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Research Paper

Optimal Cropping Pattern in Afghanistan Considering Environmental Sustainability

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Abstract

Environmental sustainability is one of the most important considerations in planning and managing agriculture in any country nowadays. Agriculture plays an important role in Afghanistan's economy and employment. Herat province is rich in agricultural production in Afghanistan. To achieve environmental sustainability along with profitability, the present research aimed to develop an optimal cropping pattern for Afghanistan with environmental considerations. The crops studied include wheat, barley, sesame, cumin, and saffron, which accounted for more than 70 percent of the cropping area in Herat province. The goal and linear programming model were used to determine the optimal cropping pattern. The goals of reducing the use of chemical fertilizers and pesticides along with maximizing gross margins were used in the goal model with the aim of achieving environmental sustainability. The results of the linear model, aimed at maximizing gross margins, showed 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.

Keywords:
Chemical fertilizers; goal programming; linear programming; optimal cropping pattern; pesticides

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INTRODUCTION

Afghanistan is a country where the economy and livelihood of most people is based on agriculture and cropping. The agricultural sector is one of the most important and capable sectors of the economy. This sector is an essential precondition for Afghanistan's economic development and plays a major and very important role in the country's Gross Domestic Product (GDP) so that 25 percent of Afghanistan's GDP is accounted for by the agricultural sector. This sector constitutes over 50 percent of the country's employment (Afghanistan Ministry of Agriculture and Livestock, 2017). Agriculture in Afghanistan has also provided raw materials for the industry and is an important source of exports (Fazlodin, 2008). This country`s agriculture has the potential to both provide food for the growing population and contribute to the economic and social development of the country (Sabouri, 2007). Agriculture in this country is in subsistence form and depends on environmental conditions and natural factors (Golestani, 2007).

On the other hand, the main goal of sustainable development is the optimal use of human and natural resources (RaheliNamin et al., 2016). But, the use of pesticides and crop protection chemicals, which was introduced in the 1940s, has been increased by 4.8 million tons during the period 1950 to 2000 (Karandish, 2019). Although the use of these pesticides has a significant positive effect on crop production, their overuse causes environmental pollution locally and results in worldwide environmental pollution through worldwide trade (Karandish, 2019). In addition, the biological damage caused by inappropriate use of chemical fertilizers and pesticides as well as inappropriate traditional farming methods can cause severe soil erosion, create non-fertile lands, and ultimately reduce crop quality and quantity. On the other side, the constant use of fertilizers and pesticides makes pests more resistant, resulting in the emergence of new pests (Samiee & Rezaei-Moghaddam, 2018).

According to Fernando et al. (2009), the concept of environmental sustainability dates back to 1995. In most scientific texts, environmental sustainability is defined as the ability to use natural resources to produce and consume the goods needed for the present generation so as not to harm the interests of future generations. Also, in most researches, three factors of water, chemical fertilizers, and pesticides in agricultural production have been used as environmental sustainability parameters in agricultural production in developing the optimal model (Amini Fasakhodi, et al. 2010; Charnsungnern & Tantanasarit, 2017; Joolaie et al. 2017; Mardani Najafabadi et al. 2019; Mardani et al. 2018; Mortazavi et al. 2014; Vivekanandan, et al. 2009).

Many studies have also used a variety of mathematical programming to incorporate environmental sustainability into the optimal cropping pattern. Linear programming (Mortazavi et al., 2014; Ramezani etedali et al. 2019), nonlinear programming (Montazar, 2013; Mortazavi et al., 2014), goal programming (Mortazavi et al., 2014; Ortuño & Vitoriano, 2011; Srivastava & Mohan Singh, 2017; Vivekanandan et al., 2009), fractional goal programming (Amini Fasakhodi et al., 2010), fuzzy goal programming (Joolaie et al., 2017), linear and multi-purpose fuzzy planning (Sahoo et al., 2006; Zeng et al., 2010), single and multi-purpose models (Mardani Najafabadi et al., 2019).

These studies show changes in cropping pattern of the areas considering environmental sustainability considerations.

Since no such research has been done in the Herat region of Afghanistan, the aim of this study was to determine a cropping pattern that, along with profitability, also considers environmental sustainability.

