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Determining an optimum cropping pattern for Egypt

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DETERMINING AN OPTIMUM CROPPING PATTERN FOR EGYPT

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ABSTRACT

Agriculture is considered to be the major economic activity in Egypt despite the government policies that favored other sectors since the second half of the 20th century. However, Egypt currently faces a food security challenge that stems from the increasing demand for food in light of huge population growth and the inability of the agricultural sector to fulfill the abovementioned increasing demand.

This research focuses on the vertical expansion of the agricultural sector through attempting to determine the optimum cropping mix for Egypt in the year 2017. A fuzzy goal programming (FGP) approach for optimal land allocation is utilized. In the model formulation, five goals were modeled; namely crop production, net profit, investment, fertilizers and water requirements. A tolerance based FGP technique was employed to account for the fuzziness of the selected goals.

Without imposing any constraints to ensure food security, results show that it is not optimal to grow strategic crops, including wheat, broad beans, and maize. Accordingly, constraints were set on the minimum land allocations to strategic crops. Results of the model indicate that achieving food security has some costs in terms of profitability and fertilizers utilization. Yet, it is possible for the government to target higher levels of self-sufficiency of strategic items as the costs are tolerable. The resulting land allocations indicated that the profit goal was fuzzily achieved only in the winter season, yielding a level of profit that is lower than the target by only 0.68%. As for the fertilizers requirements goals, they were partially achieved in both the winter and the summer seasons. As a measure of sensitivity, the model was solved using different weight structures, and setting different constraints on essential crops stemming from the potential of a population growth rate that is greater than expected.

TABLE OF CONTENTS

TABLES

FIGURES

I. Introduction and Motivation

The agricultural sector is of paramount significance to the Egyptian economy. Agriculture contributed by 14% to GDP in the year 2010; with the value of agricultural production standing at EGP 81.370 billion in constant 2006 prices (Egypt State Information Service, 2011).Agricultural exports reached USD 1.8 billion, thus accounting for 7% of total exports in the year 2008 (FAO, 2011). In addition, agriculture is considered the largest absorber of employment as it accounts for almost 30% of the total employment. Yet, the social impact of the agricultural sector is not limited to employment. A large portion of the Egyptian population is dependent on this sector; whereby rural population in Egypt reached 46.4 million in the year 2010, representing 57% of the total Egyptian populace (World Bank, 2012).

However, Egypt lags behind in achieving self-sufficiency in strategic food commodities. In the year 2007, the self-sufficiency ratios of wheat, maize and broad beans reached 54%, 53% and 52% respectively; making Egypt a net food importer (Ministry of Agriculture and Land Reclamation (MALR), 2009). In the same year, imports of agricultural commodities reached USD 8.66 billion; representing almost 18% of the total imports. In the year 2009, Egypt was the world's top broad beans importer, the fourth largest importer of wheat, and the seventh top importer of both maize and palm oil (FAO, 2011).

Two fundamental factors contribute to Egypt's food security challenge: the rapidly growing population; and the limited availability of agricultural land. The escalating demand for food in Egypt stems from a population that has almost tripled in size during the last 50 years. Population in Egypt reached almost 80 million in 2010 up from 29 million in 1960; and is currently growing at an average rate of 1.8% annually (World Bank, 2012). Meanwhile, agricultural land has increased by only 50% during the same period. Total agricultural land available in Egypt is estimated at 8.7 million feddan in 2010, representing only 3.66% of total land area of Egypt (FAO, 2011).Meanwhile, crop plantation in Egypt takes place in three seasons (winter, summer and nili), yielding a total cropped area of 15.3 million feddans, with 175% crop intensification rate. In spite of

the government's continuous efforts to expand agricultural production horizontally through land reclamation, the per capita share of agricultural land in Egypt has been declining over time. The per capita share of agricultural land has dropped from 0.22 acres to 0.10 acres during the last 50 years (FAO, 2011). This is attributed not only to the rapidly growing population, but also to different forms of land degradation in Egypt, such as urbanization and the expansion of residential areas. Thus, the horizontal expansion of agricultural land masks the loss of high quality, fertile land due to land degradation.

Expanding agricultural land in Egypt is tightly constrained by the availability of water. Egypt's total renewable water resources are estimated at 57.3 billion cubic meters per year, most of which originate from external resources. Nile River is the major source of fresh water, supplying 96% of renewable fresh water resources. The annually allocated flow of Nile water to Egypt is 55.5 billion cubic meters per year, as set by the "Nile Water Agreement" signed in 1959. Thus, the supply of water resources needed for multiple purposes is fixed in the face of growing demand as a result of the rapid population growth (Hefny & Amer, 2005). Moreover, in May 2010, a number of Nile basin countries, seeking to increase their share of water from the Nile River, signed a Cooperative Framework Agreement. The signatory countries are attempting to replace the 1959 treaty (whereby upstream countries required Egypt's and Sudan's approval prior to implementing projects that affect the flow of the Nile's water to Egypt and Sudan) with this Cooperative Framework Agreement, which furthermore endangers Egypt's supply of renewable water. The remaining percentage of Egypt's renewable water resources is supplied through underground water (1.3 billion cubic meters). The scarcity of water resources in Egypt is coupled with inefficient utilization of water. Despite the fact that 86% of Egypt's water resources are dedicated to agriculture, the amount of water losses is huge. In the year 2008, water losses of irrigation water attributed to evaporation and leakages reached 31% of total water (CAPMAS, 2008).

The escalating demand for food in Egypt cannot be met through importation only. The uncertainties associated with agricultural production causes sharp fluctuations in the yield of key food items worldwide, thus causing sharp volatility in international prices.

For instance, the adverse whether events that hit the world in 2010 caused shortfalls in the production of key grains, including wheat, maize and rice. This was translated in higher food prices. In March 2011, the World Bank's food price index reached its 2008 peak, increasing by 36% above its level in the previous year; thus, leading to a high level of food inflation in Egypt that 19% in February 2011 (World Bank, 2011). In order to meet the escalating demand for food, both the horizontal and vertical development of the Egyptian agricultural sector have become key priorities to policymakers. The continuous land losses, coupled with water scarcity magnify the importance of more efficient utilization of available resources. Therefore, integrated planning of agricultural resources is a key policy tool that should be adopted.

The study focuses on the vertical expansion of the agricultural sector through attempting to determine the optimal crop pattern for Egypt for the year 2017.Estimating the optimal crop mix shall take into account the government's multiple objectives that aim at achieving food security, efficiently utilizing the available water resources; in addition to achieving social justice by maximizing profitability to the farmers. These objectives are constrained by several factors hindering the expansion and development of the agricultural sector; the most important of which is the availability of water and capital resources. In addition, the issue of ambiguity associated with agricultural production must be accounted for in determining the optimal crop mix. Based on the Strategy for Sustainable Agricultural Development towards the year 2017, issued by MALR, the study examines three major hypotheses:

(i) Examining the applicability of the aforementioned strategy;

(ii) Assessing whether the cropping pattern proposed by the aforementioned strategy is the optimal crop plan for the Egyptian context; and

(iii) Mapping the strategy using a new methodology.

In this regard, the study accepts a number of assumptions presented in the strategy regarding the target self-sufficiency ratios of strategic crops necessary to achieving food security.

Having generally discussed the topic and the motivation, the second chapter presents a survey of the literature; and the third chapter presents an overview of the agricultural sector in Egypt. Chapter (4) describes the proposed methodology, with the results of the model presented in chapter (5). Chapter (6) presents the results of the sensitivity analysis for the model results; and chapter (7) concludes.

II. Literature Review

Crop planning involves two distinct policy tools; namely crop rotation and crop mix. The literature review shall focus on studies attempting to determine optimal crop mix. However, the first section of the literature review shall briefly present some of the key studies that discussed the optimum crop rotations.

2.1 Literature on Crop Rotations

Crop rotation involves the decision to plant a sequence of crops in successive years on the same piece of land, while sustaining crop succession requirements (Hildreth & Reither, 1951; and Mohamad & Said, 2011). Attempts to determine the optimal crop rotation existed in literature since Heady (1948), who attempted to determine the most profitable rotation of feed grains and forage crops. Heady did not apply any mathematical techniques. Rather, he presented a theoretical solution for the choice of output that maximizes farm profits using the iso-revenue and iso-cost curves, through getting the highest iso-revenue consistent with the iso-cost curve.

Later, studies on crop rotations employed various mathematical techniques, the most common of which was Linear Programming (LP). Among the earliest attempts to employ LP was that by Hildreth and Reither (1951), who developed a crop rotation model for three crops using alternative LP activities. Other studies that attempted to model optimal crop rotations using LP include Musser et al. (1985); McCarl & El Nazer (1986); Dogliotti et al. (2003); and Haneveld & Stegeman (2005). Detlefsen and Jensen (2007) further developed the use of the LP framework in solving for optimal crop rotations, as they modelled crop rotations using the network flow model[1]. By taking into account previous seasons, the model is used to estimate the optimal crop rotations in future years by maximizing the gross margins for each sequence of crops.

[1] The network flow model is a LP model with a special structure. It utilizes networks that consist of nodes and arcs, where each node represents a predetermined supply or demand. The objective of the network is to find a flow such that supply or demand is satisfied at each node and the value is maximized by converting the network to LP problem.

Other studies suggested different techniques to determine the optimum sequence of crops. In order to model uncertainty in crop rotations, Castellazzi et al. (2008) used transition matrices to quantify the crop sequence in rotations. The transition matrices had a "Markovian property" that the allocation in a given year is dependent on that of the previous year. The advantage of using transition matrices is that they represent stochastic processes that accounts for uncertainty in modeling crop rotations. Furthermore, Castellazzi et al. (2008) extended their representation of rotations to consider cases where farmers might want to change between several rotations using transition matrices as well. Another crop rotation optimization model is CropRota, a linear optimization model that "integrates agronomic and economic criteria, in addition to historical crop mixes at field, farm or regional scales to generate optimal crop rotations" (Schonhart et al., 2011). The model seeks to maximize the total agronomical value of crop sequences in crops rotations. The model was validated for empirical field observations at the farm level for 579 farms in Austria for seven years (Schonhart et al., 2011).

2.2 Literature on Determining the Optimal Crop Mix

Crop mix, on the other hand, is a crop planning system that involves "more than one crop being cultivated simultaneously during the same cropping period" (Mohamad & Said, 2011). Various mathematical techniques were also used in an attempt to model the optimal combination of crops; the most common of which was LP.

2.2.1. Applications of LP in Determining the Optimal Crop Mix

A survey of literature revealed that LP is most widely used the technique to solve optimization problems that seek to determine the optimal crop mix, either by maximizing return or minimizing costs, subject to a set of constraints. Henderson (1959) was among the earliest studies that applied LP to determine the optimum land utilization. A LP problem, based upon maximizing the farmer's expected net return, was applied for independent decision making units (individual farms) for the planning year 1955 for eleven crops (Henderson, 1959).

In 1964, Heady and Egbert used LP to determine the efficient crop production plan for 122 regions in the United States for the year 1965. The objective of the model was to minimize costs, subject to a number of constraints, including land constraints, national requirement constraints, in addition to bounds on each crop for each region. In their paper, Heady and Egbert (1964) estimated the costs for the year 1965 based on projections of trends in technology and inputs for the period 1949 - 1959. They based their estimated for consumption on population and per capita income projections and on existing knowledge of price and income elasticities of demand.

Several studies on developing countries applied LP to determine the optimum crop mix. Sarker et al. (1997) developed a LP model for annual land allocation among alternative crops in Bangladesh that seeks to determine the area to be used for different crops. The objective was to maximize the contribution from cropping and food importation. Furthermore, Sankhayan and Cheema (1991); and Singh et al. (2001) formulated a LP model to determine the optimum cropping patter for different farms in India, with the objective of maximizing net return. Their models were subject to constraints on working capital, fertilizers requirements, water availability, the cultivation of certain crops necessary for local consumption, in addition to socio-economic conditions. Khan et al. (2005); and Hassan et al. (2005) also applied a profit maximization LP model to solve for the optimum cropping pattern in different provinces in Pakistan. Recently, Mohamad and Said (2011) utilized LP to determine the optimal crop mix for Malaysia for a planning horizon of 12 months. The objective function was to maximize total revenues at the end of the planning period. The proposed LP model incorporated the age of maturity of the crops under study to account for the fact that different crops mature at different ages. The model included varying parameters of the initial level of capital and monthly requirement of administrative expenses.

However, according to Burton et al. (1987), LP is based on a number of assumptions of additivity, linearity, divisibility and finiteness, which reduce real world complexities into a mathematical formulation that generates only one optimal solution to the problem.

2.2.2 Uncertainty in Determining the Optimum Crop Mix

The agriculutral sector is charactereized by high uncertainty that is caused by exogenous factors related to the nature of agricultural production. LP models that are based on either profit maximization or cost minimization disregard uncertainty.Literature on determining the optimal cropping pattern includes different mathematical models were used to account for uncertainty, among which is quadratic programming. Hazell (1971) presented a quadratic programming model that is based on the "expected income-varince (E – V)" criterion. The model seeks to "develop a set of feasible farm plans having the property that the variance is minimum for associated expected income level" (Hazell, 1971). Also, Wiens (1976) applied quadratic programming to analyze the effect of risk aversion on farm planning using the maximization of the E-V onjective function approach. Yet, due to potential problems that might arise in the computational procedure, Hazell (1971) suggested the use of the Minimization of Total Absolute Deviations (MOTAD) model as a simplified transformation of quadratic programming. The MOTAD model measures risk as absolute deviations from a target goal. The model is transofrmed into a LP problem that minimizes the mean absolute income deviations. Maleka (1993) applied the target MOTAD model to determine the optimal cropping pattern in Zambia, given the stochastic nature of rain fall.

Alternatively, Itoh et al. (2003) tackled the problem of uncertainty by using a fuzzy model[2] that seeks to maximize the minimum values of total gains, with the profit coefficients defined as n-dimenssional discrete random variables with certain probabilities.

2.2.3. Multi-objective Programming in Determining the Optimal Crop Mix

The "Multiple Criteria Decision Making" (MCDM) is another approach used in literature on agricultural planning. MCDM applications are considered more superior over the LP modelling, as they allow for tackling multiple objectives.In agricultural

[2]The fuzzy model is then transformed to a linear programming problem that is being solved given the constraints on the model.

planning, determining the optimal allocation of land requires decisionmakers to consider a number of socio-economic objectives, including the availability of resources, profitability, investment and employment. Thus, utilizing MCDM applications makes the problem more realistic. MCDM applications yield satisfactory criteria rather than optimizing the various objectives. In addition, they generate alternative solutions; thus allowing for a more insightful decision making(Sinha et al. (1988); Siskos et al. (1994); Sarker & Quaddus, 2002; and Oliveira et al. (2003)). In the resolution of MCDM problems, scaling methods are used to standardize the data. In addition, weighting methods are used to assign a preference to each criterion according to the decision maker's evaluation (Ravindran et al., 2010).

Among the mathematical tools of MCDM is the multiobjective linear programming model (MOLP). MOLP generates a set of efficient solutions, also called "non-dominated or pareto-optimal solutions" (Piech and Rehman, 1993). Siskos et al. (1994) applied a multi-objective linear programming model to determine the optimum land allocation among different crops in a Tunisian region. The objective functions to be optimized in the problem included maximizing gross margin of profit, employment and forage production, in addition to minimizing seasonal labor and tractor utilization.

