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Multi-objective optimization of agricultural production with emphasis on improving environmental and economic factors (case study of rice product)

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Abstract

The current research seeks to determine the optimal pattern of rice cultivation in Mazandaran province as the main rice production pole of the country by using the multi-purpose mathematical planning model, emphasizing the improvement of environmental and economic factors and with the aim of maximizing production efficiency and minimizing the environmental effects of specific water consumption. to do The data required for this research were the cross-sectional data of the amount of production, the amount of consumption of agricultural inputs and the price of inputs, the amount of precipitation and the degree of humidity. These data were prepared from the relevant centers and organizations, including the Agricultural Jihad Organization and the Meteorological Organization of Mazandaran Province. In order to achieve the results of the research, in the first part, the input data was introduced, and then based on these data and the mathematical programming method and the genetic algorithm, three-purpose optimization was done. The objective functions include maximizing the amount of production, minimizing the consumption of fertilizer per unit area and its costs. Also, the decision variables including the average annual temperature, average rainfall and cultivated area were determined. The results of three-mode optimization in different modes were shown in the form of Pareto fronts. Considering that optimization is done in order to maximize production and minimize fertilizer consumption and price, three linear beam fronts (two-dimensional) were determined and all optimal points were selected.

Key words: *multi-objective optimization, environmental factors, water consumption.*

Introduction

Water is a valuable and irreplaceable commodity in the economic and social development of countries, and it is one of the important components in maintaining the balance and stability of the ecosystem and the environment,

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which plays a central role in the development of the land and the infrastructure of other sectors. Therefore, attention to the issue of sustainability and management of water resources has changed from a secondary issue to a central and important issue in recent years.

The pressure of various factors and demographic transformations have caused water allocation policies to operate outside the framework of sustainable and balanced development, and the place of the water sector in shaping land use and regional plans remains missing. Basically, the major part of the country's water management and its infrastructures is based on water supply management and generally structuralism, and water demand management has remained weak in the process of national water management developments (Samani, 2005).

Since the agricultural sector is the largest water consumer in the country and the largest water loss is also related to the agricultural sector, the main focus of water demand management should be on the agricultural sector and specifically on the design of the ship model according to the water resource facilities of different regions. In fact, the sustainability of water resources has the most important contribution to the existence and durability of agricultural systems and is largely dependent on the crop cultivation pattern.

The definition of sustainable management of water resources varies depending on the multiple uses of this resource, including power generation, water supply (agricultural, industrial and residential), recreational and ecological. Most of these uses require that the management of water resource systems involves controlling, improving or protecting the quantity and quality of available water. Because sustainability is a function of various economic, environmental, ecological, social and physical goals, therefore water resources management should be a multi-faceted decision-making process. These decisions should be made only by including all relevant practices and policies and influencing parameters.

In other words, water resources systems must be managed in such a way that they fully meet the goals of society in the present and future, while maintaining their hydrological, environmental and ecological stability and harmony (Nazimi, 2001). Considering the high importance of this issue and the lack of research that simultaneously seeks to provide solutions that optimize all components such as environmental, economic and agricultural production in order to improve water consumption, this research with the help of optimization methods seeks to improve the resources of agricultural production with The emphasis is on environmental and economic factors. Multi-objective optimization examines the optimization of systems based on various criteria, including environmental and economic aspects. (Azapajik, 1999). . In particular, the multi-objective optimization model can consider environmental concerns as decision objectives rather than constraints imposed on the system (Garcia et al., 2014). Multi-objective optimization produces a set of alternatives (Pareto optimal solutions) that are not dominant. None of the objectives at the Pareto optimal point can improve the value with any other acceptable solution without worsening at least one other objective. The analysis of these solutions brings a new concept about trade-offs between goals (Azapajik and Perdan, 2005). In agricultural areas, multi-objective optimization has been successfully applied in arid and semi-arid resource management. Along this path (Ixon and Khan, 2005) have used multi-objective optimization to optimize reservoir operation and water allocation for irrigation. Meanwhile, Chen et al. (2013) applied the use of multi-objective optimization to realize the optimal distribution of multiple reservoirs in a pond. Multi-objective optimization is still used to analyze product planning problems according to economic criteria (Duri et al., 2011; Sarkar et al., 2009; Zeng et al., 2010) or environmental goals (Khosnovisan et al., 2015). Is. However, multi-objective optimization and cycle evaluation have by no means addressed the integrated framework in the field of agriculture. Meanwhile, Chen et al. (2013) applied the use of multi-objective optimization to realize the optimal distribution of multiple reservoirs in a pond. Multi-objective optimization is still used to analyze product planning problems according to economic criteria (Duri et al., 2011; Sarkar et al., 2009; Zang et al., 2010) or environmental goals (Khosnovisan et al., 2015). has taken. However, multi-objective optimization and cycle evaluation have by no means addressed the integrated framework in the field of agriculture. In this research, a tool to optimize the allocation of products has been created, an area that has a high potential to increase access to food and reduce the environmental effects of agriculture. A systematic multi-objective optimization tool is presented that integrates a descriptive method for measuring water consumption impact with an optimization model that identifies optimal harvesting patterns that simultaneously maximize productivity and minimize environmental impact. Is. The effectiveness of the proposed tool has been shown through its application to a real case study based on rice production in northern Iran.

Methodology

In this research, in order to achieve the optimal point of consumption of agricultural inputs, in the first stage, based on the genetic programming method, analytical relations for the objective optimization functions have been determined. In the next step, based on the analytical functions determined and the use of the genetic algorithm, three objectives were optimized and different optimizations were performed for different input variables. Finally, based on the results of various optimizations and benefiting from genetic programming, an analytical relationship was presented to determine the optimization point, without the need to solve the optimization numerically.

The target functions in this research include; The amount of production that should be maximized. Fertilizer consumption per hectare should be minimized. The price should be minimized. Also, the decision variables include; It is the average annual temperature, average rainfall and cultivated area. In fact, multi-objective optimization is performed for different input values for rainfall and air temperature. To find the final optimal point, the method of minimum distance to the unreachable ideal point is used.