METHODOLOGY

To perform this study, data were provided by the Afghanistan Ministry of Agriculture and Livestock statistical reports, Directing Department of Agriculture and Livestock of

Herat Province statistical reports for availability of resources, crop acreage, production costs, and prices data for the cropping year 2015-2016. Opinions of experts in the region were also used for additional information about technical coefficients.

Study area

Herat is located in the west of Afghanistan (Figure 1) and is one of Afghanistan's most important provinces in agricultural production. It borders Badghis and Turkmenistan Republic in the north, Farah Province in the south, Ghor in the east, and the Islamic Republic of Iran in the west. It is one of the most populous provinces of Afghanistan and together with Kabul, Mazar-e-Sharif and Kandahar is the four largest cities in Afghanistan. Herat is 61,315 km^2 and is the second largest in Afghanistan after Helmand. The province's population is estimated more than 1515400. The capital of this province is the ancient city of Herat, located at 680 km from Kabul (Afghan capital) and 116 km east of the Iranian border, 110 km from the Turkmenistan border, 5 km north of the Herirood River, and 5 km north of the highlands (Directing department of Agriculture and Livestock of Herat Province, 2017).

Herat Province is one of the major natural resources of Afghanistan with more than 254,000 ha of forest area, over 25800 ha of pastures and about 150000 ha of the watershed in 15 counties and all kinds of fruitful, medical, ornamental, and unproductive plants. The total arable land in Herat Province is 381849 ha. Different types of crops in Herat Province in the year 2016 in the order of cultivated areas are as follows: grains, seafood, fruits, vegetables, forage, industrial crops, and medicinal crops. Autumn wheat, winter wheat, barley, sesame, saffron, and cumin have the largest cultivated area among different types of agricultural crops in Herat. The planting date of these crops in the region is November, February, June-July, and August-September respectively, and cumin is planted in December and March (Department of Agriculture and Livestock, 2017).

Linear programming model

The linear programming procedure in the optimal cropping pattern is to determine the agricultural map that maximizes farm income, considering the limitations of production factors (Koupahi, 1984).

Figure1. Herat Province in Afghanistan
Source: Herat (2020)

The general form of the linear programming model for the purpose of maximizing gross margin is as follows:

$$\text{Max } Z = \sum_{i=1}^{n} C_i X_i$$
$$\text{s.t:}$$
$$\sum_{i=1}^{n} a_{ij} X_i \leq b_j \qquad j = 1.2.3......m$$
$$X_i \geq 0 \qquad i = 1.2.3......n$$

Z: The objective function

X_i: Activities related to the production of various crops

C_i: Objective function coefficients

A_{ij}: Matrix of technical coefficients of production factors

B_j: Restrictions

Xi≥0: indicates that the values of variables are nonnegative.

This pattern in this study has five agricultural activities (Xs), such as wheat (X_1), barley (X_2), sesame (X_3), cumin (X_4), and saffron (X_5), which contain more than 70 percent of the real cultivated area in the region and six constraints including (Cs) pesticides (C_1), chemical fertilizers (C_2), land (C_3), machinery (C_4), manpower (C_5) and water (C_6). The objective (Z) is maximizing the total gross margin.

It should be mentioned that during recent years saffron cultivation has been increased in Afghanistan because of its profitability in comparison to other crops in the region. As the mentioned crops above (X_{1} ,.., X_5), can be replaced by each other according to different goals, they will be incorporated in the models in this study to compare the results of the models under environmental sustainability with the current situation.

Goal programming model

Goal planning models were introduced by Charnes and Collomb in 1972 (Ortuño &Vitoriano, 2011). Since then, these models have been extended. Ideal planning is actually an effort to accomplish more than one goal at a time and since it is usually not possible to achieve all the goals fully, so it offers answers that are as close to the goals as possible (Meyer, 2009).

