Alexandria Engineering Journal (2017) xxx, xxx–xxx

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Alexandria Engineering Journal

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ORIGINAL ARTICLE

Optimization of the cropping pattern in Egypt

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Received 25 February 2017; revised 12 April 2017; accepted 19 April 2017

KEYWORDS

Cropping pattern;
Linear programming;
Net return;
Optimization

Abstract Continuous increase of population in Egypt, limited fresh water, poor maintenance and low efficiency of irrigation systems lead to a real burden on the Egyptian natural water resources. Accordingly, for Egypt, land and water resources management is considered an absolutely strategic priority. In this study, a linear optimization model is developed to maximize the net annual return from the three old regions of Egypt. Data for 28 crops in five years from 2008 to 2012 are being analyzed. The spatial variations of crops, irrigation water needs, crop yields and food requirements are incorporated in the model. The results show that there is a significant reduction in the allocated areas for onion, garlic, barley, flax, fenugreek, chickpeas, lentil and lupine since they are considered as non-strategic crops. On the other side, the allocated areas for strategic crops such as wheat, maize, clover, rice, sugar products and cotton remained almost the same to satisfy their actual food requirements. However, crops with high net returns such as tomatoes have increased substantially. The trend for the gross net benefit is decreasing and is expected to reach a lower value in year 2017. Different approaches and scenarios are analyzed. The developed model proposes a change in the cropping pattern in the old lands of Egypt to increase the gross net return without adding further any other expenses.

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1. Introduction

Due to the rapid change in population and urbanization, land and water resources are becoming very limited. Subsequently, crop optimization has received extensive attention in recent years and mathematical models have been developed to determine the optimal use of the available resources for maximizing the net benefits subjected to some constraints. Land and water are the key factors for sustainable agricultural development of a nation. With the increasing trend of the population in Egypt, availability of fresh natural resources is under threat. Although there have been extensive efforts that had partly succeeded in introducing the concept of water management and led to the formation of different water board organizations at different levels, most of these organizations are not functioning properly and the need for an optimization model is crucial to support planning for water resources development and management in Egypt.

Various techniques for optimization have been developed for making the most efficient use of the available resources. Kuo et al. [17] focused mainly on developing an irrigation and planning model using a customized genetic algorithm to simulate an on-farm irrigation system, and optimize the allocation of the irrigated area to alternative crops for maximum net benefit. Benli and Kodal [4] compared a nonlinear optimiza-

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Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2017.04.015
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tion model to a linear one and found that the former can give higher farm income values than the linear one under deficit irrigation conditions. Boustani et al. [5] used multi-objective programming approach to determine the optimal cropping pattern in, Jahrom region, Iran under water deficit condition. Based on their results, it is possible to reduce water usage and conserving the current gross margin at the same time without imposing any additional risk. Karamouz et al. [16] developed an agricultural planning optimization-simulation model to optimize the cultivated area, crop pattern, and irrigation efficiency considering the climate change impact. The result shows the significance of using different tools and methods in assessing and allocating water resource in regions with limited water resources. Alabdulkader et al. [2] formulated a mathematical sector model to determine the optimal one-year cropping pattern in Saudi Arabia aiming at maximizing the net annual return of the agricultural sector and ensuring the efficient allocation of the scarce water resources and arable land among the competing crops. The optimized cropping pattern results in about 53% saving in the water use and about 48% reduction in the arable land use compared to the base-year cropping pattern.

Among these different models, Linear Programming (LP) 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 [3]. Several researchers have applied LP models to develop an optimal cropping pattern within the available resources and constraints of their study area as can be seen in Maqsood et al. [23], Haouari and Azaiez [13], Salman et al. [25], Hassan et al. [14], Aghajani et al. [1], and many others.

