An optimization technique for cropping patterns and land consolidation: A case study for irrigation network

Azim Shirdeli[*] and Somayeh Dastvar

Department of Civil Engineering, University of Zanjan, Zanjan, Iran

C H R O N I C L E	A B S T R A C T
	During the past few decades, there has been growing interest in water resources management. Presently, there are many areas in middle east facing with shortage of water for agricultural activities. Therefore, there is a growing concern to have efficient usage of water through optimization techniques. This paper presents a study to maximize famers' revenue by developing a mathematical model subject to some land and water constraints. The proposed study has been applied for a case study of agricultural program in city of Abhar, Iran and the preliminary results indicate that it could increase the efficiency of agricultural program, significantly. In our survey, the optimal cultivation yields for four five-year programs have increased the income by 20.81, 44.698, 87.18 and 250.34 percent, respectively. In addition, 7.27% development land is added to agricultural lands, there is a 17% increase in water utilization and the productivity is increased from 50% to well above 77% after four 5-year programs have been implemented.

1. Introduction

During the past few decades, there has been growing interest in water resources management (Esat & Hall, 1994; Lindenmaier et al., 2003; Colbach, 2010). There are several reasons for having water shortage for agricultural activities such as growth of population (Vasseur et al., 2013), global warming (Yang et al., 2011; Waha et al., 2013; Matthews et al., 2013). Presently, there are many areas in Middle East facing with shortage of water for agricultural activities (Kangrang & Compliew, 2010). According to Long et al. (2014), farmers must implement an assortment of management practices to ensure the sustainability, economic viability, and resilience of their operation. According to Aghajani et al. (2013), augmenting or limiting cultivation of agricultural crops in various areas could be accomplished by considering different constraints and availability of fertile agricultural land. They performed an optimization technique and reported that optimum cropping pattern could increase the total profit of regions in Iran, significantly. Mirkarimi et al. (2013) proposed a fuzzy goal

 *Corresponding author. Tel: +989127434545
E-mail addresses: azimshirdeli@yahoo.com (A. Shirdeli)

programming for optimizing cropping patterns under three scenarios and found that their proposed model could significantly increase the profit of agricultural program.

Mihara (1996) studied the effects of agricultural land consolidation on erosion processes in semi-mountainous paddy fields of Japan. Thomas (2006) performed a survey on property rights, land fragmentation and the emerging structure of agriculture in Central and Eastern European countries. Alabdulkader et al. (2012) presented a model to optimize the cropping pattern in Saudi Arabia to maximize the net annual return of the agricultural sector in the country and ensuring the efficient allocation of the scarce water resources and arable land among the competing crops. They reported a potential for Saudi Arabia to maximize its cropping pattern and to build an estimated net return equivalent to about 2.42 billion US$ per year. The optimized cropping pattern in Saudi Arabia was coupled with about 53% saving in water consumption and about 48% reduction in the arable land consumption compared with the base-year cropping pattern. Comparable weights was devoted to various crop groups by allocating about 48.4%, 35.4%, 13.1%, and 3.2% to grow cereals, fruits, forages, and vegetables, respectively.

Dariane and Hughes (1991) developed a model for real-time operation of an irrigation reservoir with the objective of maximizing the value of multiple crop yields during a growing season. Their model used monthly additive and product forms of crop yield functions for dry matter and grain crops, respectively. They claimed that the proposed model results had been better in terms of net benefits from crop yields. Dury et al. (2013) presented an analysis of farmer cropping-plan decision-making. They surveyed 30 farmers to investigate the dynamics of their cropping-plan decision-making on irrigated arable farms. They analyzed the ways farmers managed uncertainty through planning and reactive decisions and reported that representing cropping plan selection only as a resource-allocation or crop-rotation-design problem would not be enough to account for farmers' decision-making processes. They explained that cropping-plan decision making would not happen once per year or per rotation, as is usually represented in models, but is a continuous process mixing design and adaptive activities.