Like linear programming, goal programming is concerned with the maximization of an objective function subject to a number of constraints. There are two types of constraints in goal programming, i.e., system constraints and goal constraints. System constraints are identical to linear programming constraints, referring to the constraints that must always be met. As usual, they often reflect the fact that certain inputs or commodities are in fixed supply. Goal constraints represent aspiration levels or target values to be achieved. Importantly, goal constraints may not always be met. Here, d- denotes the amount by which the *i*th goal constraint is underachieved, and d+ denotes the amount by which it is overachieved. These variables are known as deviational variables and are assumed to be nonnegative. Two points are worth noting. First, when forming goal constraints, variable d- is always followed by a plus sign, and variable d+ is always followed by a minus sign. Second, since it is not possible for a goal to be both underachieved and overachieved, at least one of the deviational variables associated with a particular goal must always be equal to zero. Both deviational variables will be equal to zero whenever the goal is achieved perfectly. It is obvious that some deviations are undesirable and some are not. The objective in goal programming is to minimize the sum of the undesirable deviations (E. Fleming, University of New England, Australia, Personal Communication).

The general form of the goal planning model is as follows (Vivekanandan et al., 2009):

$$\text{Minimize } Z = d- + d+$$
$$\text{Subject to } f(x) + d- + d+ = g1 \quad \text{and ;}$$
$$i = 1,2,......,m; \; X j \geq 0,$$
$$d- \geq 0, \; d+ \geq 0$$

Different models used in the study:

Single-purpose model

In this research, a cropping model was first obtained using the optimal programming model of the area to maximize gross margin as an economic goal. In this model no goal for considering environmental sustainability has been included.

Two-goal programming models

Two-goal planning models were used to ensure environmental sustainability, as well as profitability. These models have two goals of maximizing gross margin and minimizing chemical fertilizer consumption. These models are in scenarios 1 and 2 which include 10 and 30 percent decrease in chemical fertilizer consumption respectively.

Three goal programming models

These models have three objectives of maximizing gross margin, minimizing chemical fertilizer use, and minimizing pesticide use in the cultivation of the crops in the Herat region. These models also have two scenarios for environmental sustainability purposes. Scenario 1 involves a 10 percent reduction in the use of environmental pollutants (chemical fertilizer and pesticide) and Scenario 2 involves a 30 percent reduction in their use.

RESULTS

Table 1 shows the gross margin per hectare of crops selected in the region. To obtain the information needed to calculate gross margin, Herat provincial Agriculture and Livestock Department information and expert opinion were used.

The technical coefficients of the production of crops are listed in Table 2.

Table 1
Gross Margin of Each Hectare of Studied Agricultural Crops (Unit: Afghan)

Product	Gross margin
Wheat	77500
Barley	33375
Sesame	73500
Cumin	197000
Saffron	832327.57

Source: Directing Department of Agriculture and Livestock of Herat Province (2017)

Table 2
Quantities of Production Factors Needed for Cultivation of One Hectare of Selected Crops in Herat Region (Technical Coefficients)

Product Name	Pesticides (Liters)	Chemical Fertilizers (Kilograms)	Machinery (Hour)	Manpower (Man Work Day)	Water (m^3)
Wheat	1.25	375	18.75	25.85	7250
Barley*	1	300	18.75	16.55	6500
Sesame	0	75	10	74.6	4250
Cumin	0	75	12.5	129	0
Saffron	0	400	12.5	555	4500

Source: Directing Department of Agriculture and Livestock of Herat Province (2017) and experts' view
*Barley crop in Herat has a duration of 4 months from planting to harvesting (Directing Department of Agriculture and Livestock of Herat Province, 2017).

The linear programming model

According to the results of the linear model, which is the single-purpose model, only four crops including wheat, barley, sesame, and saffron out of the five crops considered fit in the optimal cropping pattern (Table 3). The cultivated area of these crops was 44157.18, 9958.06, 11454.28, and 11227.49 ha, respectively. The total gross margin from this optimal cropping pattern is 13941370000 AFN.

As shown in Table 3, in this optimal cropping pattern, wheat had the highest cultivated area with 44157.18 hectares followed by sesame with a cultivated area of 11454.28 ha, saffron with a cultivated area of 11227.49 ha, and barley with a cultivated area of 9958.06 ha. In this optimal pattern of agricultural crops, cumin is removed from the model. However, the current cropping pattern shows that, after wheat with 81685 ha, the highest cultivated area in the region is related to barley with 4748 ha, cumin with 2831 ha, saffron with 2540.5 ha, and sesame with 429 ha of cultivated area. The current cropping pattern of the region shows that wheat production accounts for more than 88 percent of the total cultivated area followed by barley (5%), cumin (3%), saffron (2.7%), and sesame (0.4%) (Table 4).