Goal programming (GP)[3] is another multi-objective technique, commonly used in land planning problems. According to Siskos et al. (1994), "the popularity of the use of GP is attributed to the fact that it captures a rich set of properties of a real decision situtaion by incorporating the decisionmaker's judgement policy about organizational goals and their priorities". Literature on the use of GP in agricultural planning both on a farm level and national level includes studies by Wheeler and Russell (1977), Barnett et al. (1982), and Oliveira et al. (2003), where different goals were taken into consideration. Moreover, Pal and Basu (1996) presented a land planning model for an Indian district

[3]GP enables the optimization of multiple objective functions, where goals for the objectives are identified. Priorities are assigned to goals based on their relative importance, while weights are assigned to goals that have the same priority level. The objective functions are then transformed into linear constraints in order to minimize the undesirable deviation from the identified goals (Pal and Basu, 1996; and Sarker& Quaddus, 2002)

through a priority based GP model. The goals incorporated were: 1) the minimization of over-utilization of land, 2) the minimization of under achievement of production targets, 3) the minimization of over consumption of water, and 4) the minization of over utilization of of labor, machinery and cash expenditure. In the solution procedure, the highest priority was given to one of the goals and a sensitivity analysis with variation of the priority structure of the other goals where also presented. Pal and Basu (1996) introduced the "Euclidean Distance Function"[4] to choose the appropriate priority structure. Furthermore, Sarker and Quddus (2002) considered modeling a nationwide crop planning problem for Bangladesh using goal programming. Three goals were identified for the case of Bangladesh; namely, 1) maximizing returns from cultivated land, 2) minimizing the dependency on imports of basic food needs, and 3) minimizing the investment required for cropping. Results were compared to those obtained using LP with the objective of maximizing total contributions (the benefits that can be obtianed from both cultivation and importation). Results showed that the solution obtained through GP was more realistic in terms of land allocations to certain strategic crops, compared to the solution obtained from LP.

The third application of MCDM methods is Compromise Programming (CP)[5]. It was applied by Johnson et al. (1991) to a regional agricultural production model in order to determine the optimal crop production in a major Corn Belt watershed, providing information on the efficient economic-environmental tradeoffs.Three minimization functions were included in the model; namely, production costs, future value of productivity loss and sediment damage. The CP framework allows for the identification of efficient ranges of crop production, given the three goals.

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[4]According to Biswas and Pal (2005), the Euclidean Distance Function is used to measure the "ideal point dependent solution" in order to identify the best order of the identified goals that would yield the most satisfactory decision.

5 Compromise Programming (CP) attempts to find the closest solution (has the shortest distance) to the "ideal point". The ideal point is where the multiple objectives simultaneously reach optimal values (Shiau and Wu, 2006). Closeness is measured using a distance function that minimizes the distance between each solution generated and the ideal point (Piech and Rehman, 1993).

Piech and Rehman (1993) applied three of MCDM methods, namely, GP (for which sensitivity analysis for different weights assigned to the multiple goals was applied), MOP and CP to a land planning problem for a university farm in the UK. Five goals were incorporated in the model; namely maximization of gross margin, maximization of permenant labor utilization, minimization of hiring labor, minimization of total variable costs and maximization of business trading surplus. Results indicated that the three techniques give superior results to simple LP as they model multiple objectives that are important to policy makers. In addition, the study concluded that GP, despite not introducing any computational difficulties, is inferior to the two other techniques because it only gives one solution, instead of offering a set of solutions. In addition, it presents a problem to the researcher in assigning weights to different deviational variables. Furthermore, it requires many information that are sometimes difficult to obtain, such as target values and weights. MOP is more complicated in its computational process. It generates a set of efficient solution, which raises the problem of how to select the best/ most optimal solution. CP is more superior to MOP because it defines the part of the efficient set that is the closest to the ideal point (Piech and Rehman, 1993).

2.2.4.Fuzzy Sets and Multi-objective Programming in Land Allocation Problems

The use of multi-criteria programming techniques in agricultural planning has been criticized for the parameters of the model should be accurately defined, which is not always the case in agricultural planning. This is attributed to "the expert's ambiguous understanding of the nature of [the parameters]. So, assigning of definite aspiration levels to the goals of the problem frequently creates decision trouble in most of the farm planning situations" (Pal and Biswas, 2005). Therefore, the parameters of the problem are better defined in a "fuzzy sense" in agricultural planning. Fuzzy sets were introduced to the multi-objective linear programming models by Gupta et al. (2000); and Sahoo et al. (2006), who formulated a fuzzy multi-objective linear programming model (FMOLP) for agrcicultural land planning. The objectives considered in the previously mentioned

studies were net profit maximization, labor employment maximization, energy maximization, and investment minimization; subject to a set of constraints on cultivable area, water requirements and food requirements. Furthermore, Zeng et al. (2010) proposed a FMOLP model to be applied to a crop planning problem in a chinese province. In their model, Zeng et al. (2010) transfomed the FMOLP with triangular fuzzy numbers to crisp ones, which was solved using the conventional LP technique. In the formulation of the model, the targeted objectives were maximization of net return, minimization of evapotranspiration and reaching a specific target for total grain yield.

The Fuzzy Goal Programming (FGP) technique was was first introduced by Narasimhan (1980), who developed the use of membership functions as a solution procedure. It was further developed later by Ignizio (1982), Rubin and Narishman (1984), Zimmermann (1985) and Chen (1994). Different approaches to the solution of FGP problems were observed in literature, among which are Chen and Tsai (2001) employed an additive model to solve with different importance levels and with preemptive priorities. Furthermore, Kim and Whang (1998) applied tolerance concepts to FGP; thus solving FGP problems with unequal weights as a single LP problem.

FGP was also used in agricultural planning problems. In FGP, goals, whose parameters are uncertain such as those related to crop production, net profit, and water requirements, are modeled as fuzzy. Like in GP, fuzzy goals are transformed to linear constraints in order to minimize the values of the weighted sum of tolerance allowance variables, in order to obtain the most satisfactory set of land allocations (Sharma et al., 2007).A very early attempt to apply FGP to agricultural planning was a study by Sinha et al. (1988) who applied a pre-emptive priority FGP model to develop a cropping plan for Tabagaria village in India. According to Sinha et al. (1988), “fuzzy priority levels have been considered where trade-offs between the unidimensional utilities (membership values) of the goals more closely reflect the decisionmaker’s intention about the satisfaction levels of the goals… [then the decisionmaker] tries to satisfy the goals in the second pre-emptive priority level, keeping the goals in the goals in the first pre-emptive priority level satisfied… ”. Pal and Biswas (2005) also applied the priority-based FGP to

solve an agricultural planning problem in a certain district in India. To formulate the FGP model, Pal and Biswas followed Pal and Basu's (1996) method of assigning priorities to the identified goals based on an "Euclidean Distance Function". A sensitivity analysis was performed through varying priority structures of the goals. Later, Sharma et al. (2007) applied FGP to solve on agricultural planning problems in India. However, they applied a tolerance based approach to FGP that is helpful in solving problems having "unequal weights and unbalanced membership values" (Sharma et al., 2007). In their paper, the fuzzy goals specified were production goal, net profit goal, labor requirement goal, water requirement goal and machine utilization goal. Also, a sensitivity analysis on various weight strucutres for the goals were performed.

2.3 Literature on Determining the Optimum Crop Mix for Egypt

Existing literature on determining the optimum crop mix for Egypt follows the applied literature. Studies on determining the optimum crop mix for Egypt employed the previously discussed mathematical techniques; namely LP, NLP, GP and the MOTAD model. LP was the most widely applied technique to determine the optimal land distribution in Egypt. Hanna (1970) employed LP to determine the optimum cropping pattern for Dakahlya governorate, while Siam (1973) applied LP to develop future crop production plans for each governorate. The objective function in both studies was to maximize net return from the proposed pattern. Sherbiny and Zaki (1976) also used a LP model tailored to the agronomic and institutional characteristics of Egyptian agriculture in order to assess the gains from a more efficient allocation of resources created by interregional specialization. Sherbiny and Zaki used two versions of the LP model with different objective functions but identical set of constraints that are consistent with the key features of the Egyptian agricultural sector. The two models were run using data on 17 regions and 25 crops using data on the 1965-66 years average. El Berdeesy (1979) used the LP to find the optimal crop patter for Egypt. Three models were employed in the study; the first was to maximize net return, the second to maximize national net return, and the third was to maximize net national return per unit of water. The three models were solved using both farm prices and international prices. The constraints imposed on

the model were land, water and institutional constraints imposed on the production of certain crops.

To tackle the issue of food security, El Sayed (1987) used the LP technique in an attempt to suggest an optimal redistribution for the cultivated lands in Egypt. The purpose of the model is to find the optimal land allocation that will maximize the production from the available cultivated area. El Sayed applied the model on three winter crops; namely wheat, barley and beans in both Lower and Upper Egypt's governorates, as the land productivity for each crop differs from one governorate to another.

Later, Mohamad (1992); El Kheshen (1992); Hussein and Eita (2001); and Ali (2003) also solved for the optimal crop mix for specific governorates/ regions in Egypt using the LP. The models employed maximizes either net return per feddan to farmers or return per unit of irrigation water; subject to a set of constraints including constraints on cultivated areas, water resources, and other management constraints. A recent study by Enaber et al. (2009) employed LP to determine the optimum crop pattern for Egypt with the objective of maximizing net return per feddan in addition to maximizing net return per unit of irrigation water. To account for strategic crops that are essential to achieving food security or exportation, constraints were set on the cultivation of some key crops.

Non-linear programming (NLP) was used by researchers to determine the optimum cropping pattern for Egypt. A study by Ismail and Ata (2005) modelled the optimum crop mix for Egypt using a non-linear objective function that seeked to maximize net profit, subject to a number of linear constraints on land, water resources, labor and capital. Data for the priod 1990-2003 on 45 crops were modelled. The results of the study suggested that the proposed optimum cropping patter for Egypt can increase net return by EGP 410 million compared to the existing cropping pattern. Likewise, Aly et al. (2007) used a NLP model to determine the optimal cropping pattern for desert lands in Egypt that depends on ground water by maximizing the net revenue per unit of irrigation ground water.

To account for uncertainty in determining the optimal crop mix, El Maghazy (2004); Metwally (2006); and Mohamed and Gaber (2008) used the MOTAD model to

estimate risk in agricultural production. In their studies, two LP models were formulated;the first maximizes the gross margin of profit per unit of land, assuming complete certainty in production; whereas the second model seeks to solve for the optimal crop pattern, while taking risk into consideration through minimizing total absolute deviations from the overall margins. The value of risk is obtained as the deviation of the total value of the margin of the model that takes a risk into account form the total value of the margin estimated assuming full certainty.

Applications of MCDM was also found in literature on Egypt; yet, they were scarce. Bazaraa and Bouzaher (1981) applied linear GP model to determine the allocation of crops and livestock management in Egypt. As in GP, the model minimized a weighted sum of deviation from a chosen set of goals. A number of goals need to be addressed simultaneously; namely, the levels of employment, demand, and foreign exchange. The model is subject to a set of constraints that included restrictions on the availability of resources, crop rotations, and other institutional constraints. The uniqueness of their model stemmed from the fact that it was tailored to address the conditions of developing countries, "where free market and profit maximization are not inherent assumptions of the model" (Bazaraa & Bouzaher, 1981). This model was applicable to the Egyptian case during the period from the 1950s and up till mid-1980s, prior to the liberalization of the agricultural sector. El Shishiny (1988); and Fahmy and El Shishiny (1991) also proposed GP to model the optimal land allocation for newly reclaimed lands in Egypt, including agricultural and livestock production. In addition, Ali (1991) attempted to determine the optimal cropping pattern for newly reclaimed land in Egypt for each type of ownership separately using a multi-objective optimization model. The paper identified five key goals that should be pursued to determine the optimal crop mix; namely, maximizing social return, maximizing net profit for farmers, achieving a certain level of food security, maximizing return per unit of water used, and maximizing exports of key cash-generating agricultural crops. Weights were assigned to each goal; and a sensetivity analysis was performed to determine the optimal cropping pattern.

III. The Agricultural Sector in Egypt

Agriculture plays a central role in the Egyptian economy. Egyptian policymakers pay an utmost attention for the agricultural sector for its importance in ensuring food security to the rapidly growing population. In addition, agriculture is considered the major economic activity in Egypt. It contributed by 14% to GDP in 2010; and it is the largest absorber of employment as it accounts for more than 30% of the work force (WDI, 2011). Throughout the past five decades, the Egyptian agricultural sector was subject to major policy changes that had substantial impact on the sector; and that had greatly caused major shifts in the cropping pattern. The purpose of this chapter is to shed the light over the main features of the agricultural sector in Egypt, examine their evolution over time and study their effect on the cropping pattern.

3.1 Historical Background

During the two decades 1952-1970, government intervention was an important feature of the Egyptian agricultural sector. Government intervention during this period was basically motivated by political objectives. The key goals of the government were to acquire foreign exchange through agricultural exports, provide food at low prices to the rapidly growing population in order and achieve equity of wealth and income distribution to maintain political stability (Richards, 1982; and Moursi, 1993). In this respect, the Egyptian government in the early 1950s has adopted a number of key policies to regulate the agricultural sector. First is the agrarian land reform, whereby limitations were set on the ownership of agricultural land; and regulations were imposed of the relation between owners and tenants. The purpose of this policy was to redistribute wealth in order to transform Egypt's skewed land tenure system. Land holdings of more than 200 feddans were redistributed, so that a maximum limit on land ownership was set at 50 feddans per family[6]. Furthermore, the law regulated the owner/tenant relationship, whereby it set a limit on cash rent equal to seven times the value of the tax on land (Moursi, 1993).

[6]According to Richards (1982), only 12.5% of the cultivated area was directly affected by the agrarian land reform law, with about 341 thousand families acquiring land.

Secondly, the government set regulations on the production of different crops, by introducing the crop rotations system, whereby it obliged farmers to cultivate their lands with a certain sequence of crops. This was justified by the need for scientific crop planning system that would be more effective in improving yield and fighting pests (Ruf, 1993).In addition, the government imposed pricing regulations on agricultural commodities, in order to guarantee the availability of cheap food for the Egyptian population. In order to achieve this, the government established cooperatives, where all beneficiaries of the agrarian land reform were obliged to join. The role of the cooperatives was to regulate crop rotations and provide farmers with subsidized inputs and credit facilities. Furthermore, cooperatives purchased the agricultural production from farmers at pre-determined prices, less than the international prices. As a result, the agricultural sector had become heavily taxed in favor of other sectors in the economy, which later resulted in negative implications on agricultural development and food security. According to Antle (1993), taxation was imposed on the agricultural sector through both the over-value exchange rate and by the forced delivery of agricultural production to cooperatives at prices that are lower than international prices. It is estimated that the net tax rate imposed on the agricultural sector was 30-60 percent (Antle, 1993). In addition to providing basic food commodities to the population through ration cards, price ceilings were imposed on fruits and vegetables sold in private stores. This led to a major shift in the consumption pattern of the Egyptians; and a growing demand for food (Moursi, 1993; and Shehata and Mohammad, 2010).