Research findings

The target functions of this research include; The amount of production that should be maximized. Fertilizer consumption per hectare should be minimized. The price that should be minimized. Also, the decision variables include; It is the average annual temperature, average rainfall, and the area under cultivation.

In order to formulate objective functions and variables, we use symbols. Based on this, it can be written (Table 1):

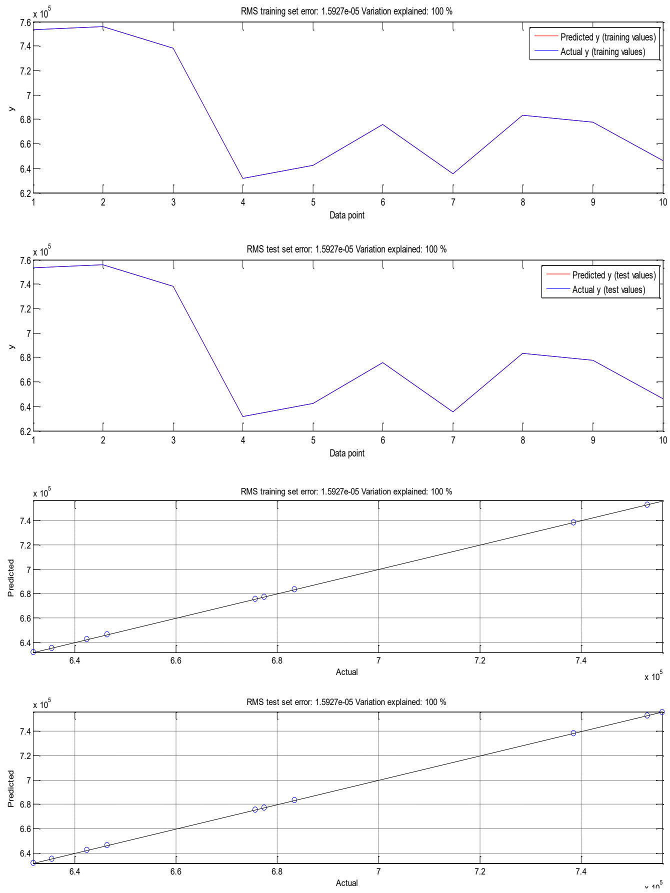
Table 1: Objective functions and variables of the symbol

Title		Symbol
Objective functions	The amount of production	f_1
	Fertilizer consumption	f_2
	Price	f_3
Variables	Temperatures	x_1

In this section, the goal is to provide an analytical relationship for the objective functions in such a way that single and multi-objective optimizations can be performed based on the obtained analytical relationships. Considering that the number of effective variables is three; A powerful tool of genetic programming is used to find the analytical relationship. Based on this, the following analytical relations are obtained for the objective functions using genetic programming.

$$f_1 = 0.0009X_2 - 1.137 \times 10^{-12}X_1 + 4.996X_3 + 1.195 \times 10^{-5}e^{\cos(X_3)-\sin(X_1)} - 3.424 \times 10^{-5}tanh(tanh(sin(X_3)))cos(2.0tanh(X_3)) - 0.0002173$$

In the figure below, the values predicted by genetic programming in the training and testing modes are drawn separately, and the mean squared error is shown on the top of each graph. As can be seen, the squared error values of the average error are about 1.5927*10-5, which is a favorable value.



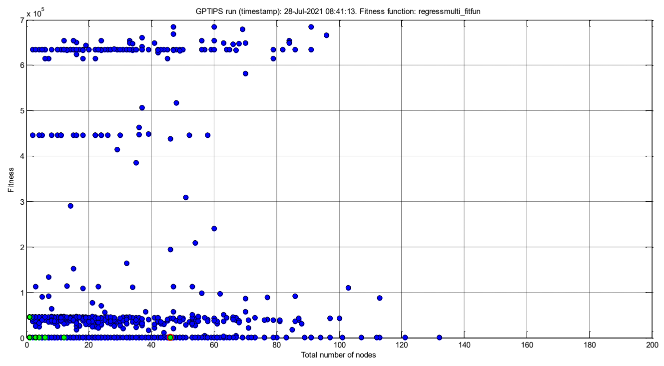
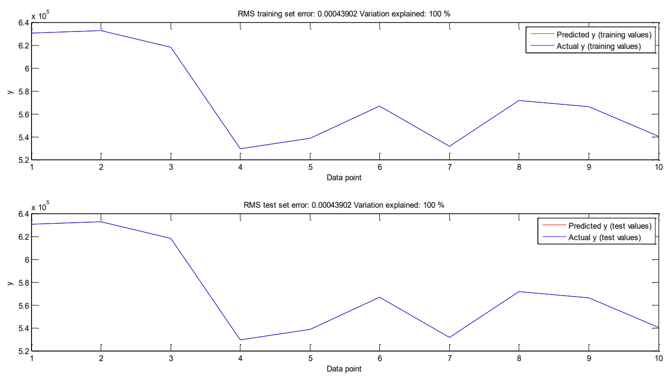


Figure 1: Predicted values by genetic programming in training and testing modes

Analytical function for fertilizer consumption f2

$$
\begin{aligned}
f_2 &= 51.66X_2 - 447.7X_1 + 4.145X_3 \\
&- 90.61 \times sin(X_1 - X_2) \\
&- 735.6 \times tanh(cos(cos(cos(X_1) - X_2)) \\
&- tanh(X_3 + 65.63)) + 3801 \times cos(sin(X_3{}^2)) \\
&- 4.145 \times e^{\tanh(9.123 \sin(\cos(X_1)))} \\
&- 18.82 \times sin(tanh(X_1 + tanh(X_2)) - X_1) \\
&+ 18.82 \times sin(X_2) - 484.7 \times sin(X_3) \\
&- 115.5 \times e^{\cos(\sin(\exp(X_1)))} e^{(\tanh(8.988X_1))} sin(1.476X_1 \\
&+ e^{X_2}) + 7135.0
\end{aligned}
$$

In the figure below, the values predicted by genetic programming in the training and testing modes are drawn separately, and the mean squared error is shown on the top of each graph. As can be seen, the mean squared error values are about 4.3902*10-4, which is a good value.