However, the optimal cropping pattern obtained from the present study accounted for about 57 percent of the total cropping area in the model. This shows that the share of wheat in the total cultivated area is decreased by 31 percent compared to the current pattern of the region. On the other hand, the optimal cropping pattern allocated about 15 percent of the total cropping area to sesame, implying more than a 14 percent increase compared to the status quo. The saffron crop also showed a 12 percent increase in the optimal cropping model compared to the current crop pattern with a 15 percent share. Barley's cultivated area (13%) is increased by about 8 percent in the optimal cropping pattern compared to the current crop pattern of the region. The information about the cultivated area of the studied crops in the current and the optimal cropping patterns is given in Table 4.

Results of the goal models

Table 5 shows the main parameters related to economic and environmental sustainability in Herat Province. The gross margin is considered an economic parameter, and the consumption quantity of chemical fertilizers and pesticides are considered the parameters that damage the environment.

As Table 5 shows, in all different scenarios of single-purpose, two-purpose, and three-purpose optimal cropping pattern modeling, the parameters related to economic and environmental sustainability show a better situation than the current cropping pattern. That is, both the gross margin of the optimal cropping pattern introduced by the model in all scenarios is higher than the gross margin of the current cropping pattern and chemical fertilizers and pesticides are used to a lower extent in all scenarios than in the current

Table 3
The Results from Linear Programming Model

Product	Optimal area under cultivation (Hectares)	Gross margin in hectares (Afghan)	Total gross margin (Afghan)
Wheat	44157.18	77500	3422181000
Barley	9958.06	33375	332350500
Sesame	11454.28	73500	841889400
Cumin	0	197000	0
Saffron	11227.49	832327.57	9344951000
Maximum gross margin obtained of linear programming model solving			13941370000

cropping pattern. The results of the two-objective goal model show that with the loss of about 73 million Afghan of the gross margin, it can reduce chemical fertilizer use by approximately 2616 tons and pesticide use by 9,000 liters and reach the level of 56.1 thousand liters compared to the single-purpose model. The two-purpose patterns in both the first scenario (10%) and the second scenario (30%) indicate a reduction in chemical fertilizer consumption, which should be offset by some benefits for environmental sustainability and environmental pollution.

Table 4

Comparison of the Results Obtained from Single- Purpose Optimal Pattern to the Current Pattern of the Area (Unit: Hectare)

Product	Region cultivation	Optimal cultivation
Wheat	81685*	44157.18
Barley	4748*	9958.06
Sesame	429	11454.28
Cumin	2831	0
Saffron	2540.5	11227.49
Total cultivated area of agricultural products in the region		217059.69
Total cultivated area of the studied products		92233.5**
Total cultivated area of the products in optimal pattern		76797

Source: Directing Department of Agriculture and Livestock of Herat Province (2017) and Research Findings

*includes only irrigated areas. **digit does not include rain fed Wheat and Barley cultivated area. Total cultivated area including rain fed Wheat and Barley cultivated areas is 155281.5 hectares.

Table 5

Parameters Related to the Economic and Environmental Sustainability Goals and Results from the Optimal Models

	Gross Margin (millions of Afghan)	Chemical fertilizers consumption (tons)	Pesticide consumption (thousands of liters)
Current Cropping Pattern	9193	33317	107
Single-Purpose Optimal Pattern	*13941.4	24896.5	65.1
Two-goal Optimal Pattern (Scenario 1)**	13828.4	22280	56.1
Two-goal Optimal Pattern (Scenario 2)	13828.4	22280	56.1
Three-goal Optimal Pattern (Scenario 1)	13941.4	24896.3	65.1
Three-goal Optimal Pattern (Scenario 2)	13941.4	24896.3	65.1

Source: Afghanistan Ministry of Agriculture and Livestock (2017), Directing Department of Agriculture and Livestock of Herat Province (2017) and Research Findings

* All figures are rounded to one decimal place. **Scenarios were designed according to the present consumption of pesticides and chemical fertilizers in the area, environmental conditions of the area, and experts' opinions.

Scenarios 1 and 2 contain 10 and 30 percent decrease in environmental pollutants respectively.