Sarker et al. [26] developed a LP model to determine the area to be used by different crops for their maximum contributions taking into account the land types, alternative crops/crop combinations, and investment. Their study reveals that the choice of the right crop for the proper type of land is the key parameter that maximizes the contribution. Garg and Ali [12] applied a two-level optimization model to Dadu canal command of Lower Indus Basin to obtain the optimal cropping pattern considering the impact of variation in sowing dates on the peak water requirements. In the first level, LP model gives optimal cropping patterns and monthly water withdrawals from canal and at second level, the optimized sowing dates are obtained using an integer programming model. The results show an overall increase of 40% in the crop intensities and 38% in the benefits over the existing ones. Singh and Panda [27] developed a LP model taking into accounts various hydrologic and economic factors: yield, cost of production of the crops, unit cost of irrigation water and groundwater, quality of mixed water and net irrigation requirements. The model results show a reduction in rice, mustard, barley, and gram areas against an increase in cotton, sugarcane, wheat, millet, and sorghum under optimal cropping pattern. The net annual return from the study area has increased by about 26%. Hove-Musekwab [15] developed a LP model that helped to determine the optimal cropping pattern for an irrigation scheme in Masvingo, Zimbabwe. As a result of the optimal solution, a farmer's income could be increased by 87%. Galán-Martín [11] presented a decision-support tool based on a multi-stage LP model that identifies optimal cropping plan and applied it to the Spanish agricultural regions. Their results show that each region could maximize its profit by implementing different cropping patterns and establishing an adequate basic payment value among farmers.

The objective of the present study focuses on finding the optimal cropping pattern for the old lands of the three regions in Egypt based on the available data from 2008 to 2012 to give the maximum profitability to the farmers assuming no deficiency in water. From the optimized results, the expected total net return for the year 2017 is obtained. Estimation of the optimal cropping pattern will take into account some of socio and economic constraints set by the government. These constraints aim to achieve food security, self sufficiency, effective use of the available water resources; in addition, keeping the available areas of the crops as high as possible for strategic crops.

2. Existing cropping pattern data

The study area is the old lands of the three regions in Egypt: Lower Egypt, Middle Egypt, and Upper Egypt. Available data from five consecutive years (2008 till 2012) are used to prepare the model. In Egypt, the agricultural year is divided into three different seasons ,namely winter (from September to November), summer (from February to May), and nili (from July to August) seasons. Twenty-eight crops are selected for the study according to their importance to the decision makers, and populations.

2.1. Available cultivated area

Table 1 shows the area utilized for cultivation of some of the major crops in the old lands of the three regions in Egypt under the existing cropping pattern during the five years 2008 up to 2012. According to the table, the maximum total available area for cultivation is found in year 2008, about 9.987 Million feddan (1 feddan (fed) $\simeq$1.038 acres), while the minimum total area is 9.486 Million fed in 2010. The available area for cultivation is approximately equals to 9.654 ± 0.2 Million fed on average for the whole five years. The total available cropped area for each year is distributed over winter, summer and nili seasons of the year. During the period (2008–2012), the cropped area in winter season has represented approximately 50.22% of the total cropped area compared to the summer season area (45.75%) and the nili season area (4.03%).

For ease of presentation, some crops that are cultivated in different seasons or that have different species or that are related to the same product are grouped together. For example, summer and nili Maize are grouped as Maize; the same for Tomatoes and Potatoes; Perennial Clover and Tahreesh Clover are grouped as Clover; Sugar Cane and Sugar Beet are grouped as Sugar products; Peanut, soybean, sesame and sunflower are grouped as food oils products.

The crops occupying the major areas of the study area are Wheat (26.11% of the total area), Maize (21.18%), Clover (17.44%) and Rice (13.96%) as shown in Fig. 1. However, crops such as cotton, sorghum, sugar cane and sugar beet are being cultivated in reasonably small quantities. Lastly comes tomatoes, and potatoes as important crops for farmers for their high net return and vegetable oils as a strategic food commodities such as peanut, sesame, soybean, and sunflower with less than 0.5%. According to the Ministry of Agriculture and Land Reclamation, Egypt suffers a large deficit in the production of edible oils and costs the state budget about 1.5

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