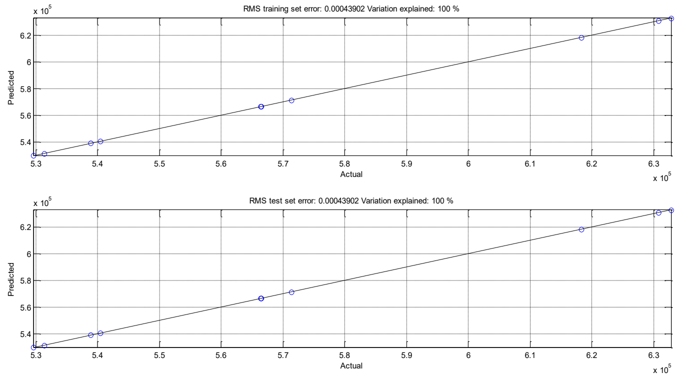
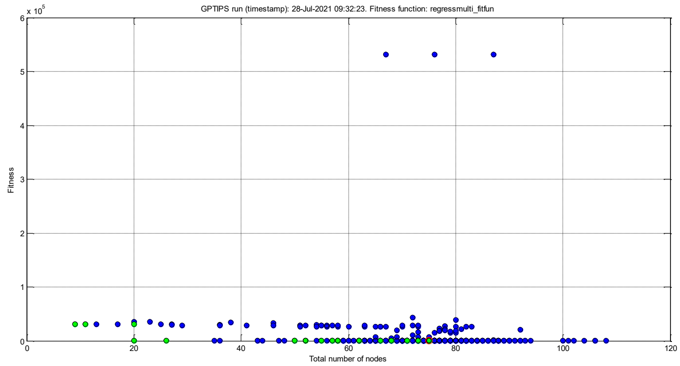


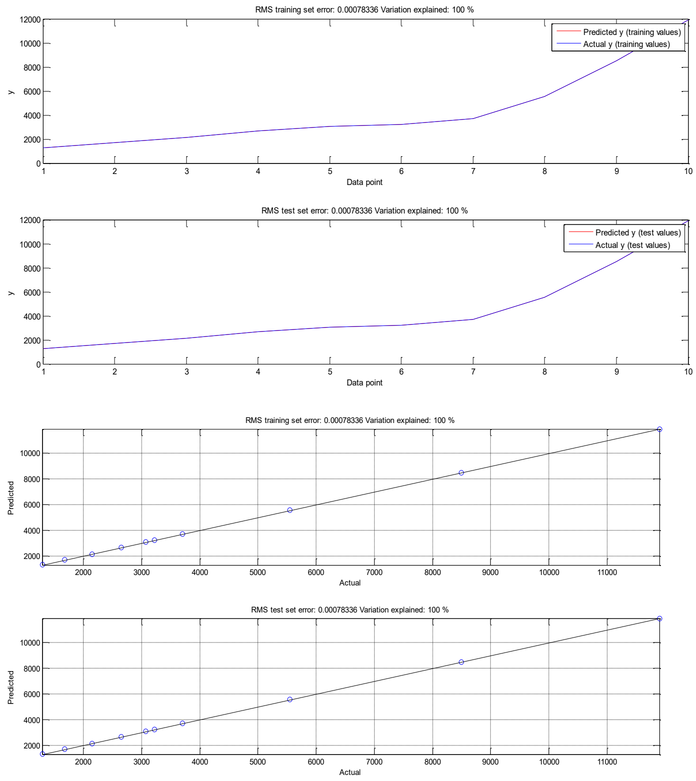
Figure 2: Predicted values by genetic programming in training and testing modes



Analytical function for price f3

$$
\begin{aligned}
f_3 &= 3537.0 \times sin\big(cos(X_2 + X_3)\big) - 0.2113X_3 \\
&+ 126.6 \times e^{\cos(X_2 + \sin(X_3))} \\
&- 1794.0 \times sin(tanh(cos(X_3))) \\
&- 2261.0 \times tanh(exp(tanh(cos(exp(X_2)) \\
&+ cos(X_2)))) - 956.8 \times sin(X_1) \\
&- 1215.0 \times sin(X_3) \\
&+ 2475.0 \\
&\times e^{tanh(sin(x1)) + cos(X_1 X_2)} (cos(sin(X_1)) \\
&+ tanh(X_1 + 3.121) - tanh(sin(sin(X_1)))) \\
&- 50.59 \times X_1{}^2 + 44655.0
\end{aligned}
$$

In the figure below, the values predicted by genetic programming in the training and testing modes are drawn separately, and the mean squared error is shown on the top of each graph. As can be seen, the mean squared error values are around 7.8336*10-4, which is a good value.



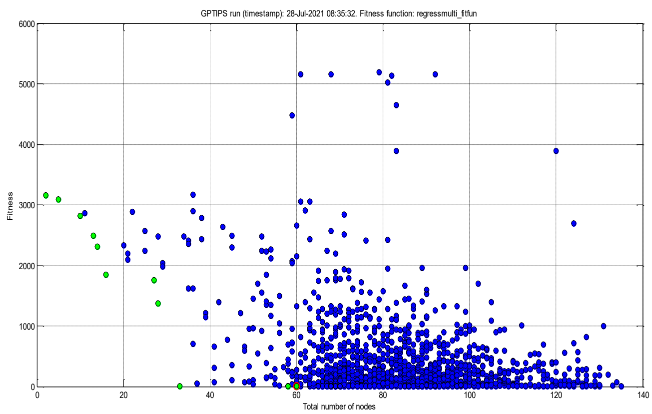


Figure 3: Predicted values by genetic programming in training and testing modes

Optimization

Multi-objective optimization is done to maximize the amount of production, and minimize the amount of fertilizer consumption and the finished product price. The optimization variable is the area under cultivation. The input variables are rainfall and air temperature. In fact, multi-objective optimization is performed for different input values for rainfall and air temperature. To use the genetic algorithm optimization tool, variables and functions are defined as follows.