The policies adopted by the government during the 1950s and 1960s had, in fact, hindered the development of the agricultural sector. Growth in agricultural production lagged behind population growth; and for the first time, Egypt became a net food importer in 1974 (Richards, 1980).Therefore, by the early 1980s, reforming the agricultural sector has become a must. Being a strategic sector in the Egyptian economy, great attention was paid to reforming the agricultural sector, through adopting the first of three agricultural development strategies. The main objective of the 1980s agricultural development strategy was to liberalize the sector to increase investments. This, in turn,

would lead to increasing the production, as well as the productivity, of the agricultural sector; hence help in increasing contribution of the sector to national growth and competitiveness (Mandour, 1995). Several measures were taken in this regard, including the elimination of inputs subsidies, the elimination of quotas and the government procurement system, the liberalization of crop pricing, the reduction of protection on agricultural crops, in addition to modifying the agricultural credit system (Shousha and Pautsch, 1997). For almost all agricultural crops, farmers were allowed to sell the production directly in the market. The 1990s agricultural development strategy aimed at proceeding further with reforming the agricultural sector, increasing the annual value of agricultural exports to EGP 5 billion, in addition to achieving an annual growth rate of 3% (MALR, 2009).

The two strategies of the 1980s and the 1990s had their positive spillover effects, directly impacting the role of the agricultural sector in national income and promoting exports. Agricultural output increased significantly. In addition, growth in the agricultural sector reached 3% per annum throughout the period 1981/82 to 1986/87. During the period 1987/88 to 1991/92, the average growth rate declined to 2% per annum, but picked up again to average 3.3% (MALR, 2009). Land available for cultivation increased through the reclamation of about 2.5 million feddans. Moreover, total cropped area has increased from 11.6 million acres in 1982 to 16 million acres in 2003, as a result of the increase in cropping intensity to 180%, as there were three crop harvests per year (FAO, 2005). Moreover, the two strategies of the 1980s and 1990s shifted from targeting self-sufficiency, in its narrow sense, to targeting food security, at a broader sense through the utilization of competitive advantage in the export of certain agricultural commodities to finance the importation of other products (Siam and Moussa, 2003).

Yet, Egypt did not reap the full fruits of the agricultural reform programs, as evident by the modest growth rates of the agricultural sector, the increasing inequality, the lower productivity, and the noticeable decrease in the value of agricultural exports. There are many justifications for the less than expected outcomes for the 1980s agricultural reform strategy. Mandour (1995) attributed the less-than-expected outcomes

to many factors. First, despite the liberalization, the government continued to "fix a floor price that ensures the producer a marginal profit exceeding that of competing crops". This led to the fact that, for some crops, local market prices have become higher than the international prices. To mitigate this, the government reduced the prices of exporting commodities, such as maize, rice and cotton from the declared prices to encourage exportation, which made farmers refrain from cultivating these crops. Furthermore, the elimination of subsidies on inputs and on agricultural credit resulted in redistributing income at the expense of small land-owners and agricultural workers. The real revenue of small farmers (who have land holdings of less than two feddans) decreased greatly. In addition, there was a sharp decrease in the real wages of agricultural workers (Mandour, 1995). Also, due to the fact the Egyptian asset market was not liberalized at the same time, small, inefficient farmers were not able to liquidate their assets to be replaced by more efficient farmers (Shousha and Pautsch, 1997).

Two new development strategies for the agricultural sector are currently being implemented; the first towards 2017 and the second towards 2030. The Agricultural Sustainable Development Strategy towards 2017 aims at achieving a growth rate in the agricultural sector of 4.1% per annum; in addition to achieving self-sufficiency of strategic agricultural crops. The 2030 Sustainable Agricultural Development Strategy aims at achieving economic and social development in the agricultural sector, through achieving a number of goals including an efficient utilization of natural agricultural resources, food security through reaching self-sufficiency of strategic agricultural crops, competitiveness of Egyptian agricultural products in local and international markets and improving the living standard of the rural population and decreasing poverty levels in rural areas.

3.2 The Agricultural Problem

In light of the previously presented historical background, this section highlights the major determinants of the current problems of the agricultural sector.

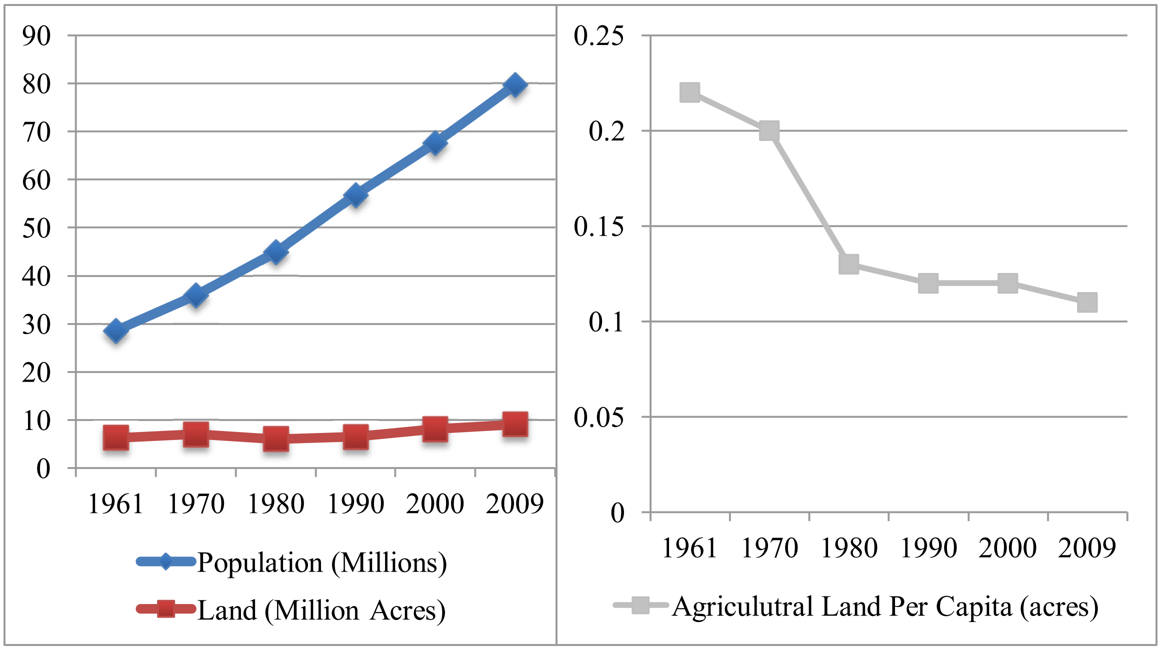

Figure 1: Population and Agricultural Land
Source: FAO, 2011 and Author's calculations

3.2.1 An Overview:

Over the past century, the population in Egypt has grown by more than the double during the past 50 years. Meanwhile, cultivated area has only increased by less than 50%. This has led to the decline of per capita share of agricultural land from 0.22 acres to 0.10 acres during the past 50 years (FAO, 2011), making Egypt the lowest in the world in terms of agricultural land per capita (Abdel Hady, 2004).

With a population growing rapidly at an annual rate of 1.8%, together with the limited land area and the inefficient utilization of agricultural resources, Egypt is facing a severe food security problem. Despite being a major food producer, Egypt is far from achieving self-sufficiency in strategic food commodities. Egypt has managed in achieving self-sufficiency in a number of agricultural products, including rice, vegetables, and fruits. However, self-sufficiency ratios of wheat, maize, sugar and broad beans have reached 54.4%, 53.2%, 76.9% and 52.1% respectively in 2007 (MALR, 2009). Egypt imports about 7.15 million tons of wheat annually, which represents 6.5% of the wheat traded worldwide (Shehata and Mohammad, 2010). The gap between total

consumption and total production of food is projected to widen further with the growing population that is expected to reach 92 million by 2017 (MALR, 2009).

Yet, the agricultural problem in Egypt is attributed to the inefficient utilization of available resources. Resources in the agricultural sector include natural resources, such as land and water; and productive resources that include labor, capital and technological resources. This section studies the agricultural resources in Egypt, their inefficiencies and the potential for improving their utilization.

3.2.2 The Land Problem

Land is considered the most limiting resource for agricultural production in Egypt. Total agricultural land in Egypt currently stands at 8.7 million feddans (9.1 million acres), representing 3.66% of total land area, of which 3.2 million ha lies within the irrigated Nile Basin and Delta. Agricultural land covers three different production zones. First are the "Old Lands" along the Nile Valley and the Delta that are the most fertile, with an area of 6.1 million feddans (6.33 million acres). Second are "New Lands" that were reclaimed, as part of the government's efforts to horizontally expand agriculture. These lands, with an area of 1.1 million feddans (1.15 million acres), are of poorer soil quality. A small portion of agriculture in Egypt is rain fed, located in the Northwest Coast and North Sinai, with area about 1.5 million feddans (Abdel Hady, 2004; MALR, 2009).

Land Availability

Egypt is among the lowest in the world in terms of the per capita share of agricultural land. The steady decline in agricultural land per capita (table 1) is attributed to many reasons. The most important of which is the rapidly growing population. Egypt's population is growing at an average rate of 1.8% per annum, compared to an average growth rate of 1.3% per annum for agricultural land, thus resulting in the steady decline in the per share of agricultural land.

In an effort to horizontally expand the agricultural sector in Egypt to cater for the escalating demand for food, the government started to turn to desert land reclamation.

During the period 1952-1959, land reclamation was not part of a national plan. During this period, the government has managed to reclaim about 79 thousand feddans (82 thousand acres). Starting 1960, the government has adopted reclamation of desert land as a part of its medium term five-year plan. Implementation of the plan during the period 1960-1967 was very rapid, as the government managed to reclaim 712 thousand feddans. According to Richards (1982), 74% of the EGP 208 million allocated for agriculture under the five-year plan of 1960-1965 was directed to land reclamation. The period from 1967 till 1982 witnessed very little efforts to reclaim desert land, as only 250 thousand feddans were reclaimed during this period. However, since the, wide land areas were reclaimed, resulting in a significant increase in agricultural area. Agricultural land has increased by about 44% from 1980 to 2007 (from 58.7 million feddans in 1989 to 8.44 million feddans in 2007). The table below shows the area of land reclaimed throughout the past 6 decades, since the adoption of the reclamation plan.

Table 1: Land Reclamation (1952 - 2010)

Period	Area ('000 Feddans)[7]
1952 till 1959	78.9
1960-1965	536.4
1956-1969	254.7
1969-1982	6.6
1982-1987	10.9
1987-1996	49
1996-00	115.1
2000-05	97.4
2005-10	2781.6

Source: Annual Bulletin of Land Reclamation, CAPMAS (various issues).

As a result of the land reclamation plan, the total cultivated area has been increasing overtime. However, the increase is not very significant as a result to the various forms of land degradation taking place, including urbanization and the expansion of residential areas at the expense of agricultural land. Total cultivated area has increased

[7] 1 feddan = 1.038 acres

from 5.8 million feddans in 1980 to 8 million feddans in 1997; to reach 8.7 million feddans in 2010. Cultivated land is expected to reach 9.6 million feddans in 2017 (MALR, 2009).

Land Quality

Another key reason for the continuous decline of the per capita share of agricultural land in Egypt is urbanization and the expansion of residential areas at the expense of agricultural land. In spite of enacting several laws to limit this trend, encroachment on agricultural land is still taking place at an annual rate of 20,000 feddans (MALR, 2009). Furthermore, the quality of agricultural land in Egypt has been deteriorating over the past 5 decades due to various reasons. First is the low investment in drainage since the 1950s, which led to salinity problems. According to Richards (1982), the FAO estimated that in mid-1970s, 35% of the cultivated area in Egypt suffered from salinity problems; thus leading to reduction in yield. The problem of fertility is the second major reason for the deterioration of the quality of land in Egypt. It was caused mainly by the absence of silt from the Nile; as it remained in canals under the system of perennial irrigation, adopted instead of the basin irrigation system. Furthermore, the use of the top layer of the soil to manufacture bricks adds to the loss of fertility in agricultural land (Richards, 1982). Finally, the rising ground water level, due to not applying the scientifically recommended crop rotations and the repeated cultivation of particular crops, is another reason for the declining fertility of agricultural land in Egypt (MALR, 2009). Accordingly, areas of the first grade lands in 2001-2005 declined to less than one third of the area in 1996-2000. Meanwhile, the percentage of the second and third grade land has increased by 25% and 102% respectively during the same period (Shehata and Mohammad, 2010).

Land Fragmentation

The land tenure system is a key factor shaping the pattern of resource allocation and the growth of the economy, since it has an impact on the distribution of income in rural areas (Richards, 1993). During the 1950s, the government started the

implementation of an agrarian land reform system to improve social equality. The purpose of this policy was wealth redistribution that transformed Egypt's skewed land tenure system, whereby a maximum limit on land ownership was set at 50 feddans per family. These land reforms, along with the fixed supply of agricultural land and the Islamic inheritance laws turned Egypt into a country of small farms, thus leading to the problem of land fragmentation (Richard, 1993). The problem of land fragmentation has been increasing in severity over time. The percentage of holdings of less than 3 feddans has increased from 2.29 million feddans in 1980 to nearly 3 million feddans in 2000. Additionally, average land ownership has decreased from 6.3 feddans in 1950 to 3.2 feddans in 1960 and 2.1 feddans in 2000 (Shehata and Mohammad, 2010).

The land fragmentation problem is more profound in Old Lands, compared to New Lands that are mostly owned by larger farmers. This makes Egypt a "bimodal agrarian system", in which there are a large number of small farmers along with a small number of large farmers (Richard, 1993). According to the MALR (2009), land fragmentation leads to a 12% loss in the most fertile agricultural land. Also, land fragmentation limits agricultural productivity as small peasant farms and large estates face different factor prices. Large framers are generally able to adopt new technologies more readily than small peasants, which has an adverse impact on the productivity of the old fertile lands (Richard, 1993).

Table 2: Land Ownership Structure according to the consensus of year 2000

Ownership Structure	Number of Farmers (thousands)	% of total Farmers
Without land	824	18.14
Less than 1 feddan	1,616	35.57
1-	881	19.4
2-	517	11.38
3-	239	5.26
4-	107	2.36
5-	169	3.72
7-	65	1.43
10-	57	1.26
15-	24	0.54
20-	22	0.48
30-	112	2.46
50-	6	0.12
100-	3	0.06
Total	**4,542**	

Source: Bulletin of Agricultural Land Ownership, MALR, 2000

3.2.3 The Water Problem

Water availability is a key challenge facing the sustainable development of the agricultural sector in Egypt. Egypt's water resources are highly limited, whereby total annual water resources are estimated at 73 billion m^3. Renewable water resources are estimated at 57.3 billion cubic meters per year, almost 97% of which originate from external resources (FAO, 2011). Nile River is the major source of surface renewable freshwater. With an annual quota of 55.5 billion m^3, set by the "Nile Water Agreement" signed in 1959 with Sudan, the Nile supplies 96% of renewable fresh water resources. Other sources of water supply in Egypt include groundwater in the Western desert, and rainfalls in the Western desert and Sinai. In addition to renewable water, Egypt depends on other non-renewable sources of water that include reusing the agricultural drainage

water, recycling sewage water, in addition to the desalination of sea water[8] (FAO, 2011; and MWRI, 2005).