2. The proposed study

In this section, we present mathematical model to determine the amount of land for cultivating different products and the amount watering each product in order to maximize total profit. Let p be the index of each product, c_p be the selling price of product p, s_p be the area of land, which is devoted for product p. In our survey, each product has a specific yield y_p, $w_r(p,t)$ and $w_d(p,t)$ be the amount of water assigned and the amount of devoted water for product p at time i, respectively. Finally, let $l(p,t)$ be the amount of water stress for product p at time t. The proposed study of this paper maximizes the following objective function,

$$\max z = \sum_{p=1}^{n} c_p s_p y_p \prod_{t=1}^{T} \left[\frac{w_r(p,t)}{w_d(p,t)} \right]^{l(p,t)} . \tag{1}$$

There are two constraints associated with the proposed study of this paper. The first constraints specifies the limit on the amount of land devoted to all products as follows,

$$\sum_{p=1}^{n} s_p \leq s_0 , \tag{2}$$

where s_0 is the total amount of available land to be given to all products. In addition, we consider the following constraint for the amount of water specified to all products.

$$\sum_{p=1}^{n} w_r(p,t) \le w_0(t),$$

(3)

where $w_0(t)$ represents total amount of water, which could be specified to all products. As we can observe from the results of the mathematical model, there are two types of variables, s_p and $w_r(p,t)$.

3. Case study

The city of Abhar is a county in Zanjan Province in Iran. The capital of the county is Abhar and at the 2006 census, the county's population was 158,544, in 41,333 families. Abhar in the southeastern city of Zanjan in the range of 49 degrees 12 minutes east longitude and 36 degrees 11 minutes north. The city has an area of 3,200 square kilometers and the average elevation of 1550 meters above sea level. This city includes of four regions of Abhar, Soltanieh, Sayyn castle and Hydj. There are some efforts to build some dams to provide necessary water supply for agricultural product. Fig. 1 also shows Cadastral maps for Boein coastal dams before integration and the development of agriculture.
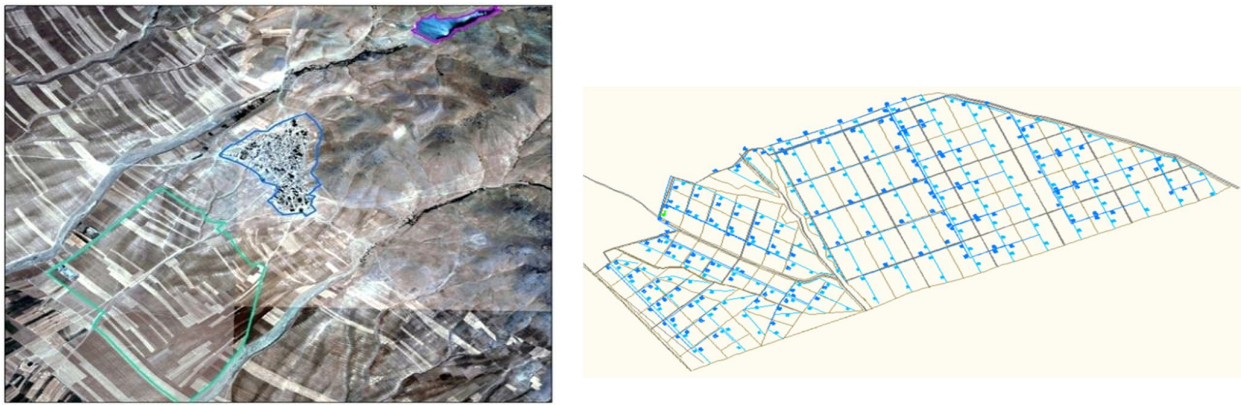

Fig. 1. Satellite photo of Cadastral maps Boein coastal dams before integration and the development of agriculture

There are two types of dry and land farming. Table 1 demonstrates the maximum amounts of products produced.

Table 1
The maximum amount of products obtained based on two systems in terms of kilogram per hectare

Item	Product	Land farming	Dry farming
1	Grain	8200	1185
2	Corn	65000	-
3	Potato	64500	-
4	Wheat	8324	1850
5	Beans	4435	-
6	Hay	8700	1339
7	Lentils	-	500
9	Peas	450	-
10	Tomato	85000	-
11	Apple	94998	-
12	Peach	5962	-
13	Grapes	44998	-
14	Nuts	5300	-

In addition, Table 2 demonstrates the amount of water flow in each month for each product.