Input parameters: temperature and precipitation

Decision variable: cultivated area

Objective functions for optimizing three objectives: production rate; Amount of fertilizer consumption, price

To find the final optimal point, the method of minimum distance to the unreachable ideal point is used. The results related to the beam front for different input modes are as follows:

Table 2. Beam front results for different input modes

Scenario 2: The temperature will be 15 degrees Celsius and the precipitation will be 50 mm				**Scenario 1: The temperature will be 15 degrees Celsius and the precipitation will be 30 mm**			
Optimization objective functions	Optimization variable			Optimization objective functions	Optimization variable		
Area under cultivation	production rate	Fertilizer consumption	Price	Area under cultivation	production rate	Fertilizer consumption	Price
140122.5	700052.2	585436.4	4138.996	143653.9	717695.1	599142	5812.066
Scenario 4: The temperature will be 20 degrees Celsius and the precipitation will be 30 mm				**Scenario 3: The temperature will be 15 degrees Celsius and the precipitation will be 70 mm**			

Optimization objective functions	Optimization variable			Optimization objective functions	Optimization variable		
Area under cultivation	production rate	Fertilizer consumption	Price	Area under cultivation	production rate	Fertilizer consumption	Price
114794.9	575515.4	476381.5	1412.077	159701.6	797869	667765.2	5779.409
Scenario 6: The temperature will be 20 degrees Celsius and the precipitation will be 70 mm				**Scenario 5: The temperature will be 20 degrees Celsius and the precipitation will be 50 mm**			
Optimization objective functions	Optimization variable			Optimization objective functions	Optimization variable		
Area under cultivation	production rate	Fertilizer consumption	Price	Area under cultivation	production rate	Fertilizer consumption	Price
126709.3	633039.6	337.161	633039.6	129963.8	649299.3	541024.2	1100.018
Scenario 8: The temperature will be 25 degrees Celsius and the precipitation will be 50 mm				**Scenario 7: The temperature will be 25 degrees Celsius and the precipitation will be 30 mm**			
Optimization objective functions	Optimization variable			Optimization objective functions	Optimization variable		
Area under cultivation	production rate	Fertilizer consumption	Price	Area under cultivation	production rate	Fertilizer consumption	Price
109459	547806.6	454307.6	99.65347	116473.9	581903.7	481876.8	553.2646
Scenario 9: The temperature will be 25 degrees Celsius and the precipitation will be 70 mm							
Optimization objective functions	Optimization variable						
Area under cultivation	production rate	Fertilizer consumption	Price				
118723.7	593143.7	494710.5	1072.141				

We can present the optimizations performed at different temperatures and precipitations as follows.

Table 3: Optimizations performed at different temperatures and precipitations

Optimizations	Input		Decision variable	Optimal functions		
	Temperature	Rainfall	Area under cultivation	Rate of production	Fertilizer consumption	Price
1	15	30	143653.9	717695.1	599142	5812.066
2	15	50	140122.5	700052.2	585436.4	4138.996
3	15	70	159701.6	797869	667765.2	5779.409
4	20	30	114794.9	573515.4	476381.5	1412.077
5	20	50	129963.8	649299.3	541024.2	1100.018
6	20	70	132381	661375.5	553069.5	239.4887
7	25	30	116473.9	581903.7	481876.8	553.2646
8	25	50	109649	547806.6	454307.6	99.65347
9	25	70	118723.7	593143.7	494710.5	1072.141

According to the results of Table (4), using genetic programming, we can present an analytical relationship to find the optimal point based on temperature and precipitation.

$$\text{area under cultivation} = -22.5 \times {X_1}^3 X_2 + 1.613 \times {X_1}^2 {X_2}^2 + 1184.0 \times {X_1}^2 X_2 + 4251.0 \times {X_1}^2 - 65.42 \times X_1 {X_2}^2 - 19666.0 \times X_1 X_2 - 1.736 \times 10^5 X_1 + 647.2 \times {X_2}^2 + 1.022 \times 10^5 X_2 + 1.84 \times 10^6$$

$$\text{rate of production} = 362 \times X_1^3 + 8.058 \times X_1^2 {X_2}^2 - 847.7 \times X_1^2 X_2 - 474.0 \times X_1^2 - 326.8 \times X_1 {X_2}^2 + 34211.0 \times X_1 X_2 - 4.417 \times 10^5 X_1 + 3219.0 \times {X_2}^2 - 3.348 \times 10^5 X_2 + 6.477 \times 10^5$$

$$\text{fertilizer consumption} = 7.814 \times {X_1}^4 - 0.09252 \times {X_1}^3 {X_2}^2 - 1.055 \times {X_1}^3 X_2 + 7.814 \times {X_1}^3 + 0.09252 \times {X_1}^2 {X_2}^3 - 1.597 \times {X_1}^2 {X_2}^2 + 11.22 \times {X_1}^2 X_2 - 11366.0 \times {X_1}^2 - 2.11 \times X_1 {X_2}^3 - 64.93 \times X_1 {X_2}^2 + 12355.0 \times X_1 X_2 - 2920.0 \times X_1 + 38.18 {X_2}^3 - 2336.0 \times {X_2}^2 - 338.5 X_2 + 1.057 \times 10^5$$

$$\text{price} = 0.2069 \times {X_1}^4 - 0.06099 \times {X_1}^3 - 1.991 \times {X_1}^3 + 0.1459 \times {X_1}^2 {X_2}^2 - 9.507 \times {X_1}^2 X_2 - 47.48 \times {X_1}^2 - 0.03215 \times X_1 {X_2}^3 - 1.25 \times X_1 {X_2}^2 + 252.0 \times X_1 X_2 - 382.5 \times X_1 + 0.7417 \times {X_2}^3 - 48.86 \times {X_2}^2 - 6.655 \times X_2 - 39.9$$

Discussion and conclusion

In this research, based on the received information, we use the input data for decision variables and optimization objective functions. The objective functions include the maximization of the amount of production, minimization of fertilizer consumption per hectare and reduction of the price to the minimum. We determined also the decision variables including the average annual temperature, average rainfall and area under cultivation. In order to provide an analytical relationship, we used genetic programming tools and computer code written in MATLAB software. To benefit from the genetic algorithm optimization tool, variables and functions included input parameters: temperature and precipitation, decision variable: area under cultivation and objective functions for three-objective optimization: production rate, fertilizer consumption and price. The results of three-state optimization in different modes, in the form of Pareto fronts, showed that considering that the optimization is done in order to maximize production and minimize fertilizer consumption and price, we will have three linear (two-dimensional) Pareto fronts as follows: All points in the following figures can be selected as the optimal point.