Table 3: Available Water Resources in Egypt in 2005 and 2017

	2005 Billion m^3/ year	**2017 Billion m^3/ year**
Nile water according to the 1959 agreement	55.5	55.5
Groundwater	0.9	4
Rain	1.30	1.30
Desalinated water	0.05	0.10
Reuse/ increase in efficiency:		
Recycling of agricultural drainage water	7.5	7.4
Recycling of Sewage water	1.4	2.4
Nile groundwater (reused Nile water)	6.10	8.4
Improved Irrigation system; and changes in crop patterns		9.7
Total amount of water available	**72.75**	**90.1**

Source: MWRI (2005); and Saleh (2008)

[8] Desalination of sea of water produces only 30 million m^3 per year at a cost of USD 0.5 – 2/ m^3 (Hamza and Mason, 2004).

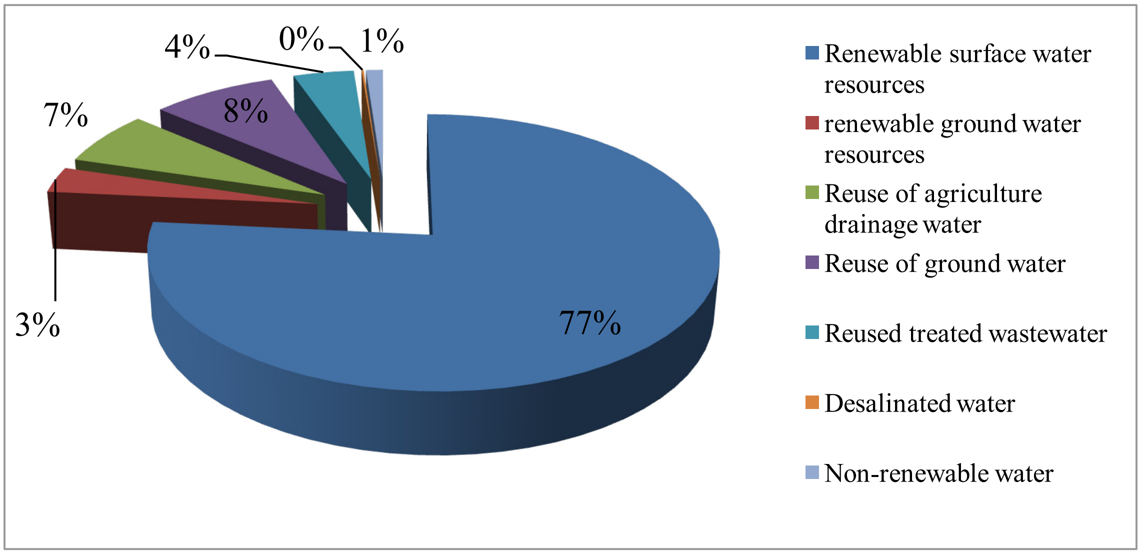

Figure 2: Water Resources in Egypt
Source: FAO, 2011

Egypt is suffering from a severe water scarcity problem. According to Hamza and Mason (2004), Egypt is considered highly water stressed as per the UN (1997) criteria[9]. Given the existing freshwater supply and the rapidly growing population, the per capita share of freshwater in Egypt has declined from 1078 m^3 per year in 1987 to 816 m^3 per year in 2002; and further declined to reach 718 m^3 in 2009. Moreover, the per capita share of fresh water is expected to drop further to reach 350 cubic meter by 2025 (FAO, 2011; and Abdel Hady, 2004). Therefore, Egypt is considered below the water poverty line of 1000 m^3 per capital per annum. Furthermore, Egypt's share of the Nile water is expected to decrease, as a number of Nile basin countries, seeking to increase their share of water from the Nile River, signed a Cooperative Framework Agreement. This agreement is to replace the treaty signed in 1929 between Egypt and Britain, whereby

[9] According to the UN criteria, countries that withdraw less than 10% of their available freshwater supply are low water stress countries. Countries that withdraw 10-20% of their freshwater are moderately water stressed; and 20-40% are medium high water stressed. Finally, countries that withdraw more than 40% of their available water resources are considered highly water stressed.

upstream countries had to take Egypt's permission prior to implementing projects that affect the flow of water, which endangers Egypt's supply of renewable water.

Indeed, water availability is the major constraint to the horizontal expansion of agricultural land in Egypt. The agricultural sector in Egypt is considered the major consumer of water; as 85% of Egypt's freshwater withdrawal from the Nile is directed to agriculture. Therefore, water availability directly impacts the state of food security in Egypt. In fact, Egypt imports about 236 m^3 of water per capita annually in the form of food (Hamza and Manson, 2004). However, water resources in Egypt are subject to inefficiency in utilization. Large amounts of irrigation water are actually being lost during water transfer from the Aswan Dam to fields. According to table (4), irrigation water at the Aswan Dam has increased by about 20% from 2000 to 2009. Yet, losses during the process of transferring irrigation water from the Aswan Dam to fields due to transpiration and evaporation has increased from 30.90% in 1985 to 35.46% in 2005, and reached 31% in 2008. In addition, to water losses during the transfer process, the efficiency of the field irrigation system is estimated at 50% (MALR, 2009). Egyptian farmers are still using traditional irrigation techniques, which result in excessive use of irrigation water.

Given the scarcity of water resources in Egypt, there is an urgent need for the use non-conventional water resources. According to Hamza and Mason (2004), reuse of drainage and sewage water, in addition to improving efficiency in irrigation systems and adopting more water efficient cropping patterns, can save additional 29.3 billion m^3 by 2017 (table 3), equivalent to almost 40% of the total amount of water used in 2005. Given the government's plan to expand the cultivated area to reach 10.8 million feddans in 2017, up from 8 million feddans that are currently cultivated, it is estimated that the amount of water needed for irrigation in 2017 will be 63.6 billion m^3, of which 42.3 billion m^3 will actually be used (33% loss) (MWRI, 2005).

Table 4: Water Waste in Agriculture

Period	**Irrigation Water**			**Total Loss**[10]	
	At Aswan Dam	At Canals	At Fields	Amount	%
1990	56.17	50.26	42.72	13.45	23.95
1995	50.15	49.11	48.07	2.8	4.15
2000	52.50	47.25	39.38	13.12	24.99
2005	46.13	35.44	29.78	16.36	35.46
2006	59.70	47.08	40.94	18.76	31.42
2007	61.14	48.14	42.08	19.06	31.17
2008	62.10	48.85	42.85	19.25	31.00

Source: Bulletin of Water Resources and Irrigation (various issues); Saleh (2008); and author's calculations

3.2.4 Labor in the Agricultural Sector

The agricultural sector in Egypt is considered the largest absorber of labor, accounting for almost 30% of the total labor force. However, the capacity of the agricultural sector to absorb more labor is very limited. This is attributed to the fact that the pace of agricultural expansion of Egypt is far below the rate of growth of the labor force.

[10] Loss in irrigation water at fields, compared to water allocations at the Aswan Dam (Saleh, 2008)

Table 5: Labor Force in Egypt (1980 - 2009)

	Population (million)	Rural Population (% of total population)	Labor Force (million)	Employment in Agriculture (% of total employment)
1980	44.43	56.1	13.23	42
1985	50.65	56.1	14.84	41
1990	57.78	56.5	16.84	39
1995	63.86	57.2	17.77	34
2000	70.17	57.4	20.07	30
2005	77.15	57	23.94	31
2009	79.7	57	26.43	30

Source: WDI

As the population has been growing at an average rate of 2.1% over the period 1980-2009, the proportion of agricultural labor in total labor force has declined from 42% in 1980 to 34% in 1995 and further declined to 30% in 2009. Despite the increase in the absolute number of labor in the agricultural sector, the relative importance of agriculture in total employment has decreased significantly over time. This is attributed to a number of reasons. With the 1952 revolution, the government of Egypt embarked at an economic development program that was based on industrial development, which led to the transfer of resources (labor included) from agriculture to other sector of the economy (Antle, 1993). This fact was coupled by a significant decline in labor wages in the period 1980s – mid 1990s. According to table (6), real wages per feddan of different crops has decreased noticeably from 1983 to 1995 (48% decline in the real wage of labor in wheat, 65% decline in real wage in barely, and 61% decline in real wages for cotton). This fact was even magnified during the post oil boom decade as a result of the growing trend of the rural-to-urban migration; and the labor migration to oil-producing Gulf countries. In addition, the improvement in living standards in rural areas led to the increased enrollment of the rural population in secondary and high education, resulting in rural population avoiding the employment in the agricultural sector (Saleh, 2008). Real wages in the agricultural sector started to pick up again after the year 2000. Yet they are considered low relative to wages in other sectors in the economy; thus resulting in skilled labor scarcity in the agricultural sector.

Table 6: Real Wages in Agriculture (Constant 2005 Prices)

	1983	1990	1995	2000	2005	2010
Wheat	736.1	476.5	385.6	401.5	376	460.7
Barely	555.4	311.5	192.5	268.5	291	325.4
Rice	1074.3	530.9	514.9	462.4	485	478.6
Maize	945.6	664.8	504.2	497.1	517	681.9
Broad Beans	721.5	509.6	393.1	375.9	448	505.0
Sugar cane	2,278.1	1293.5	1312.7	1082.8	895	978.3
Sugar beet	-	742.1	444.0	447.6	448	503.0
Cotton	2169.9	1107.6	840.9	904.4	694	841.0
peanuts	970.7	579.3	538.2	517.7	413	553.8
Perennial Clover	435.6	631.4	103.3	83.3	104	129.4
One-cut Clover	200.6	362.1	77.8	50.5	54	72.0

Source: Annual Bulletin of Indicators of Agricultural Statistics, MALR (various issues)

3.2.5Other Challenges

In addition to the land fragmentation, land degradation, and lack of resources required for expansion, the agricultural sector is faced by a number of challenges hindering its development.

Agricultural Products Exports

Promoting exports of agricultural commodities has been among the top objectives of the previous agricultural development strategies. Yet, Egyptian agricultural exports are still far below potential. This is attributed to many reasons, the first of which is the fact that agricultural exports in Egypt are mainly traditional goods, including rice, raw cotton and potatoes. Cultivating non-traditional agricultural, cash generating crops such as fruits, medical and aromatic pants, and ornamental plants has been a new trend followed by many farmers. However, the contribution of these crops of these crops in agricultural exports is still very weak. Another reason for the limited agricultural exports is the weak participation of small farmers in exportation activities, despite the fact that the majority of farmers in Egypt are small ones. Exportation of agricultural crops in Egypt relies heavily on large producers (MALR, 2009).

Agricultural Production Waste

The Egypt agricultural sector suffers from very high level of pre and post-harvest losses. According to MALR (2009), waste in horticultural crops, legumes, and cereals reach 30%, 20% and 10% respectively, with overall agricultural waste ranging from 10 to 20% of total agricultural income. This is attributed to the lack of contract farming, the limited attention to proper harvest practices and the inefficient transportation and storage techniques currently used. This high level of waste leads to increasing farmers' losses.

Climate Change

Literature on the impact of climate change on agricultural production in Africa suggests that potential vulnerability of agriculture in the continent to climate change. Rosenzwelg and Parry (1994) asserted that with the doubling of the carbon dioxide concentration, only small decreases in global crop production are expected. However, there is a large discrepancy in the impact of climate change on food production in developed and developing countries. Developing countries (including African countries) are more likely to suffer from the consequences of climate change on crop yield. The agricultural sector in Egypt is highly vulnerable to climate change. This is attributed to different reasons including the heavy dependency of agricultural sector in Egypt on the Nile as a primary water source, and the long coastline in Egypt that is enduring erosion (El-Shaer et al., 1996). However, according to El-Shaer et al. (1996), the future of agriculture in Egypt in light of the continuous climate change is very hard to project in light of the expected impact of climate change on water availability and the potential effects of the sea-level rise phenomenon.

Therefore, it is highly advisable for policymakers in the agricultural sector in Egypt to adopt appropriate measures to limit the impact of climate change on agriculture, basically through tackling the water waste. Furthermore, it is important for policymakers to pay special attention to adopting adaptation practices in the cropping pattern in order to alleviate the hardship of the changing weather condition.

3.3 Key Features of the Egyptian Agricultural System

Agriculture in Egypt can be described as intensive, as the agricultural land is grown with crops all year round in three seasons (El Shaer, 1996). Agriculture in Egypt takes place in different production zones; namely North Coastal, where occasional rain-fed crops are grown; the Old Land around the Nile (includes the Delta region; Middle Egypt and Upper Egypt) and the newly reclaimed land in the desert. The weather conditions vary significantly from one zone to another; and accordingly the types of crops grown. Another criterion in selecting the crops grown in each region is the soil and water limitations. The Old Lands in the Nile valley are the main growing areas in Egypt that are characterized by complex-year long cropping pattern. The richest crop production area is the Mid-Delta region due to the high quality of soil. The Northern Delta region is characterized by high salinity, especially near the Mediterranean Coast and lakes. Upper Egypt is characterized by heat; thus, certain types of crops are being grown there. Reclaimed agricultural land in the desert are characterized by having advanced technology; yet their constraints arise from the low fertility (El- Shaer, 1996)

Crop cultivation in Egypt takes place during three consecutive cropping seasons; the winter, summer and nili (Kharif) seasons, depending on the irrigation cycle. Winter season crops (including wheat, barely, beans and clover) are irrigated during the period October – December, and are harvested in May. Following the winter, crops of the summer season are irrigated from April – June and are harvested in October. Those include rice, cotton, maize and sugar cane. The irrigation of Nili season crops takes place during the months of July and August and harvest takes place in November. Crops of the Nili season are mainly similar to summer crops (mainly maize, peanuts, and cotton). Vegetables and fruits are grown all year round, depending on their type (appendix A summarizes the cropping pattern in Egypt).

3.4 The Cropping Pattern in Egypt

The previously mentioned policy development in the Egyptian agricultural sector has, indeed, affected the cropping pattern significantly. Table (7) tracks the evolution of the cropped area of key crops in Egypt during the 1950s, 1960s and 1970s. Given the heavy price and area restrictions, the cropping pattern shifted away from major field crops with controlled prices towards untaxed, higher value products. The cropped area of cotton and grains, whose prices were highly controlled, declined relative to other high-value, less regulated crops, such as clover, rice, vegetables and fruits (Richards, 1982; and Moursi 1993). According to table (7), the relative importance of wheat has declined from 15% in the period 1955-1959 to 12% in 1975-1979. The same happened for maize and broad beans, which had negative implications on food security. Also, the relative importance of cotton has declined from 17.8% in the period 1955-1959 to 14.3% in the period 1970-1974 and further declined to 11.7% in the period 1975-1979. Meanwhile, the relative importance of rice, clover, sugar cane and horticultural crops has increased noticeably.

Table (8) presents the evolution of the cropping pattern since the liberalization of the agricultural sector. Indeed, the liberalization of the agricultural sector in the early 1980s brought about fundamental changes in the cropping patter. With the liberalization of the sector, agricultural output increased significantly as cultivation of most crops became more profitable for farmers. However, according to Shousha and Pautsch (1997), the response of the aggregate cropping pattern to the liberalization strategy was very slow, which is another evidence for the moderate success of the agricultural liberalization strategy. Cropped area has increased from 11.18 million feddans in 1985 to 12.18 million in 1990 and further to 13.82 million feddans in 1995. In 2010, cropped area stood at 15.3 million feddans, with a crop intensification rate of 175%.