On the other hand, the results of the three-purpose optimization goal models show a slight difference with the results of the single-purpose optimization model. This is a small difference in gross margin and the amount of chemical fertilizer use, which has not been shown due to the rounding of the figures in the profit table. Therefore, the three-purpose optimization models in both scenarios to maximize gross margin and minimize the use of chemical fertilizers and pesticides show results similar to the single-purpose profit maximization model.

The results of changes in these parameters in different optimization patterns compared to the current cropping pattern (Table 6) show that there is a 51 percent increase in gross margin in the single-purpose pattern with the goal of maximizing gross margin over the current crop pattern. Also, the rate of using chemical fertilizers and herbicides in this model shows a 25 percent and 39 percent decrease compared to the current model, respectively. However, in the two-purpose goal model, which aims at maximizing gross margin and minimizing chemical fertilizer use, in both scenarios of 10 percent and 30 percent reduction in fertilizer use, the gross margin pattern of the model shows an increase by 50 percent over the current cropping pattern. The two-purpose pattern in both scenarios of 10 percent and 30 percent reduction in chemical fertilizer use also shows a 33 percent and 47 percent decrease in chemical fertilizers and herbicides application compared to the current cropping pattern, respectively. Interestingly, the results of the three-purpose goal pattern with the goals of maximizing gross margin, minimizing fertilizer and herbicide use in both scenarios of 10 percent and 30 percent reduction in environmental pollutants are quite similar to those obtained from the single-purpose optimizing model. In other words, in the three-purpose decision model, the amount of gross margin increased by 51 percent compared to the current cropping pattern in both scenarios. In both scenarios of this pattern, the use of chemical fertilizers and herbicides was decreased by 25 percent and 39 percent compared to the current cropping pattern, respectively.

Table 6

Percentage of Changes in Economic and Environmental Sustainability Parameters of Different Optimal Patterns in Comparison to the Current Crop Pattern in Herat Province

	Single-Objective Optimal Pattern	**Two-goal Optimal Pattern (Scenario 1)**	**Two-goal Optimal Pattern (Scenario 2)**	**Three- goal Optimal Pattern (Scenario 1)**	**Three- goal Optimal Pattern (Scenario 2)**
Changes in gross margin	+51	+50	+50	+51	+51
Changes in chemical fertilizers Consumption	-25	-33	-33	-25	-25
Changes in poisons ponsumption	-39	-47	-47	-39	-39

Scenarios 1 and 2 contain 10 and 30 percent decrease in environmental pollutants use respectively.

Table 7 shows the cultivated areas of the studied crops in the current cropping pattern as well as in different single-purpose and multi-purpose patterns with different scenarios. As noted in the Table 7, the highest cultivated area in the current pattern is allocated to wheat. Different optimization patterns also assigned the highest area of cultivation to wheat although the cultivated area of wheat was lower in the optimal pattern than in the current cropping pattern. Another notable point about wheat's cultivated area is that in all crop optimization patterns and in all their different scenarios, the cultivated area allocated to wheat is quite similar. In other words, it can be concluded that these patterns imply food security implicitly. Another remarkable point about the results of the optimization patterns is that although in the current cropping

pattern, the cultivated area of sesame is the lowest among the five crops in the region, all single-purpose and multi-purpose optimization patterns in all their scenarios dedicated the second-highest cultivated area to sesame with an area of about 11454 ha. The next highest cultivated areas were assigned to saffron, barley, and cumin, respectively. These patterns also show the same cultivated area of about 11227 ha for saffron in all scenarios.

Tables 7 and 8 indicated that the cultivated areas of wheat, sesame, and saffron do not change and they have the highest cultivated areas in all types of single-purpose and multi-purpose models with different scenarios. This means that by adding environmental goals to the single-purpose economic model, no change happens in the cultivated area of these crops by the patterns.