1. If the air temperature is 15 ° C and the precipitation is 30 mm, the optimum is as follows:

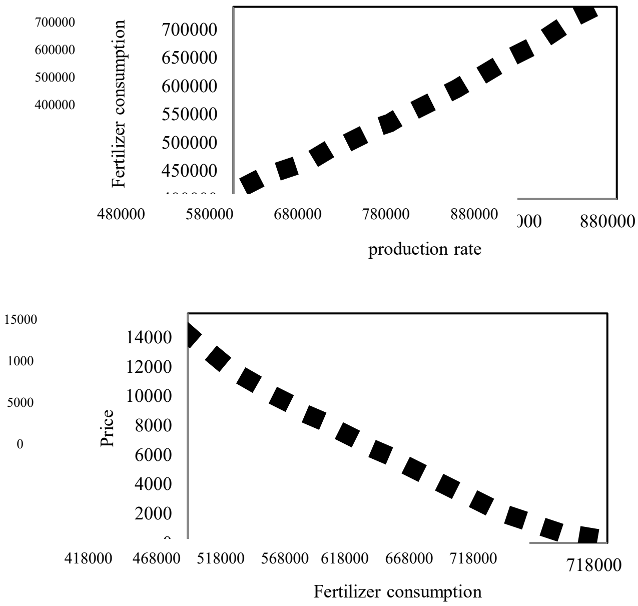
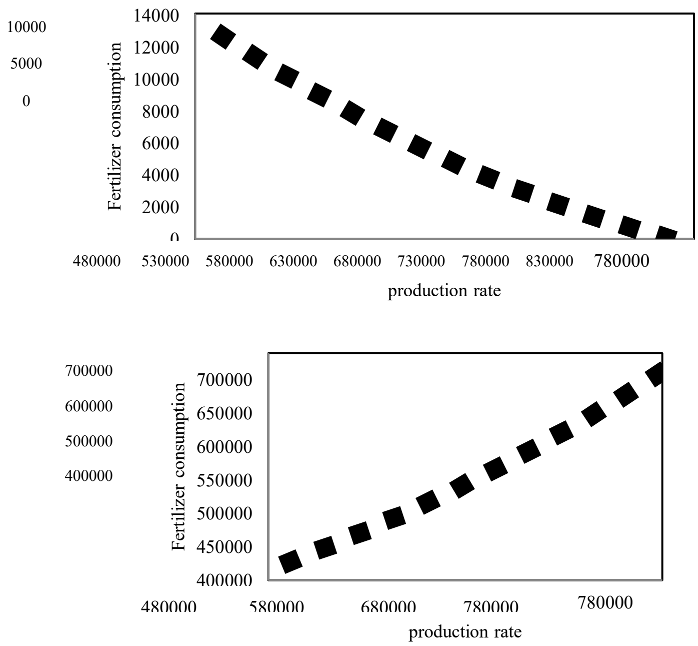


Figure 4: Optimal conditions for a temperature of 15 degrees Celsius and a precipitation of 30 mm

2. If the air temperature is 15 ° C and the precipitation is 50 mm, the optimum is as follows:



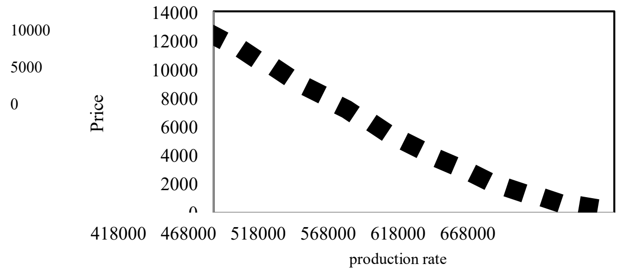


Figure 5: Optimal conditions for a temperature of 15 degrees Celsius and a rainfall of 50 mm

3. If the air temperature is 15 ° C and the precipitation is 70 mm, the optimum is as follows:

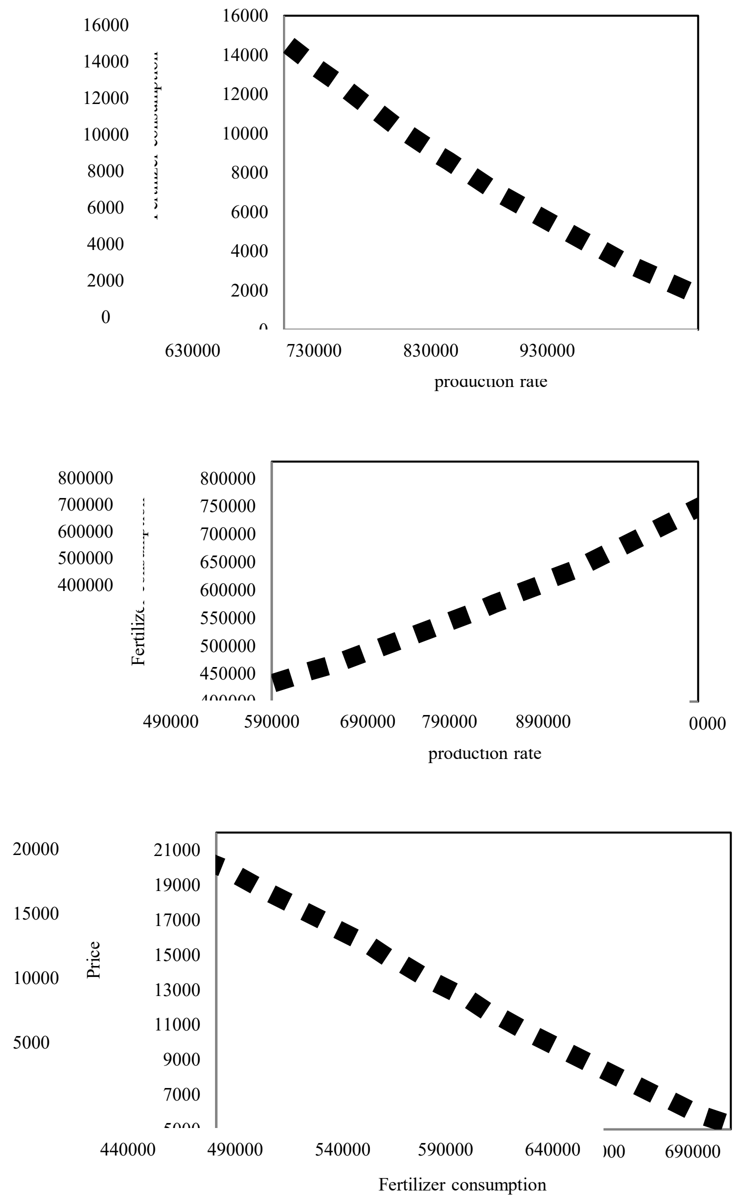


Figure 6: Optimal conditions for a temperature of 15 degrees Celsius and a rainfall of 70 mm