Table 7: The Evolution of the Cropping Pattern: Pre-Liberalization (1955 - 1979)

('000 feddans)	1955 –1959		1960 –1964		1965 –1969		1970 –1974		1975-1979	
	Land Area	%	Land Area	%	Land Area	%	Land Area	%	Land Area	%
Wheat	1,501	14.9	1387	13.5	1268	12	1302	12	1345	12
Rice	641	6.4	791	7.7	1028	9.8	1093	10	1042	9.3
Maize	1,850	18.4	1727	16.8	1510	14.3	1593	14.7	1831	16.5
Total Grains	**4,578**	**45.4**	**4502**	**43.8**	**4423**	**42**	**4563**	**42**	**4776**	**42.9**
Broad Beans	353	3.5	365	3.6	349	3.3	283	2.6	260	2.3
Clover	2,362	23.4	2444	23.8	2630	25.0	2801	25.8	2834	25.5
Sugar Cane	111	1.1	122	1.2	145	1.4	197	1.8	248	2.2
Cotton	1,791	17.8	1751	17.0	1694	16.1	1551	14.3	1296	11.7
Vegetables	**395**	**3.9**	**447**	**4.3**	**668**	**6.3**	**761**	**7.0**	**914**	**8.2**
Fruits	**114**	**1.1**	**147**	**1.4**	**208**	**2.0**	**255**	**2.3**	**311**	**2.8**
Cropped Area	**10,077**		**10289**		**10537**		**10855**		**11125**	

Source: Richard (1982)

Table 8: The Evolution of the Cropping Pattern: Post Liberalization (1983 - 2010)

	1983		1990		2000		2010	
	'000 feddans	%	'000 feddans	%	'000 feddans	%	'000 feddans	%
Wheat	1320	11.9	1955	16.05	2463	17.69	3066	19.99
Maize	1953	17.5	1975	16.21	1928	13.85	1968	12.83
Rice	1013	9.1	1036	8.51	1569	11.27	1094	7.13
Total Grains	**4801**	**43.1**	**5478**	**45**	**6655**	**47.8**	**7120**	**46.4**
Broad Beans	326	2.9	345	2.83	307	2.21	202	1.32
Cotton	998	8.96	993	8.15	518	3.72	369	2.41
Sugar Cane	249	2.23	263	2.16	319	2.29	320	2.09
Sugar Beet	18	0.16	34	0.28	136	0.98	386	2.52
Clover	2736	24.6	2457	20.2	2423	17.4	2685	17.5
Total Vegetables	**1031**	**9.3**	**1122**	**9.2**	**1690**	**12.1**	**2112**	**13.8**
Total Fruits	**404**	**3.6**	**866**	**7.11**	**1019**	**7.32**	**1377**	**8.98**
Cropped Area	**11140**		**12180**		**13922**		**15334**	

Source: Annual Bulletin of Indicators of Agricultural Sttistics, MALR (various issues).

I. *Cereals:* cereals have had the highest relative importance among other groups, accounting for approximately half of the cropped area. Total area cropped with cereals has increased from 4.8 million feddans in 1983 to 7.1 million feddans in 2010. Among all cereals, wheat occupies the largest cropped area that almost tripled to reach 3 million feddans in 2010 as a result of the government's policies that encourage the cultivation of wheat to ensure food security. On the other hand, the relative importance of rice has been declining since 2000 due to the agricultural policy that aims at saving water as rice is among the crops that are intensive in the use of water.

II. *Fibers:* In 2010, fiber crops have occupied 377 thousand feddans of the cropped areas. Since the 1990s, the relative importance of fiber crops has been declining in favor of cash-generating, horticultural crops (vegetables and fruits). Furthermore, the area cultivated with cotton has been declining steadily over time, yet it is accompanied by an increase in the yield (FAO, 2005).

III. *Sugar Crops:* The relative importance has been slightly increasing over time.The sugar beet crop was introduced to the cropping pattern in mid 1980s; and since then, the government has been encouraging both the vertical and horizontal expansion in the cultivation of sugar beet. The area under sugar beet is increasing rapidly, especially in the newly reclaimed land, reaching 386 thousand feddans in 2010 (representing 2.5% of the cropped area).

IV. *Horticultural crops:* Egypt enjoys a strong comparative advantage in the production of horticultural crops (Siam and Moussa, 2003). The production of horticultural crops, especially fruits, has been increased noticeably to meet domestic demand and provide surplus for exportation. The relative importance of fruits has increased from 3.1% in 1980 to 9% in 2010.

Appendix (A) depicts the detailed cropping pattern for Egypt for the year starting 1950 until 2010.

3.5The Sustainable Agricultural Development Strategy towards 2017 and 2030

The sustainable agricultural development strategy towards 2017 aims at increasing the annual growth rate of the agricultural production to 4.1%. In addition, it aims at achieving food security and a more efficient use of the limited agricultural resources; including water and land resources. As mentioned in section 3.2.3, the strategy aims at improving the efficiency of water use in agriculture through modifying the crop pattern. It is projected that with the improvement of field irrigation systems and reducing areas planted by rice, this would save an estimated amount of 5.3 and 12.4 billion cubic meters of water by 2017 and 2030 respectively. The water amounts to be saved shall be used to horizontally expand agricultural land by the reclamation of desert land. A total of 2.2 million feddans and 5 million feddans are to be reclaimed by 2017 and 2030 respectively; resulting in the increase in total cultivated areas to reach 9.665 million feddans by 2017 and 11.5 million feddans by 2030. This would represent an annual increase of 130-140 thousand feddans. The strategy also aims at maximizing the benefit from rain-fed agriculture in North Coast to cultivate key crops including wheat, barley and olives. The table below summarizes the key targets for 2017 and 2030 regarding achieving a better utilization of agricultural resources.

Table 9: Estimated Land Areas and Water Quantities in 2017 and 2030

	2007	2017	2030
Projected Land Area (mnfeddans)	8.4	9.6	11.5
Areas Projected to Be Reclaimed (‘000 feddans)	-	2250	5000
Cropped Area (mnfeddans)	15.4	19.2	22.9
Intensification (%)	184	199	200
Quantity of Water Used in Irrigation (bn m^3)	58	61	64
Field Water Use Efficiency (%)	50	75	80

Total Water Quantities Expected to be Saved as a Result of Developing the Irrigation System (mn m^3)	-	5,300	12,400
Average Water Share Per Feddan	6,900	6,320	5,565
Average Return Per Water Unit (EGP)	1.91	3.2	4.17
Average Return of the Land Unit (1,000 EGP)	13.2	20.3	22.9

Source: MALR, 2009

Being a key objective in the Sustainable Strategy of Agricultural Development towards 2017, policymakers are concerned with achieving the state of food security through increasing the self-sufficiency rate of strategic food items. In addition to the horizontal expansion of cultivated land, increasing crop production can also be achieved via vertical expansion through improving agricultural productivity and increase plant yields. Greater attention shall be paid to the development and cultivation of high salinity resistant varieties suitable for the use of agricultural drainage water, in addition to early maturing varieties that lead to saving irrigation water and achieving higher crop intensification rates. Furthermore, crop production is to be developed in a way that increases yield to lower the feeding costs of livestock. Also, the strategy aims at making the best use of Egypt's competitive advantage in the production of high value exportable crops, such as medical and aromatic crops[11] and horticultures that are limited water consumption.

These goals shall be clearly reflected in the cropping pattern proposed for 2017. For example, the area allocated to the cultivation of wheat shall be increased to 3.75 million feddans to achieve a self-sufficiency rate of 74%. Furthermore, the strategy seeks to expand the area cultivated with maize to reach 3.1 million feddans; thus achieving 78% sufficiency level. Meanwhile, it is planned to limit the areas to be cultivated with rice and sugar cane to 1.25 million feddans and 340 thousand feddans respectively in

[11] The target is to increase the area allocated to medical and aromatic plants from 85 thousand feddans in 2010 to 120 thousand feddans in 2017 (table 10).

pursuit of saving irrigation water for horizontal expansion. To cater for the growing demand for sugar, the sugar beet crop shall partially substitute sugar cane in sugar production. The land area allocated to the cultivation of sugar beet is expected to increase from thousand feddans in 2010 to 340 thousand feddans in 2017. Table (10) below presents the cropping pattern suggested by the strategy in 2017 and 2030.

Table 10: The Cropping Pattern Suggested by the Sustainable Agricultural Development Strategy

Commodity Group	2010	Estimates for 2017	Estimates for 2030
I. Cereals			
Wheat	3066	3750	4200
Rice	1095	1250	1300
Maize[12]	1968	3150	3700
Total Cereal Crops	**7120**	**9038**	**10258**
II. Sugar Crops			
Sugar Cane	320	340	350
Sugar Beet	386	500	800
Total Sugar Crops	**706**	**840**	**1150**
III. Oilseed Crops			
Groundnut	159	230	350
Sesame	88	85	100
Total Oilseed crops	**318**	**378**	**525**
IV. Legume Crops			
Broad Beans	202	300	400
Other Legumes	30	38	45
Total Legumes	**232**	**338**	**445**
V. Fiber Crops			
Cotton	369	750	1000
Other Fibers	8	18	21
Total Fiber Crops	**377**	**768**	**1021**
VI. Fodder Crops			

[12]Includes both yellow and white maize

Perennial Clover	1612	1900	2200
One-cut Clover	310	540	650
Total Fodder Crops	**2685**	**3300**	**4250**
VII. Vegetables			
Tomatoes	515	580	620
Potatoes	335	300	350
Other Vegetables	1262	1400	1675
Total Vegetable Crops	**2112**	**2280**	**2645**
VIII. Fruits			
Citrus	149	450	500
Grapes	164	200	250
Mango	209	160	180
Other Fruits	540	690	825
Total Fruits	**1377**	**1500**	**1755**
IX. Medical and Aromatic Plants	**85**	**120**	**220**
Total Cropped Area	**15334**	**19162**	**22984**

Source: MALR, 2009

IV. Methodology

Determining the optimal crop production policy involves the pursuit of multiple objectives that are conflicting in nature. Therefore, a multi-criteria optimization model; namely a goal programming (GP) model, shall be employed. Besides, due to the uncertainty in the parameters of the model, they shall be defined as fuzzy. According to Gupta et al. (2000), "a fuzzy set is a class with unsharp boundries, i.e., a class in which transition from membership to non-membership is gradual rather than abrupt". The poposed study shall follow the study by Sharma et al. (2007), where a tolerance based Fuzzy Goal Programming (FGP) modelwill be formulated. Different scenarios, where weights assigned to tolerance allowance variables change, shall also be presented.

4.1 Model Specification

Accoridng to Pal and Biswas (2004) and Sharma et al. (2007), goals in a fuzzy goal programming model have certain aspiration/ target level b_k of the k^{th} objective $F_k(x)$, where k = 1, 2, …, K; so that the fuzzy goals shall take one of two forms:

$$\boldsymbol{F_k(x) \gtrsim b_k} \qquad\qquad \boldsymbol{F_k(x) \lesssim b_k}$$

where $\gtrsim$ and $\lesssim$ indicate that the goal is fuzzily greater/ less than the pre-determined aspiration level.

A membership function $\mu_k(x)$ is to defined for each fuzzy goal $F_k(x)$, by defining lower and upper tolerance limits, where $\mu_k(x) \in [0, 1]$ is the membership grade of achieving the goal. If t_{lk} is the lower tolerance limit, then $(b_k - t_{lk})$ is the lower tolerance range; and if t_{uk} is the upper tolerance limit, then $(b_k + t_{uk})$ is the upper tolerance range.

Therefore, the membership function $\mu_k(x)$ corresponding to a fuzzy goal of type $F_k(x) \gtrsim b_k$ is

$$\mu_k(x) = \begin{cases} 1, & F_k(x) \geq b_k \\ \dfrac{F_k(x) - (b_k - t_{lk})}{t_{lk}}, & b_k - t_{lk} \leq F_k(x) < b_k \\ 0, & F_k(x) < b_k - t_{lk} \end{cases}$$

And the membership function μ_k (x) for a fuzzy goal of type $F_k(x) \lesssim b_k$ is

$$\mu_k(x) = \begin{cases} 1, & F_k(x) \leq b_k \\ \dfrac{(b_k + t_{uk}) - F_k(x)}{t_{uk}}, & b_k < F_k(x) \leq b_k + t_{uk} \\ 0, & F_k(x) > b_k + t_{uk} \end{cases}$$

where $\mu_k(x) \in [0, 1]$ is the membership grade of achieving the goal. The 0 and 1 are the lowest and the highest grades. If $\mu_k(x) = 1$, then x is fully included in the fuzzy set, i.e., the goal is completely achieved and do not need tolerance. If $0 \leq \mu_k(x) < 1$, then the goal x is either not included in or partially belongs to the fuzzy set, i.e., it is perfectly or partially unachieved; thus a tolerance limit is needed.

Tolerance values are used to transform the FGP model into a single equation LP model. For fuzzy goals of type $\boldsymbol{F_k(x) \gtrsim b_k}$, undesirable deviations are lower tolerance limits. Thus, given a lower tolerance of $\boldsymbol{u_i^-}$ and a membership grade of $\lambda_i^- \in [0, 1]$, fuzzy goals of this type are transformed as

$\boldsymbol{F_k(x) - \lambda_i^- u_i^- \geq b_k - u_i^-}$, which is equivilent to

$\boldsymbol{F_k(x) + \theta_i^- \geq b_k}$, where $\boldsymbol{\theta_i^- = 1 - \lambda_i^-}$.

And given an upper tolerance of $\boldsymbol{u_i^+}$ and a membership grade of $\lambda_i^+ \in [0, 1]$, fuzzy goals of type $\boldsymbol{F_k(x) \leq b_k}$ are transformed as

$\boldsymbol{F_k(x) - \lambda_i^+ u_i^+ \leq b_k - u_i^+}$, which is equivilent to

$\boldsymbol{F_k(x) - \theta_i^+ \leq b_k}$, where $\boldsymbol{\theta_i^+ = 1 - \lambda_i^+}$.

FGP model is then converted into a single objective linear programming problem, where the objective function is to minimize the positive and negative tolerance variables for the given set of goals, as follows:

$$\text{Min: } \sum_{i=1}^{I} w_i \theta_i^- + \sum_{i=1}^{I} w_i \theta_i^+$$

where w_i are the respectived weights corresponding to the fuzzy goals.

As tolerance variables (θ_i^+; and θ_i^+) are minimized, they become close to one for each fuzzy goal, thus causing the membership grade to become larger (Sharma et al., 2007).

4.2 Variables and Data Sources

Table 11: Variables and their Definitions

Notation	Definition
C	Index for the crop; c ϵ {1, 2, …, C}.
E	Index for essential crop; e ϵ {1, 2, …, E}; and e ϵ c.
S	Index for season; s ϵ {1, 2, 3}.
X_{cs}	Area of land allocated to cultivate crop c in season s (feddan).
X_{es}	Area of land allocated to cultivate essential crop e in season s (feddan).
L_s	Total area of land expected to be cultivated in season s in 2017, based on the 2030 agricultural strategy (feddan).
L_{es}	Total area of land for cultivation of essential crops in season s (feddan).
P_{es}	Yield of essential crop e in season s (ton/feddan).
P_{cs}	Yield of crop c in season s (ton/feddan).
TP_c	Total production target of crop c in 2017 (tons).
TP_e	Total production target of essentail crop e that would achieve the target level of self sufficiency (tons).
N_{cs}	Net profit per feddan of crop c in season s (constant 2005 EGP/ feddan).
N_s	Expected net profit for all crops cultivated in season s in 2017 (constant 2005 EGP).
W_{cs}	Water required to grow crop c in season s (cm^3/ feddan).
W_s	Total amount of water available for irrigation in season s.