The cultivated area of wheat in all these optimized patterns was decreased by 46 percent compared to the status quo which is equal to 44157.2 ha, whereas sesame's cultivated area was increased by 2570 percent versus the status quo to 11454.3 ha and saffron cultivated area was increased by 342 percent versus the status quo and reached 11227.5 ha. This is not the case for the other

Table 7

Cultivated Areas of the Studied Crops in Different Patterns in Herat Province (Unit: Hectare)

Agricultural Products	Wheat	Barley	Sesame	Cumin	Saffron
Current Cropping Pattern	81685	4748	429	2831	2540.5*
Single-Objective Optimal Pattern (Gross Margin Maximization)	44157.2	9958.06	11454.3	0	11227.5
**Two-goal Optimal Pattern (Scenario1)	44157.2	947.7	11454.3	1156	11227.5
Two-goal Optimal Pattern (Scenario 2)	44157.2	947.7	11454.3	1156	11227.5
***Three-goal Optimal Pattern (Scenario 1)	44157.2	9957.7	11454.3	0.05	11227.5
Three-goal Optimal Pattern (Scenario 2)	44157.2	9957.7	11454.3	0.05	11227.5

Source: Directing Department of Agriculture and Livestock of Herat Province (2017) and Research Findings

* All figures are rounded to one decimal place.

Scenarios 1 and 2 contain 10 and 30 percent decrease in environmental pollutants use respectively.

**Two-goal pattern has the goals of maximizing gross margin and minimizing chemical fertilizers use

***Three-goal pattern has the goals of maximizing gross margin and minimizing both chemical fertilizers and herbicides use

Table 8

Percentage of Change in Cultivated Area in Optimal Models in Comparison to Current Crop Pattern

	Wheat	Barley	Sesame	Cumin	Saffron
Single-Objective Optimal Pattern (Gross Margin Maximization)	-46*	+110	+2570	-100	+342
*Two-goal Optimal Pattern (Scenario1)	-46	-80	+2570	-59	+342
Two-goal Optimal Pattern (Scenario 2)	-46	-80	+2570	-59	+342
Three-goal Optimal Pattern (Scenario 1)	-46	+109	+2570	-99.9*	+342
Three-goal Optimal Pattern (Scenario 2)	-46	+109	+2570	-99.9	+342

* All figures are rounded to one decimal place.

two crops, i.e., barley and cumin. First, cumin in the single-purpose optimal pattern is completely eliminated from the model, whereas its current cultivated area amounts to 2831 ha, which is the highest after wheat and barley. Also, despite the result of the single-purpose model in the two-purpose model, the cultivated area for cumin in both scenarios is 1156 ha, which is 59 percent lower than that in the current cropping pattern (Table 8). Also, in the three-purpose model, a very little amount of 0.05 hectares is allocated to cumin. As shown in Table 7 for barley, although its current cultivated area (4748 ha) is the highest after wheat, it has almost the lowest cultivated area in the optimization patterns (without taking cumin in the single-purpose and three-purpose patterns into account) (Table 7). As is present in Table 8, although barley had the lowest cultivated area in most patterns, its cultivated area has been increased over the current cropping pattern (except for the two-purpose pattern in which barley's cultivated area has reached approximately 947 ha).

Table 9 shows that the optimized cropping patterns for Herat Province use less water and machinery over the current cropping pattern in the area.

This decrease in the machinery and water consumption in the optimized two-purpose models (425.5 million m^3 and 1115 thousand hours, respectively) versus the current model (636.3 million m^3 and 1692 thousand hours) are more optimized than the other models. Table 10 presents the percentage of these changes. On the other hand, the water and machinery use in the single-purpose and three-purpose models are almost the same (given that the figures in the table are rounded to one decimal place) because of having almost the same patterns of these models.

The remarkable point about the results of the optimized models is that all of these models have fully utilized the workforce capacity. In other words, although for studied crops in the region, the employment rate is about 3,997,000 working days, in all optimal patterns, the employment level for these crops has increased significantly and has reached 9,009,000 working days in the agricultural sector of Herat Province. These results confirm that the designed patterns can contribute to social sustainability along with economic and environmental sustainability.

Table 10 shows the percentage of changes in labor, machinery, and water consumption in optimization patterns compared to the current cropping pattern in Herat Province.

These patterns represent more than a 100 percent increase in employment. The two-purpose patterns also showed the largest reduction in machinery and water consumption (34 percent and 33 percent, respectively) compared to the single-purpose and three-purpose models. In single-purpose and three-purpose models, the percentage of reduction in machinery and water use is 25 percent and 24 percent versus the status quo, respectively.