4. If the air temperature is 20 ° C and the precipitation is 30 mm, the optimum is as follows:

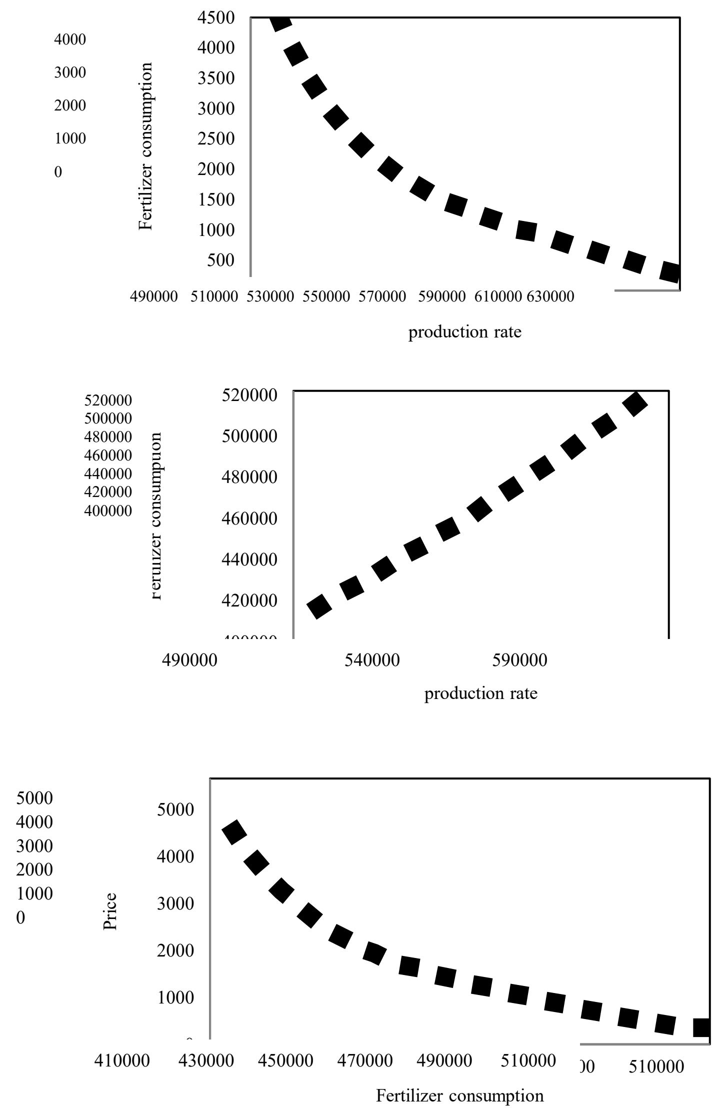
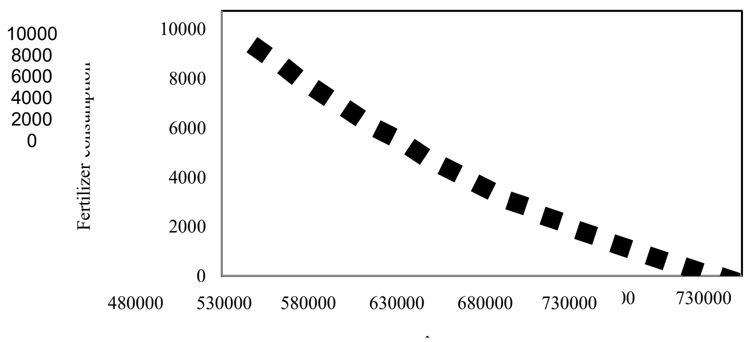


Figure 7: Optimal conditions for a temperature of 20 degrees Celsius and a precipitation of 30 mm