I_{cs}	Investment per feddan of crop c in season s (constant 2005 EGP/ feddan); working capital is used as a proxy.
TI_s	Expected total investments required for supply of resources in season s in 2017 (constant 2005 EGP); working capital are used as a proxy.
$T_{f,s}$	Estimated total amount of fertilizers of typs f required during season s (tons); $f \in \{1, 2, \ldots, F\}$
Ff_{cs}	Amount of fertilizer f required for cultivating one unit of land for crop c in season s

More than 100 crops are being grown by Egyptian farmers. The agricultral year in Egypt is divided into three cropping seasons; namely winter (s=1), summer (s=2), and nili (s=3) seasons. Table (12) shows the 12 crops are selected for the purpose of the study. Crops were chosed based on their importance to decisionmakers and the availability of data.

Table 12: Crops Used in the Model

Number	Crop name
1. Winter Season Crops	
1	Wheat
2	Broad Bean
3	Sugar beet
4	Perennial Clover
5	One-cut Clover
6	Potatoes
7	Tomatoes
2. Summer Season Crops	
1	Rice
2	Maize
3	Peanuts
4	Sugar cane
5	Cotton
6	Potatoes
7	Tomatoes
3. Nili Season Crops	
1	Maize
2	Tomatoes
3	Potatoes

The crops selected for the Winter, Summer and Nili seasons respectively account for almost 87%, 65% and 61% of the total cropped area of the three seasons.

Historical Data on yield (tons/ feddan), land use (feddan), net profit (EGP/ feddan) and cash expenditure (EGP/ feddan) are obtained from the Annaul Bulletin of Indicators of Agricultural Statistics, issued by the Ministry of Agriculture and Land Reclamation (MALR). Data on net profit and cash expenditure are to be deflated to 2005 constant prices. Net profit and investment for each crop are to be forecasted in order to determine the expected net profit and investment for each crop in year 2017. The required data on water requirements for different crops (cubic meter/feddan) in 2017 are directly obtained from the Strategy of Sustainable Agricultural Development issued by MALR.

4.3 Goals, Constraints and Objective Function

4.3.1. Defining Goals

A set of five goals are identified in determining the optimum crop mix for Egypt. In this section, the goals pursued by the government are modeled, where X_{cs} is the endougenous variable to be solved for in the model.

1. *Production goal*:In determining the optimum cropping pattern the decisionmaker seeks to maximize expected crop production in order to meet domestic demand and achieve some surplus for exportation. The production goal for each season (s) can be modeled as:

$$\sum_{c=1}^{C} P_{cs} X_{cs} \gtrsim \sum_{c=1}^{C} TP_{c,s}$$

2. *Profit goal*: Since the liberalization of the agricultural sector in Egypt in the 1980s, profit maximization has become a key objective in selecting the optimal crop mix. Therefore, a decisionmaker sets a certain level of target profit from the cultivation of crops during the season.

$$\sum_{c=1}^{C} \boldsymbol{N_{cs}X_{cs}} \gtrsim \boldsymbol{N_s}$$

3. *Investment requirements goal*: investments in the Egyptian agricultural sector are limited. This is attributed to the fact that most landlords in Egypt are small farmers who have a limited capacity with respect to committing large investments to their land areas. Therefore, for each season (s), farmers tend to select a crop mix that minimizes the investment required per unit of land.

$$\sum_{c=1}^{C} \boldsymbol{I_{cs}X_{cs}} \lesssim \boldsymbol{TI_s}$$

4. *Fertilizers requirements goal*: the Egyptian agriculture is a heavy user of chemcial fertilizers that increase land productivity in order to increase total annual production to meet the growing demand for food. However, the extensive use of chemical fertilizers results in increasing the pressure on soil and water (Abdel Hady, 2004). Therefore, the optimal cropping pattern shall try to select crops that require less fertilizers to be grown.

$$\sum_{c=1}^{C} \boldsymbol{F_{f\,cs}X_{cs}} \lesssim \boldsymbol{T_{f,s}}$$

where f = 1, 2, 3 (types of fertilizers)

The total amount of fertilizers to be used in season s ($T_{f,\ s}$) shall be obtained by summing the product of the fertilizers required for cultivating one unit of land of crop c by the land areas allocated to each crop c, as proposed by the 2030 strategy.

5. *Water requirements goal*: Because water scarcity is a major limitation for the expansion of the argicultural sector, an optimal crop mix should minimize the use of water. Given the available supply of water, decisionmakers shall try to select the crop

mix that would save water to be directed to other uses, including agricultural land expansion.

$$\sum_{c=1}^{C} \boldsymbol{W_{cs} X_{cs}} \lesssim \boldsymbol{W_s}$$

4.3.2 The Constraint Set

The previously stated goals are subject to some constraints that are to be satisfied within the model; which include:

Land availability constraint: the sum of land allocated for the cultivation of all crops must not exceed the total available land for cultivation

$$\sum_{c=1}^{C} \boldsymbol{L_{cs}} \leq \boldsymbol{L_s}$$

Food security constraint: in the 2030 Strategy for Sustainable Agricultural Development, production targets are set for essential crops, of which the government is targeting to achieve certain self sufficiency ratios (Appendix B). Therefore, some land area should be reserved to these crops in each season.

$$X_{es} \leq L_{es}$$

$$\sum_{e=1}^{E} \boldsymbol{L_{es}} \leq \boldsymbol{L_s}$$

Non-negativity constraint:

$$\boldsymbol{X_{cs}} \geq \boldsymbol{0}$$

Constraint on weights: the summation of all weights assigned to different goal in the LP function should be one

$$\sum_{i=1}^{I} \boldsymbol{w_i} = \mathbf{1}$$

4.4 Transforming Fuzzy Goals

According to the tolerance based FGP model, proposed by Sharma et al. (2007), described above, the production and net profit goals for each season of the three seasons (winter = 1; summer = 2 and Nili = 3) can be transformed as:

$$\sum_{c=1}^{C} \boldsymbol{P_{cs}X_{cs}} + \boldsymbol{\theta_{1,s}^{-}u_{1,s}^{-}} \geq \sum_{c=1}^{C} \boldsymbol{TP_{c,s}} \qquad \forall \boldsymbol{s}$$

$$\sum_{c=1}^{C} \boldsymbol{N_{cs}X_{cs}} + \boldsymbol{\theta_{2,s}^{-}u_{2,s}^{-}} \geq \boldsymbol{N_s} \qquad \forall \boldsymbol{s}$$

while the capital requirement goals, fertilizers requirement goals, and the water requirement goals for each season can be transformed as:

$$\sum_{c=1}^{C} \boldsymbol{I_{cs}X_{cs}} - \boldsymbol{\theta_{1,s}^{+}u_{1,s}^{+}} \lesssim \boldsymbol{TI_s} \qquad \forall \boldsymbol{s}$$

$$\sum_{c=1}^{C} \boldsymbol{F_{f\,cs}X_{cs}} - \boldsymbol{\theta_{2,f,s}^{+}u_{2,f,s}^{+}} \leq \boldsymbol{T_{f,s}} \qquad \forall \boldsymbol{f \text{ and } s}$$

$$\sum_{c=1}^{C} \boldsymbol{W_{cs}X_{cs}} - \boldsymbol{\theta_{3,s}^{+}u_{3,s}^{+}} \leq \boldsymbol{W_s} \qquad \forall \boldsymbol{s}$$

Therefore, the final LP form for the land allocation in Egypt can be presented as follows:
For each season s:

$$Min\colon \sum_{i=1}^{2} w_{i,s}\,\theta_{i,s}^{-} + \sum_{i=3}^{4} w_{i,s}\theta_{i,s}^{+} + \sum_{f=1}^{3} w_{5,f,s}\theta_{3,f,s}^{+}$$

Subject to:

$$\sum_{c=1}^{C} \boldsymbol{P_{cs}X_{cs} + \theta_{1,s}^{-}u_{1,s}^{-} \geq \sum_{c=1}^{C} TP_{c,s}} \qquad \forall \boldsymbol{s}$$

$$\sum_{c=1}^{C} \boldsymbol{N_{cs}X_{cs} + \theta_{2,s}^{-}u_{2,s}^{-} \geq N_{s}} \qquad \forall \boldsymbol{s}$$

$$\sum_{c=1}^{C} \boldsymbol{I_{cs}X_{cs} - \theta_{1,s}^{+}u_{1,s}^{+} \lesssim TI_{s}} \qquad \forall \boldsymbol{s}$$

$$\sum_{c=1}^{C} \boldsymbol{F_{f\,cs}\,X_{cs} - \theta_{2,f,s}^{+}u_{2,f,s}^{+} \leq T_{f,s}} \qquad \forall \boldsymbol{f\ and\ s}$$

$$\sum_{c=1}^{C} \boldsymbol{W_{cs}X_{cs} - \theta_{3,s}^{+}u_{3,s}^{+} \leq W_{s}} \qquad \forall \boldsymbol{s}$$

$$\sum_{c=1}^{C}\sum_{s=1}^{S} \boldsymbol{X_{cs} \leq L_{s}}$$

$$\sum_{e=1}^{E} \boldsymbol{L_{es} \leq L_{s}}$$

$$\boldsymbol{X_{cs} \geq 0}$$

$$\sum_{i=1}^{I} \boldsymbol{w_{i} = 1}$$

$$\boldsymbol{0 \leq \theta_{1,s}^{-}, \theta_{2,s}^{-}, \theta_{1,s}^{+}, \theta_{2,f,s}^{+}, \theta_{3,s}^{+} \leq 1} \qquad \forall \boldsymbol{s}$$

V. Model Estimation and Results

5.1 Forecasting Variables

Data on average net profit per feddan; and working capital (cash expenditure) per feddan for each crop throughout the period (1983-2010) were obtained from the Annual Bulletin of Indicators of Agricultural Statistics, issued by MALR. The data were converted to 2005 prices using the Producer Price Index (PPI), obtained directly from the International Financial Statistics Database. The net profit per feddan and cash expenditure per feddan in constant 2005 prices for all crops do not exihibit a clear trend (Appendix C). Therefore, forecasting those variables using linear or polynomial trend analysis did not result in good forecasts. Due to the high volatility of the discounted profit and expenditure of each crop, the median of the series for each crop was used as a forecast for 2017 for both variables. As mentioned in chapter 4, data on the forecasted quantity of water required in 2017 for the cultivation of one feddan of each crop was directly obtained from the 2030 Strategy for Sustainable Agricultural Development issued by MALR. The data required for the model are summarized in appendix D.

5.2 Determining the Aspiration/ Target Level

The FGP problem to determine the optimal cropping mix in Egypt identifies four goals; namely the production requirement goal, the profit goal, the investment goal, the fertilizers and water requirement goals. Each fuzzy goal has a certain target level. The target level of production for each of the three seasons,$\sum_{c=1}^{C} TP_{cs}$;the target level of the net profit for all crops in season s, N_s, and the target level of investment for all crops to be cultivated in season s in 2017, TI_s were obtained by summing for each season (s) the product of the expected yield for each crop, the expected profit for each crop and the expected working capital for each crop respectively by the land area expected to be allocated to each crop, as proposed by the Strategy for Sustainable Agricultural Development. Likewise, The total amount of fertilizer of type (*f*) to be used in season s ($T_{f,\ s}$) was obtained by summing the product of the fertilizer of type (*f*) required for

cultivating one unit of land of crop c in season s by the land areas allocated to each crop c, as proposed by the strategy. Finally, according to the 2017 National Water Policy (MWRI, 2005), the total amount of water to be allocated to irrigation in 2017 is estimated at 63.6 billion m^3, of which 42.3 billion m^3 to be actually used. Target level of irrigation water to be allocated to each season was determined based on the ratio of irrigation water allocated to each season to total irrigation water in historical years.

5.3 Determining the Tolerance Level

The production and net profit goals are of type $F_k(x) \gtrsim b_k$; thus, require lower tolerance level$u_1^-$and u_2^- respectively to be transformed into a linear constraint. The lower tolerance for the production goal was set, accounting for the risk of adverse weather conditions. Yields of almost all crops were subject to noticeable decrease, relative to previous years, as a result of the adverse weather conditions and the associated decrease in the quantity of water available. Therefore, the lower tolerance level for the production goal for each season was set based on the expected decrease from the target yield, in case of similar adverse weather conditions. Lower tolerance for the net profit goal for each season was set as the minimum profit of the cropping pattern in the past ten years (in constant 2005 prices).

On the other hand, the total investment, fertilizers and water requirement fuzzy goals, of type $F_k(x) \lesssim b_k$, require an upper tolerance limit u_i^+. The upper tolerance limit for the investment requirement goal for each season was set as the highest working capital needed for the cropping pattern in historical years (in constant 2005 prices). The upper tolerance limit for the water requirement goal is defined as the highest water allocation for each season in 1992, the year that witnessed the highest allocation of water for irrigation purpose. Finally, the upper tolerance limit for the fertilizers requirement goals, for each type of fertilizers in each season, is determined as the amount of fertilizers required for new lands. Less fertile, newly reclaimed lands require the use of larger amount of fertilizers compared to Old Lands. Thus, the tolerance limit for the fertilizers requirement goals was set as the maximum amount of fertilizers needed for the

cultivation of the crops under examination. Table (13) summarizes the description of each goal for each of the three seasons.

Table 13: Aspiration and Tolerance Levels of the Selected Goals for Each Season (s)

Goal	Aspiration Level	Tolerance Limit	
		Upper	Lower
Production (thousand tons)			
Winter Season	106,994	-----	106,422
Summer Season	43,143	-----	42,110
Nili Season	2,962	-----	2,817
Net Profit (Constant 2005 prices; EGP thousand)			
Winter Season	15,112,100	-----	13,139,853
Summer Season	9,434,800	-----	6,242,055
Nili Season	770,000	-----	455,337
Cash Expenditure (Constant 2005 prices; EGP thousand)			
Winter Season	13,172,000	13,579,338	-----
Summer Season	14,296,126	16,438,144	-----
Nili Season	1,399,426	1,492,618	-----
Water Requirement (thousand cubic meters)			
Winter Season	11,607,224	12,369,820	-----
Summer Season	22,003,921	24,655,197	-----
Nili Season	1,354,214	1,734,033	-----
Fertilizers Requirements (thousand tons)			
Nitrogenous (N)			
Winter Season	409,563	589,813	-----
Summer Season	579,871	681,724	-----
Nili Season	73,326	81,923	-----
Phosphate (P)			
Winter Season	154,915	213,415	-----
Summer Season	166,732	172,357	-----
Nili Season	21,478	21,478	-----
Potassium (K)			
Winter Season	139,807	147,007	-----
Summer Season	137,092	161,892	-----
Nili Season	23,921	23,921	-----

5.4 Constraints

According to the model outlined in chapter (4), the FGP problem is transformed into a single objective LP problem that seeks to minimize the undesirable deviations from the given set of goals; subject to a number of constraints. These constraints include the fuzzy goals that were transformed into linear constraints after introducing the tolerance values; in addition to constraints on land availability. The constraints on land availability were set in line with the fact that total cultivated land is expected to reach 9.6 million feddans by 2017 (MALR, 2009). Thus, the constraint on land availability in each season was set according to the ratio of land cultivated with the crops under study to total cultivated land available in season s in historical years.