CONCLUSION AND DISCUSSION

The results of the optimized models showed that the cultivated area of wheat was reduced compared to the current cropping pattern in the region. But, the cultivated areas of sesame and saffron were increased compared to the current cropping pattern. Barley shows a 100 percent increase in its cultivated area in the single-purpose model versus the current pattern, which is almost similar to that of the three-purpose goal model. But, in the two-purpose goal model, its cultivated area is reduced by about 80 percent compared to the current model. Cumin is also eliminated from the optimal cropping pattern in the single-purpose model. It also gets very little cultivated area in the three-purpose optimization model. However, in the optimal two-purpose model, the cultivated area of cumin is reduced by 59 percent compared to the optimal pattern and reaches 1156 ha.

Table 9

Optimal Utilization of Other Agricultural Production Factors in Herat Using Optimization Models

	Manpower (thousand man- day works)	Machinery (thousand hours)	Water (million cubic meters)
Current Cropping Pattern	3997.3*	1692	636.3
Single-Objective Optimal Pattern (Gross Margin Maximization)	9009.5	1269.5	484
*Two-goal Optimal Pattern (Scenario1)	9009.5	1115	425.5
Two-goal Optimal Pattern (Scenario 2)	9009.5	1115	425.5
Three-goal Optimal Pattern (Scenario 1)	9009.5	1269.5	484
Three-goal Optimal Pattern (Scenario 2)	9009.5	1269.5	484

* The numbers in the table are rounded to one-tenth of a decimal.

Table 10

Percentage of Changes in Other Production Factors in Optimal Patterns in Comparison to the Current Pattern

	Manpower	Machinery	Water
Single-Objective Optimal Pattern (Gross Margin Maximization)	+125	-25	-24
*Two-goal Optimal Pattern (Scenario1)	+125	-34	-33
Two-goal Optimal Pattern (Scenario 2)	+125	-34	-33
Three-goal Optimal Pattern (Scenario 1)	+125	-25	-24
Three-goal Optimal Pattern (Scenario 2)	+125	-25	-24

These results showed that by applying the optimal cropping patterns obtained from the single-purpose and multi-purpose planning models, more profit can be made. These patterns also showed that the consumption of pesticides and fertilizers in these patterns was significantly reduced compared to the current pattern. This indicates that optimal patterns can be effective in reducing environmental pollution too. On the other hand, optimal patterns show less water consumption and less use of machinery compared to the current situation. Therefore, although water in the present study was not included as an environmental sustainability indicator in the objectives of the region's goal models (since the Herirood River is located near the Herat region, it is currently less prone to dehydration), the results of optimal cropping pattern models for the purposes of maximizing profit, minimizing the use of fertilizers, and minimizing the use of pesticides and herbicides, they show that in addition to achieving the desired goals, they reduce water consumption. Also, by reducing the use of machinery, they can help reduce environmental pollution through lower demand for fuel.

On the other hand, the results of the optimized models showed that in all types of single-purpose and goal models, the labor capacity is fully utilized. Therefore, these patterns also increase employment in the agricultural sector of Herat Province from a social perspective and thus contribute to the social sustainability of the region. Also, according to the results of different optimal models, it seems that the two-purpose models aim to maximize profit and minimize chemical fertilizer consumption. Although they will result in the loss of some profit, they are more robust than the other models in reducing consumption and production factors including chemical fertilizers and pesticide consumption as considered the indicators of environmental sustainability in this research. These results seem reasonable given that pesticides in the region are only used for two crops of wheat and barley. As a general conclusion, using the results obtained from different optimization models with environmental sustainability approach, it can be concluded that by changing the current cropping pattern of Herat Province, in addition to achieving environmental and economic sustainability goals, other goals are achieved, including social sustainability.

The following suggestions can be made for the cultivated areas according to discussions:

According to the results, the optimal patterns in all models indicate changes in comparison to the current pattern. In this regard, it is suggested to make these changes according to the goals in the cultivated area of the crops in the region.

It is suggested to consider the consumption needs of the region to these crops for self-consumption and food security in modeling the cropping pattern of the region in future research. As Herat region supplies wheat and other grains to other provinces of Afghanistan, this should be taken into account with regard to food security considerations.

Since climate change and water availability in agriculture sector is an important issue in recent decades, it is suggested to consider this issue as a goal in goal programming models in this region in future studies.

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