5. If the air temperature is 20 ° C and the precipitation is 50 mm, the optimum is as follows:



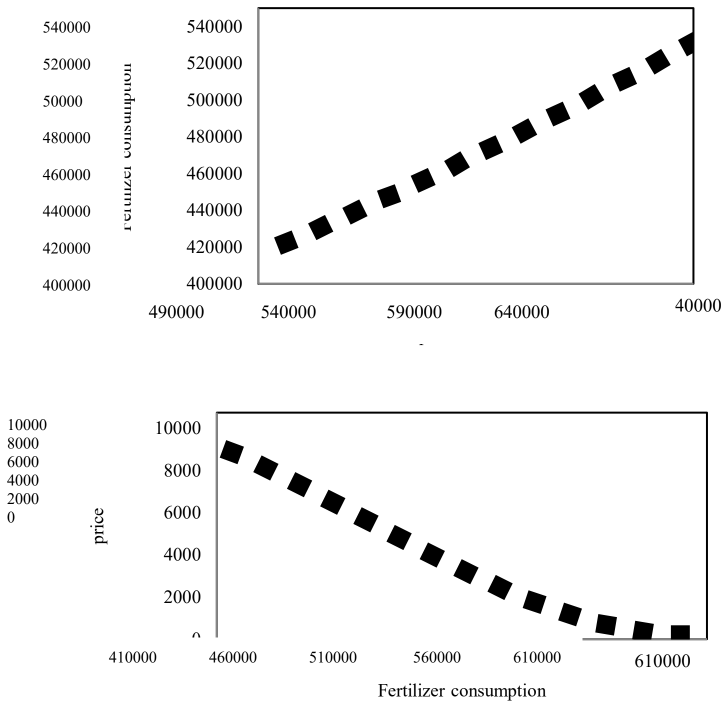
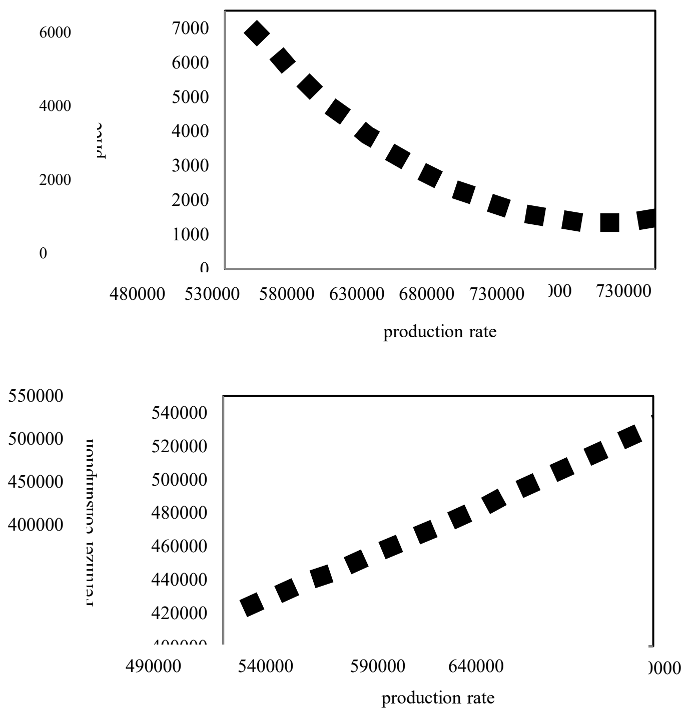


Figure 8: Optimal conditions for a temperature of 20 ° C and a rainfall of 50 mm

6. If the air temperature is 20 ° C and the precipitation is 70 mm, the optimum is as follows:



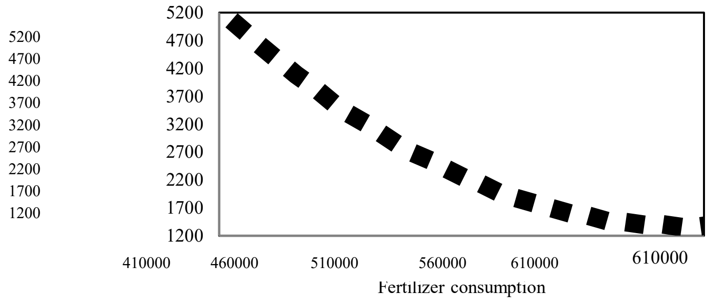


Figure 9: Optimal conditions for a temperature of 20 ° C and a rainfall of 70 mm

7. If the air temperature is 25 ° C and the precipitation is 30 mm, the optimum is as follows:

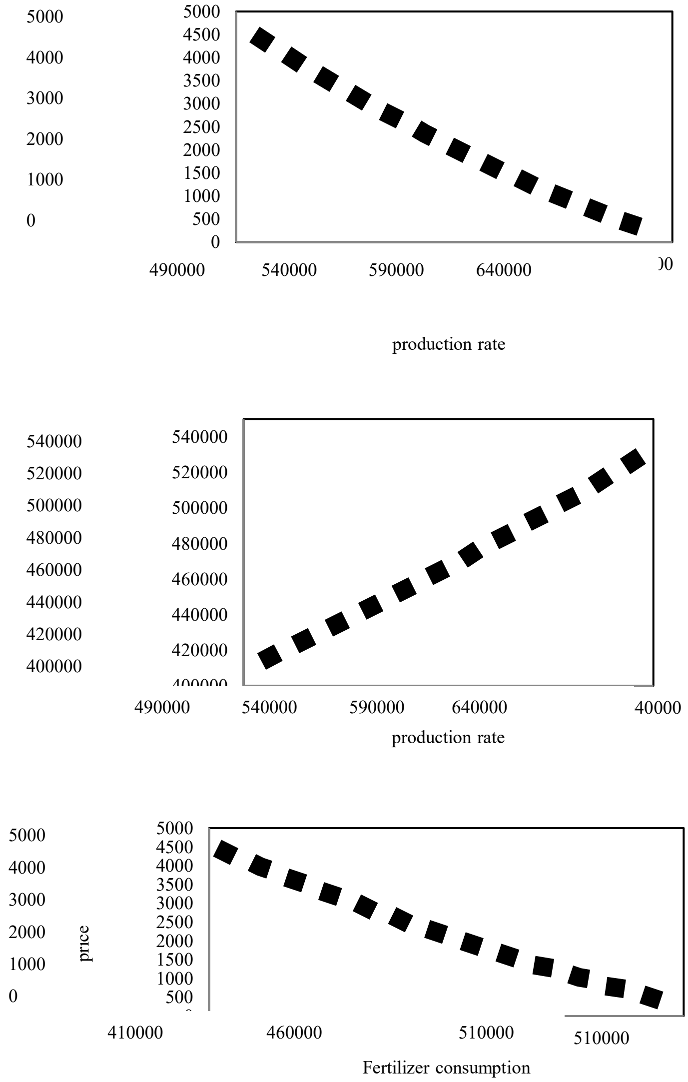


Figure 10: Optimal conditions for a temperature of 25 degrees Celsius and a rainfall of 30 mm