Table 14: Land Availability Constraint for Each Season (s)

Land Availability Constraint	Thousand feddans
Winter Season	7,300
Summer Season	5,280
Nili Season	580

Fuzzy goals for each season and their transformation into linear constraints are presented in Appendix (E)

5.5 Decision Variables

Table 15: Decision Variables

(1) **Winter Season Crops**			
$X_{1,1}$	Wheat	$X_{2,1}$	Broad Beans
$X_{3,1}$	Sugar Beet	$X_{4,1}$	Perennial Clover
$X_{5,1}$	One-cut Clover	$X_{6,1}$	Winter Potatoes
$X_{7,1}$	Winter Tomatoes		
(2) **Summer Season Crops**			
$X_{1,2}$	Rice	$X_{2,2}$	Maize
$X_{3,2}$	Peanuts	$X_{4,2}$	Sugar Cane
$X_{5,2}$	Cotton	$X_{6,2}$	Summer Potatoes
$X_{7,2}$	Summer Tomatoes		

(3) <u>Nili Season Crops</u>			
$X_{1,3}$	Maize	$X_{2,3}$	Nili Tomatoes
$X_{3,3}$	Nili Potatoes		
<u>Membership Grades</u>			
$\lambda_{1,1}^{-}$	Membership grade for production goal in the winter season	$\lambda_{1,2}^{-}$	Membership grade for production goal in the summer season
$\lambda_{1,3}^{-}$	Membership grade for production goal in the nili season	$\lambda_{2,1}^{-}$	Membership grade for profit goal in the winter season
$\lambda_{2,2}^{-}$	Membership grade for profit goal in summer season	$\lambda_{2,3}^{-}$	Membership grade for profit goal in nili season
$\lambda_{1,1}^{+}$	Membership grade for the investment goal in winter season	$\lambda_{1,2}^{+}$	Membership grade for the investment goal in summer season
$\lambda_{1,3}^{+}$	Membership grade for the investment goal in nili season	$\lambda_{2,N,1}^{+}$	Membership grade for the fertilizer (N) goal in winter season
$\lambda_{2,P,1}^{+}$	Membership grade for the fertilizer (P) goal in winter season	$\lambda_{2,K,1}^{+}$	Membership grade for the fertilizer (K) goal in winter season
$\lambda_{2,N,2}^{+}$	Membership grade for the fertilizer (N) goal in summer season	$\lambda_{2,P,2}^{+}$	Membership grade for the fertilizer (P) goal in summer season
$\lambda_{2,K,2}^{+}$	Membership grade for the fertilizer (K) goal in summer season	$\lambda_{2,N,3}^{+}$	Membership grade for the fertilizer (N) goal in nili season
$\lambda_{2,P,3}^{+}$	Membership grade for the fertilizer (P) goal in nili season	$\lambda_{2,K,3}^{+}$	Membership grade for the fertilizer (K) goal in nili season
$\lambda_{3,1}^{+}$	Membership grade for water goal in winter season	$\lambda_{3,2}^{+}$	Membership grade for water goal in summer season
$\lambda_{3,3}^{+}$	Membership grade for water goal in nili season		

5.6 Preliminary Results

Assuming equal weights for each of the five goals in the three seasons[13], the model was executed using the General Algebraic Modeling System (GAMS). The code for the GAMS program is shown in Appendix (F).Initially, the model was executed for each season without imposing any constraints on the land areas to be reserved to essential crops (up to constr8 in Appendix F). The corresponding land allocations and membership grades are presented in table (7).

Table 16: Preliminary Results

Variable	Value(Assuming Equal Weights)	Variable	Land Allocations ('000 feddans) (Assuming Equal Weights)
(1) Winter Season			
$\lambda^{-}_{1,1}$	1	Wheat	0
$\lambda^{-}_{2,1}$	1	Broad Beans	0
$\lambda^{+}_{1,1}$	1	Sugar Beet	0
$\lambda^{+}_{2,N,1}$	1	Perennial Clover	1131.71
$\lambda^{+}_{2,P,1}$	1	One-cut Clover	5632.82
$\lambda^{+}_{2,K,1}$	1	Winter Potatoes	0
$\lambda^{+}_{3,1}$	1	Winter Tomatoes	535.47
(2) Summer Season			
$\lambda^{-}_{1,2}$	1	Rice	4832.755
$\lambda^{-}_{2,2}$	1	Summer Maize	0
$\lambda^{+}_{1,2}$	1	Peanuts	0
$\lambda^{+}_{2,N,2}$	1	Sugar Cane	444.493
$\lambda^{+}_{2,P,2}$	1	Cotton	0
$\lambda^{+}_{2,K,2}$	1	Summer Potatoes	0
$\lambda^{+}_{3,2}$	1	Summer Tomatoes	2.752

[13]Weight structure is 0.2, 0.2, 0.2, 0.067, 0.067, 0.067, 0.2 respectively for the production, profit, investment, nitrogenous fertilizer, phosphate fertilizer, potassium fertilizer and water goals

(3) **Nili Season**			
$\boldsymbol{\lambda_{1,3}^{-}}$	1	Nili Maize	509.16
$\boldsymbol{\lambda_{2,3}^{-}}$	1	Nili Tomatoes	70.84
$\boldsymbol{\lambda_{1,3}^{+}}$	1	Nili Potatoes	0
$\boldsymbol{\lambda_{2,N,3}^{+}}$	1		
$\boldsymbol{\lambda_{2,P,3}^{+}}$	1		
$\boldsymbol{\lambda_{2,K,3}^{+}}$	1		
$\boldsymbol{\lambda_{3,3}^{+}}$	1		

Winter Season:

Results for the winter season indicate that all goals were fully achieved, with a membership grade of 1; thus no tolerances were required for them. The table below summarizes the "solve summary" report of the GAMS.

Table 17: Preliminary Results - GAMS Solve Summary for the Winter Season

	Lower	Level	Upper	Marginal
EQU Obj	0	0	0	1
Production Constraint	1.0699E+5	1.2636E+5	+INF	0
Profit Constraint	1.5112E+7	1.5112E+7	+INF	EPS
Investment Constraint	-INF	7.0643E+6	1.3172E+7	0
Fertilizers Constraint (type N)	-INF	4.0956E+5	4.0956E+5	EPS
Fertilizers Constraint (type P)	-INF	66079.694	1.5492E+5	0
Fertilizers Constraint (type K)	-INF	51405.484	1.3981E+5	0
Water Constraint	-INF	7.4325E+6	1.1607E+7	0

According to the preliminary results of the model, more than half the land available in the winter season was allocated to cultivating clover crops, while 535 thousand feddans were allocated to the cultivation of winter tomatoes. It is essential to note that, with no constraints imposed on the model, it is not optimum to cultivate crops that are considered strategic in terms of their demand by the population, such as wheat and broad beans. Wheat, broad beans, sugar beet and potatoes are considered less profitable and heavier in terms of their need for resources relative to clover crops and

tomatoes. As a result, the model does not allocated land for their cultivation during the winter season.

Summer Season:

The proposed land allocation plan managed to fully achieve all fuzzy goals; thus yielding a membership grade of 1.As suggested by the model, land available for cultivation in the summer season was allocated as follows: 4.8 million feddans are to be allocated to the cultivation of rice, 444 thousand feddans to be cultivated with sugar cane, and 2.7 thousand feddans for tomatoes. Rice, sugar cane and tomatoes are considered relatively more profitable relative to other crops cultivated in the model. Meanwhile, they require relatively fewer resources in terms of working capital and fertilizers compared to other summer crops.

With no constraints imposed on the model, it is suggested that no land area shall be allocated to the cultivation of maize, peanuts, or cotton during the summer season. Apparently, these crops are relatively less profitable compared to rice, sugar cane and summer tomatoes; and they require the use of more resources.

Table 18: Preliminary Results - GAMS Solve Summary for the Summer Season

	Lower	Level	Upper	Marginal
EQU Obj	0	0	0	1
Production Constraint	44607.000	46960.726	+INF	0
Profit Constraint	9.4348E+6	9.4348E+6	+INF	EPS
Investment Constraint	-INF	1.3859E+7	1.4296E+7	0
Fertilizers Constraint (type N)	-INF	4.2728E+5	5.7987E+5	0
Fertilizers Constraint (type P)	-INF	99326.021	1.6673E+5	0
Fertilizers Constraint (type K)	-INF	10984.337	1.3709E+5	0
Water Constraint	-INF	2.2004E+7	2.2004E+7	EPS

Nili Season:

Similar to other cropping seasons, all goals in the nili season were completely achieved, with a membership grade of 1. Land was allocated among nili maize (509 thousand feddans) and Nili tomatoes (70 thousand feddans).

Table 19: Preliminary Results - GAMS Solve Summary for the Nili Season

	Lower	Level	Upper	Marginal
EQU Obj	0	0	0	1
Production Constraint	2962.000	3657.063	+INF	0
Profit Constraint	7.7000E+5	7.7000E+5	+INF	EPS
Investment Constraint	-INF	1.2185E+6	1.3994E+6	0
Fertilizers Constraint (type N)	-INF	68324.927	73326.000	0
Fertilizers Constraint (type P)	-INF	19525.121	21478.000	0
Fertilizers Constraint (type K)	-INF	19020.291	23921.000	0
Water Constraint	-INF	1.0670E+6	1.3542E+6	0

The previously presented cropping pattern, suggested by the FGP model is considered optimum in terms of the achievement of the five goals pursued by the government. Land allocations either maximize production (have high yield) or profit or require the use of relatively less resources (including cash expenditure, fertilizers and water). Yet, the proposed cropping pattern does not account for the importance of cultivating certain crops that are considered “strategic” due to their importance for achieving food security. Furthermore, the suggested cropping pattern does not account for the importance of cultivating a minimum level of certain crops that are necessary for some industries, such as cotton and sugar beet. Therefore, constraints on land area to be allocated to some essential crops (for food security, industry or exportation purposes) shall be added to the model.

5.7 Essential Crops Constraints

Winter Season:

According to the Sustainable Agricultural Development Strategy Towards 2017, two winter crops are identified as being “strategic” in order to achieve food security; namely wheat and broad beans. According to Appendix B, the Sustainable Agricultural Development Strategy Towards 2017 aims at achieving self-sufficiency rate of 73.9% of wheat. This requires the production of a total amount of 12 million tons of wheat. To achieve this goal, at least 3.75 million feddans shall be reserved for growing wheat.

$$x11 \geq 3750$$

Moreover, the broad beans crop is among the essential crops for achieving food security, as the daily diet of the wide mass of the Egyptian population includes broad beans. Egypt is the top importer of broad beans worldwide (FAO, 2012). According to the Strategy for Sustainable Agricultural Development towards 2017 (Appendix B), policymakers are targeting to achieve a self-sufficiency rate of almost 70%; which requires the production of 480 thousand tons. To achieve this goal, at least 300 thousand feddans shall be reserved for growing broad beans.

$$x21 \geq 300$$

Limiting constraints are to be set for cultivating clover. Clover crops have high yield, high profitability. Despite being a very important natural provider of nitrogenous fertilizer, constraints must be set on the maximum amount of land area to be allocated to clover in order to secure some land area for other strategic crops. According to the Sustainable Agricultural Development Strategy Towards 2017, the following constraints shall be set on clover crops;

$$x41 \leq 1900$$

$$x51 \leq 540$$

A limiting constraint should also be imposed on the land area to be allocated to cultivating tomatoes. Despite being a major export crop, there are limits to the exportation capacity of a certain crop that is imposed by the market demand in other markets. Therefore, a constraint shall be imposed on the maximum land area to be reserved to cultivating tomatoes[14]; as follows:

$$x71 \leq 255$$

Summer Season:

The area to be allocated to the cultivation of rice shall be limited to the government target for rice production in 2017. Rice is the second highest crop in terms of water use relative to other summer crops (see figure 1 for the amount of water allocated to rice relative to other summer crops); thus, the government has been imposing restrictions on the cultivation of rice to save water. Area planted with rice has declined from 1.77 million feddans in 2008 to 1.09 million feddans in 2010. By 2017, the government is targeting total production of 4.1 million tons of white rice (equivalent to 5.6 million tons of rice crop). This would result in a self-sufficiency ratio of 105% to cover domestic demand and achieve surplus for exportation. Given the expected yield of rice, this shall require total land area of 1.25 million feddans to be allocated to rice cultivation.

$$x12 \leq 1250$$

[14]Based on the ratio of tomatoes production during the winter season to total tomatoes production during the year.

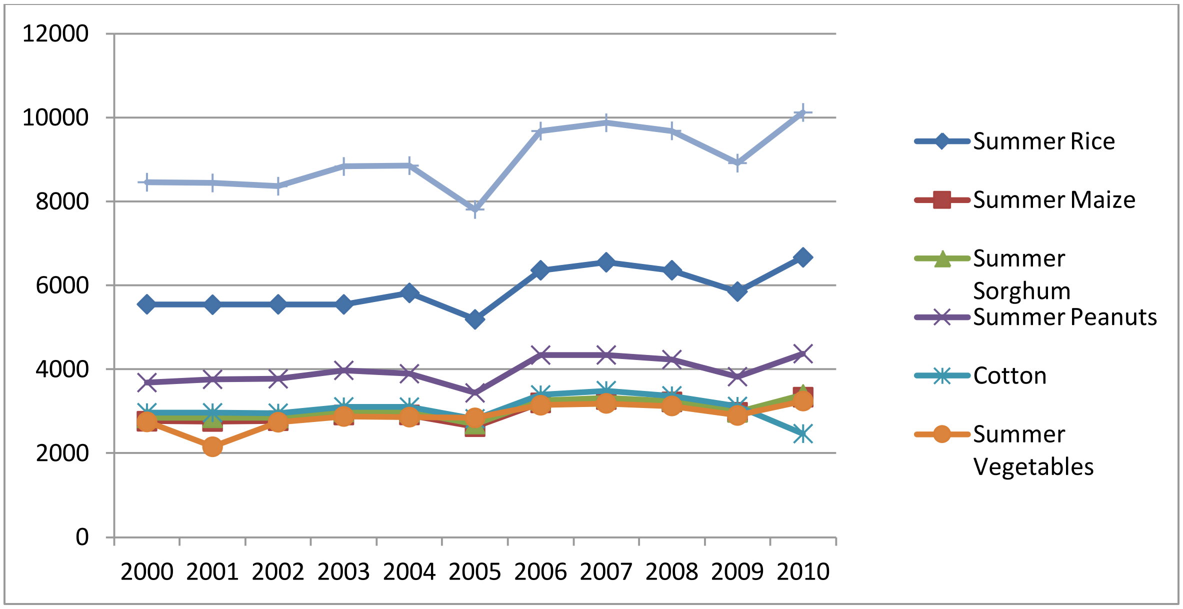

Figure 3: Water Allocations to Key Summer Crops (2000 -2010)
Source: Annual Bulletin of Water Resources and Irrigation, CAPMAS (various issues)

