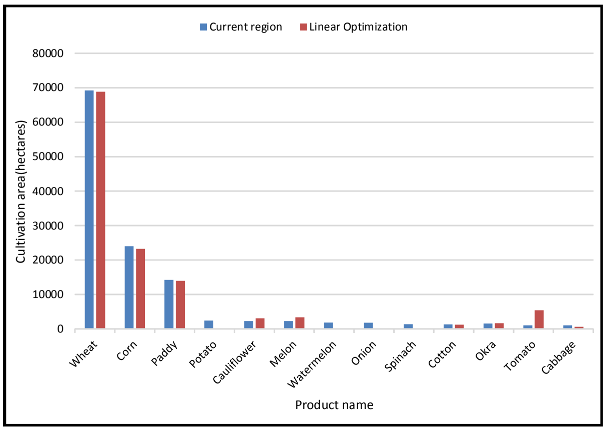

Fig. 2. The amount of changes in the cultivated area of crops.

(2.05%), cotton 90 ha (6.94%) and cabbage was 437 ha (41.72%) decreased. Next, Table 4 shows the consumption of inputs in current and linear patterns.

By implementing the optimal linear model, the consumption of agricultural inputs was reduced, so that the consumption of phosphate, urea and nitrogen fertilizers was 5.16, 3.17 and 4.65%, respectively, the consumption of herbicides, insecticides and fungicides, respectively, was 2.99, 4.36 and 1.77% and water consumption in the months of April, May, June, July, August, November, December and January, respectively, was decreased 1.86, 1.92, 10.11, 2.29, 2.67, 0.00, 0.00, 1.18, 0.52, 4.47, 0.00 and 0.00%. Also, in this cultivation pattern, water consumption in the months of September, October, February and March did not change compared to the current pattern.

Table 4. The consumption of agricultural inputs in current and linear models

Agricultural inputs		Cropping pattern		
		Current region	Linear optimization	Changes rate (%)
Fertilizer (t)	Phosphate	20811.7	19738.3	-5.16
	Urea	2212.54	2142.40	-3.17
	Nitrogen	29535.8	28161.08	-4.65
Agricultural pesticides (thousand liters)	Herbicide	159.01	154.25	-2.99
	Insecticide	199.58	190.88	-4.36
	Fungicides	141.54	139.03	-1.77
Irrigation water (million m^3)	April	247.74	243.12	-1.86
	May	260.86	255.87	-1.92
	June	26.87	24.16	-10.11
	July	210.77	205.94	-2.29
	August	158.34	154.10	-2.67
	September	57.93	57.93	0.00
	October	7.48	7.48	0.00
	November	91.68	90.59	-1.18
	December	91.07	90.59	-0.52
	January	222.64	212.70	-4.47
	February	212.92	212.92	0.00
	March	229.01	229.01	0.00

CONCLUSION AND RECOMMENDATIONS

Increasing farmers' income and improving their living conditions is always one of the priorities of planners and policy makers in the agricultural sector. The linear programming method determines the best crop combination by selecting the products that have the highest gross margin. The results of the present study showed that if the optimal cultivation model was implemented, the gross margin of crops in Nangarhar province could be increased by about 5%. Meanwhile, the consumption of chemical fertilizers, agricultural poisons and irrigation water will decrease by 4.33, 3.04 and 2.09%, respectively. Therefore, the application of this model led to the improvement of the environment. It should be noted that in the linear programming model, a part of the agricultural land equivalent to 2.32% was left out of cultivation. One of the consequences of this will be the reduction of employment in the agricultural sector. Therefore, the planners of Afghanistan need to pay attention to the creation of employment in other agricultural sectors when carrying out research and studies regarding the cropping pattern. By implementing this model, important crops such as onions will be removed from the cropping pattern. Therefore, it is suggested to include "minimum cultivated area" as a constraint in the model in future studies for important crops. Also, through the application of appropriate commercial policies, they should consider the food needs of this province and the citizens' demand regarding the products removed from the model.

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