8. If the air temperature is 25 ° C and the amount of rainfall is 50 mm, the optimum is as follows:

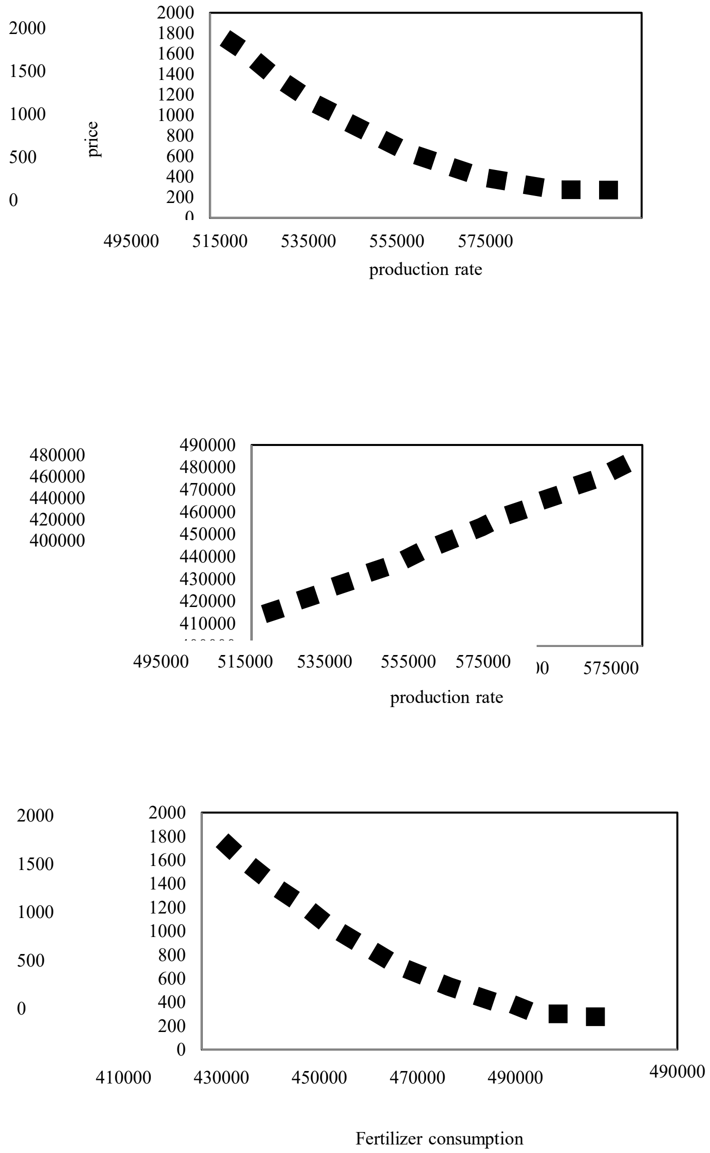
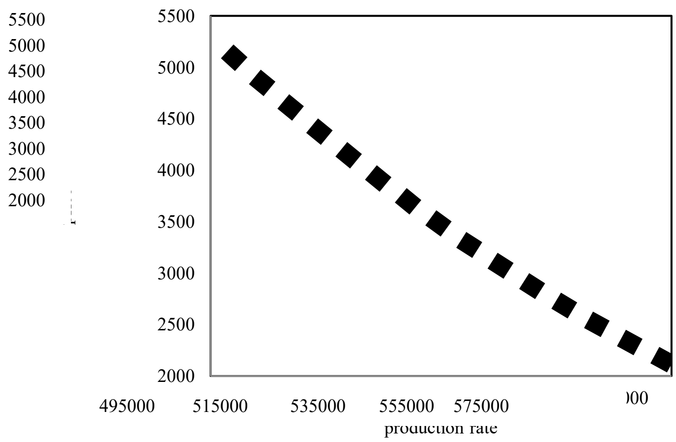
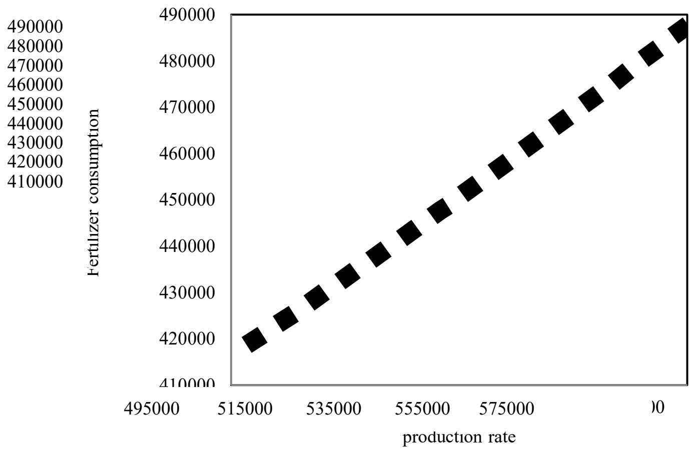


Figure 11: Optimal conditions for a temperature of 25 degrees Celsius and a rainfall of 50 mm

9. If the air temperature is 25 ° C and the amount of rainfall is 70 mm, the optimum is as follows:





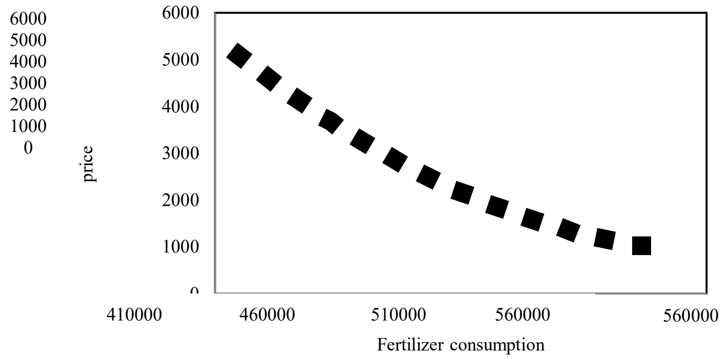


Figure 12: Optimal conditions for a temperature of 25 degrees Celsius and a rainfall of 70 mm

We should note that the choice of the final optimal point depends on government policies in the field of agriculture, but usually the use of defining the inaccessible ideal point and calculating the distance of the optimal points is associated with this point. A point from the Pareto front that has the shortest distance to the irreversible ideal point is selected as the final optimal point. The systematic tool used in this research is to support decision-making and policy-making by providing a set of optimal options and useful guidelines for formulating appropriate regulations that ultimately ensure a sustainable agricultural sector. It is noteworthy, however, that these policies only succeed if the social and economic costs associated with the transfer process are offset by a set of effective incentives (farmers must compensate for additional costs and potential income losses). In general, the framework of the present research can help to develop sustainable patterns of agricultural production, strengthen food security and reduce the problems of water scarcity and environmental degradation.

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