Table 2
The amount of water flow needed for each product in term of thousand cubic meter per hectare

Month	March	April	May	June	July	August	September	October	November	December	January	February
Grain	0.57	0.82	0.37	0	0	0	0	0	0	0	0	0.14
Corn	0	0	0.61	1.76	1.8	1.05	0	0	0	0	0	0
Potato	0	0.19	1.31	1.88	1.77	1.12	0	0	0	0	0	0
Wheat	0.57	0.89	0.84	0	0	0	0.06	0	0	0	0	0.14
Beans	0	0	0.53	1.59	1.77	0.88	0	0	0	0	0	0
Hay	0.63	0.97	1.78	2.145	2.06	1.54	0.98	0.29	0	0	0	0
Lentils	0	0.66	1.55	0.7	0	0	0	0	0	0	0	0
Peas	0	0.66	1.55	0.7	0	0	0	0	0	0	0	0
Tomato	0	0	0.96	2.12	2.11	1.1	0	0	0	0	0	0
Apple	0	0.26	1.17	1.42	1.35	0.55	0	0	0	0	0	0
Peach	0	0.08	1.27	1.6	1.51	1.19	0.19	0	0	0	0	0
Grapes	0	0.6	1.54	1.85	1.75	1.38	0.19	0	0	0	0	0
Nuts	0	0.52	1.25	1.51	1.44	0.93	0	0	0	0	0	0

The implementation of the proposed study based on the information given in Table 1 and Table 2. The results of the optimal amount of land and water devoted to two types of dry and land farming and the results are given in Table 3. The optimal solutions are provided in terms of four phases of an economic program as well as some basic plan.

Table 3
The optimal solution

	Phase 1		Phase 2		Phase 3		Phase 4		Basic	
	Land	Dry	Land	Dry	Land	Dry	Land	Dry	Land	Dry
Grain	12.57	19.61	5.8	20.11	4.35	20.61	3.62	11.21	6.57	7.12
Corn	0	0	0	0	0	0	4.62	0	2.89	0
Potato	8.29	0	8.48	20.11	8.67	0	4.71	0	5.26	0
Wheat	8.29	19.61	8.48	0	8.67	20.61	4.71	60.71	18.4	88.54
Beans	8.29	0	8.48	20.11	8.67	0	4.71	0	15.77	0
Hay	8.29	19.61	8.48	20.11	8.67	20.61	12.39	11.21	20.24	0.33
Lentil	8.29	19.61	8.48	20.11	8.67	20.61	4.61	11.21	0	2.45
Peas	8.29	19.61	8.48	0	8.67	20.61	4.61	11.21	0	1.56
Tomat	8.29	0	8.48	0	8.67	0	4.71	0	3.61	0
Apple	8.29	0	8.48	0	8.67	0	4.71	0	19.41	0
Peach	12.3	0	19.64	0	21.67	0	52.56	0	5	0
Grape	8.29	0	8.48	0	8.67	0	4.7	0	2.55	0
Nuts	8.29	0	8.48	0	8.67	0	4.71	0	7.69	0

4. Discussion and conclusion

Being situated in arid and semi-arid climate, has manifested water as the most limiting and important factors of production in many agricultural parts of Iran. Small agricultural lands, improper irrigation and drainage techniques, inefficient cropping pattern and water allocation with other similar problems, are major barriers for increasing agricultural production in Iran. In this paper, we have presented an optimization technique for increasing water use efficiency in agricultural systems. The proposed study has gathered some information such as satellite imagery and cadastral maps with available data and information such as cultivated area, yield and price for irrigated and rain-fed crops in Abhar District, Zanjan province. In addition, the impacts of agricultural land consolidation and optimal cropping pattern on cultivated area and water use efficiency, as well as water productivity and farmers' gross income have been investigated. The results of our survey have indicated that the amount of water used in the city for agricultural program presently has reached to 422 million cubic

meters. According to the results of Table 3, the farmers' income will substantially increase when the mathematical model has been implemented for optimally using land for special products. The efficiency of water consumption for agricultural products can be increased from 50% to 76%. In addition, total incomes of the farmers have increased by 250.34% and 7.27% of the agricultural lands would be increased when the plan is completely implemented.

Acknowledgement

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