The peanuts crop is characterized by high return compared to other crops cultivated in the summer season. Return per feddan of peanuts reached EGP 1.49 in 2010, compared to EGP 0.84 per feddan of rice, EGP 0.94 per feddan of cotton and EGP 1.10 per feddan of sugar cane. It is basically a cash-generating crop that is mostly exported. Therefore, a constraint should be imposed on the maximum land to be allocated to the cultivation of peanuts, equivalent to 230 thousand feddans, which is the land area targeted by the government in the Sustainable Agricultural Development Strategy.

$$x32 \leq 230$$

Sugar cane is the most important sugar crop grown in the summer season. As mentioned before, sugar cane is one of the heaviest users of water among different sugar crops (figure 1). Water requirements for the sugar cane are 30-50% more than other traditional crops. Therefore, it is among the objectives of the Sustainable Agricultural Development Strategy Towards 2017 is to limit the expansion in the cultivation of sugar cane, while expanding the cultivation of sugar beet to meet the growing gap in sugar

demand. It is assumed that the government shall not try to increase the area allocated to sugar cane, as the available capacities for processing sugar cane would remain constant. Meanwhile, the government shall try to expand sugar refineries that use sugar beet as an input. Land area to be allocated to sugar cane shall be restricted to the land area planted with sugar cane in 2010.

$$\boldsymbol{x42 \ \leq 320}$$

Constraints shall be imposed on the maximum areas to be allocated to horticultural crops. Due to their high profitability, high yield and low consumption of water, the model allocates larger land areas to horticultural crops. A constraint shall be imposed on the maximum land area to be allocated to the tomato crop due to the market demand on tomatoes in Egypt's trade partners. Therefore, a constraint is to be set on the maximum land area to be allocated to growing tomatoes in the summer to generate half of the total target production of tomatoes for 2017[15].

$$\boldsymbol{x72 \ \leq 290}$$

5.8 Results

Table 20: Model Results

Variable	Value (Assuming Equal Weights)	Variable	Land Allocations ('000 feddans) (Assuming Equal Weights)
(1) Winter Season			
$\boldsymbol{\lambda^-_{1,1}}$	1	Wheat	3750
$\boldsymbol{\lambda^-_{2,1}}$	0.992	Broad Beans	304.39
$\boldsymbol{\lambda^+_{1,1}}$	1	Sugar Beet	571.24
$\boldsymbol{\lambda^+_{2,N,1}}$	0.967	Perennial Clover	1900
$\boldsymbol{\lambda^+_{2,P,1}}$	0.983	One-cut Clover	422.74
$\boldsymbol{\lambda^+_{2,K,1}}$	1	Winter Potatoes	101.02
$\boldsymbol{\lambda^+_{3,1}}$	1	Winter Tomatoes	255

[15]Based on the historical ratio of tomatoes production during the summer season to total tomatoes production during the year

(2) <u>Summer Season</u>			
$\lambda_{1,2}^{-}$	1	Rice	1250
$\lambda_{2,2}^{-}$	1	Summer Maize	2461.25
$\lambda_{1,2}^{+}$	1	Peanuts	230
$\lambda_{2,N,2}^{+}$	1	Sugar Cane	320
$\lambda_{2,P,2}^{+}$	1	Cotton	477.36
$\lambda_{2,K,2}^{+}$	0.975	Summer Potatoes	251.40
$\lambda_{3,2}^{+}$	1	Summer Tomatoes	290
(3) <u>Nili Season</u>			
$\lambda_{1,3}^{-}$	1	Nili Maize	509.16
$\lambda_{2,3}^{-}$	1	Nili Tomatoes	70.84
$\lambda_{1,3}^{+}$	1	Nili Potatoes	0
$\lambda_{2,N,3}^{+}$	1		
$\lambda_{2,P,3}^{+}$	1		
$\lambda_{2,K,3}^{+}$	1		
$\lambda_{3,3}^{+}$	1		

<u>Winter Season:</u>

After adjusting the model for essential crops constraints, results show that for the winter season, no tolerances are required for the production, investment, water and potassium goals; since they are fully achieved, with a membership grade equal to 1. This indicates that the suggested cropping pattern fully minimizes the tolerances for these goals. On the other hand, other goals were only fuzzily achieved. For the profit, Nitrogenous (N) and Phosphate (P) fertilizers goals, membership grades are 0.992, 0.967, and 0.983 respectively. This high membership grades (approaching unity) indicate that tolerance values are almost minimized. Table (21) below presents the GAMS solve summary.

Table 21: Model Results - GAMS Solve Summary for the Winter Season

	Lower	Level	Upper	Marginal
EQU Obj	0	0	0	1
Production Constraint	1.0699E+5	1.0699E+5	+INF	1.5107E-6
Profit Constraint	1.5112E+7	1.5112E+7	+INF	1.5221E-8
Investment Constraint	-INF	1.3117E+7	1.3172E+7	0
Fertilizers Constraint (type N)	-INF	4.0956E+5	4.0956E+5	-1.136E-7
Fertilizers Constraint (type P)	-INF	1.5492E+5	1.5492E+5	-3.139E-7
Fertilizers Constraint (type K)	-INF	1.3981E+5	1.3981E+5	-8.174E-8
Water Constraint	-INF	1.0338E+7	1.1607E+7	0

Compared to the preliminary results of the model (table 16), with slight decline in membership grades of the profitability, Nitrogenous and phosphate goals (decline of 0.8%, 3.3% and 1.7% respectively), the target self-sufficiency ratios of important food items were achieved; thus resulting in a balanced cropping pattern. Table (22) shows the values of production and profit achieved by the suggested cropping pattern; and the resources required. The level of production generated by the suggested cropping pattern exceeds the target level by 6 tons. However, the profit target was under-achieved; as the level of profit achieved by the suggested pattern is only EGP 15 billion, compared to a target level of EGP 15.11 billion. Furthermore, the suggested allocation of land during the winter season fully minimizes the use of all resources (investment, phosphate and potassium fertilizers and water resources). Yet, it does not minimize the use of Nitrogenous fertilizers; as the required level of Nitrogenous fertilizer exceeds the target level by 381 kgs.

Table 22: Winter Season Cropping Pattern: Fuzzy Goals Achievement

	Production ('000 tons)	Profit (000 EGP)	Investment (000 EGP)	Fertilizers (kg)			Water ('000 m3)
				N	P	K	
Wheat	12,000	5,663,053	7,512,576	281,250	56,250	90,000	4,500,000
Broad Beans	487	313,723	560,188	4,566	6,849	-	280,039
Sugar Beet	15,995	531,929	1,060,221	45,699	17,137	13,710	816,302
Perennial Clover	66,500	5,856,887	2,189,646	28,500	42,750	-	3,680,300
One-cut Clover	5,707	622,878	283,122	6,341	9,512	-	306,487
Winter Potatoes	1,212	437,236	572,751	17,577	6,061	11,617	208,202
Winter Tomatoes	5,100	1,582,381	946,504	26,010	15,300	24,480	550,800
Total	**107,000**	**15,008,087**	**13,125,007**	**409,944**	**153,859**	**139,807**	**10,342,129**
Target	**106,994**	**15,112,100**	**13,172,000**	**409,563**	**154,915**	**139,807**	**11,607,224**
Evaluation	*Perfectly achieved**	*Fuzzily Achieved***	*Perfectly achieved**	*Fuzzily Achieved***	*Perfectly achieved**	*Perfectly Achieved**	*Perfectly Achieved**
Deviation from the Target	*6*	*(104,013)*	*46,993*	*(381)*	*1,056*	*0*	*1,265,095*
Deviation from the Target (%)	*0.0056%*	*(0.688)%*	*0.3568%*	*(0.093)%*	*0.682%*	*0.00%*	*10.89%*

* "Perfectly achieved" indicates that the goal was fully achieved (with a membership grade of 1). For the production goal this means that the total production resulting from the suggested cropping pattern exceeded the target level of production. For the investment, fertilizers and water goals, it indicates that the suggested cropping pattern minimizes the use of these resources; thus the total value is less than the target value.

** "Fuzzily achieved" indicates that the suggested cropping pattern does not fully achieve the goal (with a membership grade below 1). For the profitability goals this means that the profit level of the suggested cropping pattern is lower than the target level of profitability. For the Nitrogenous fertilizers goal, this indicates that the cropping pattern requires the use of more fertilizers than the target level.

Summer Season

According to table (21) above, results indicate that, with the exception of the Potassium fertilizers goal (K), all goals were fully achieved, with a membership grade equivalent to 1. The Potassium fertilizer goal required a tolerance value of 0.975 to be assigned. Table (23) below presents the GAMS solve summary.

Table 23: Model Results - GAMS Solve Summary for the Summer Season

	Lower	Level	Upper	Marginal
EQU Obj	0	0	0	1
Production Constraint	44607	44607	+INF	3.4088E-7
Profit Constraint	9.4348E+6	9.4348E+6	+INF	8.5841E-9
Investment Constraint	-INF	1.3840E+7	1.4296E+7	0
Fertilizers Constraint (type N)	-INF	5.6140E+5	5.7987E+5	0
Fertilizers Constraint (type P)	-INF	1.6191E+5	1.6673E+5	0
Fertilizers Constraint (type K)	-INF	1.3709E+5	1.3709E+5	-4.139E-7
Water Constraint	-INF	1.4127E+7	2.2004E+7	0

According to table (24), both the production and profit targets were exactly achieved. The levels of production and profitability of the suggested land allocations are exactly equal to the target values of the two goals. Furthermore, the suggested cropping pattern minimizes the use of all resources required (working capital, nitrogenous and phosphate fertilizers, water), whereby the suggested cropping pattern for the summer seasons requires the use of less than the target values for these goals. The exception to the minimization of required resources was the potassium fertilizer. The suggested cropping pattern requires the use of an additional 4.66 thousand kgs of the potassium fertilizer.

Table 24: Sumer Season Cropping Pattern: Fuzzy Goals Achievement

	Production ('000 tons)	Profit (000 EGP)	Investment (000 EGP)	Fertilizers (kg)			Water ('000 m3)
				N	P	K	
Rice	5,625	2,130,804	3,068,646	86,250	18,750	-	5,000,000
Summer Maize	10,830	2,851,982	5,104,087	295,350	73,838	59,070	4,417,944
Peanuts	460	396,284	437,878	6,900	6,900	5,520	608,350
Sugar Cane	18,112	851,205	1,428,993	67,200	19,200	8,960	1,920,000
Cotton	764	606,218	1,316,302	29,596	10,741	11,457	1,035,871
Summer Potatoes	3,017	1,088,112	1,425,357	43,744	15,084	28,911	518,135
Summer Tomatoes	5,800	1,510,231	1,058,848	29,580	17,400	27,840	626,400
Total	**44,607**	**9,434,835**	**13,840,110**	**558,620**	**161,912**	**141,758**	**14,126,700**
Target	**44,607**	**9,434,803**	**14,296,126**	**579,871**	**166,732**	**137,092**	**22,003,921**
Evaluation	*Perfectly achieved**	*Perfectly achieved**	*Perfectly achieved**	*Perfectly achieved**	*Perfectly achieved**	*Fuzzily Achieved***	*Perfectly Achieved**
Deviation from the Target	*0*	*0*	*456,016*	*21,251*	*4,820*	*(4,666)*	*7,877,221*
Deviation from the Target (%)	*0.00%*	*0.00%*	*3.189%*	*3.66%*	*2.891%*	*(3.404)%*	*35.79%*

* "Perfectly achieved" indicates that the goal was fully achieved (with a membership grade that is equal to 1). For the production and profitability goals, this means that the total production level and the total profit level resulting from the suggested cropping pattern are equal to/ exceeding the target level of production/ profit. For the investment, fertilizers and water goals, it indicates that the suggested cropping pattern actually minimizes the use of these resources; thus the total value is less than the target value.

** "Fuzzily achieved" indicates that the suggested cropping pattern does not fully achieve the goal (with a membership grade below 1). For the potassium fertilizers goal, this indicates that the cropping pattern requires the use of more fertilizers than the target level.

Nili Season

No constraints were imposed on the minimum land area to be allocated to essential crops in the Nili season due to the small number of crops considered for the nili season. Accordingly, all fuzzy goals were completely achieved with a membership grade of 1. Table (19) shows the GAMS solve summary for the Nili season.

According to table (25), the suggested cropping pattern yield levels of production and profit that are greater than the target levels. Furthermore, it minimizes all required resources (working capital, water and fertilizers) during the season.

Table 25: Nili Season Cropping Pattern: Fuzzy Goals Achievement

	Production ('000 tons)	Profit (000 EGP)	Investment (000 EGP)	Fertilizers (kg)			Water ('000 m3)
				N	P	K	
Nili Maize	2,240	281,735	958,480	61,099	15,275	12,220	913,942
Nili Tomatoes	1,417	488,283	260,021	7,226	4,250	6,801	153,014
Nili Potatoes	-	-	-	-	-	-	-
Total	**3,657**	**770,018**	**1,218,501**	**68,352**	**19,525**	**19,020**	**1,066,957**
Target	**2,962**	**770,000**	**1,399,426**	**73,326**	**21,478**	**23,921**	**1,354,214**
Evaluation	*Perfectly achieved**	*Perfectly achieved**	*Perfectly achieved**	*Perfectly achieved**	*Perfectly achieved**	*Perfectly Achieved**	*Perfectly Achieved**
Deviation from the Target	*695*	*18*	*180,925*	*4,974*	*1,953*	*4,901*	*287,257*
% Deviation from the Target	*23.464%*	*0.0023%*	*12.929%*	*6.783%*	*9.093%*	*20.488%*	*21.21%*

* "Perfectly achieved" indicates that the goal was fully achieved (with a membership grade that is equal to 1). For the production and profitability goals, this means that the total production level and the total profit level resulting from the suggested cropping pattern are equal to/ exceeding the target level of production/ profit. For the investment, fertilizers and water goals, it indicates that the suggested cropping pattern actually minimizes the use of these resources; thus the total value is less than the target value.

Figure (4) depicts the land allocations for in the year 2017 based on the cropping pattern presented in the Strategy of Sustainable Agricultural Development Towards 2017

and the optimal land allocations as proposed by the FGP model, after imposing constraints on land areas to be reserved to essential crops.

Compared to cropping pattern proposed in the 2017 strategy, the proposed cropping pattern allocates the same land areas to wheat, rice and peanuts. According to the results of the model, it is optimal to allocate more land area to the cultivation of broad beans (304 thousand feddans, versus 300 thousand feddans required to achieve the target self-sufficiency ratio of 69.8% in broad beans). The additional 4 thousand feddans to be allocated to broad beans yield an additional production of 6.4 thousand tons; thus contribute to raising the self-sufficiency ratio of broad beans to 70.5%. Furthermore, according to the results of the FGP model, the land area expected to be allocated to maize exceeds the land area proposed in the strategy by 95 thousand feddans, which raises the self-sufficiency ratio of maize to reach 81%. As for sugar crops, the FGP model minimizes the area to be cultivated by sugar cane in light of the government's objective to minimize the use of water in agriculture. Meanwhile, the FGP model allocates more land area to sugar beet that is more profitable and requires less use of resources, especially water. The area to be allocated to cotton according to the FGP model is significantly less than the allocation plan of the 2017 strategy. This is due to the fact that the profitability of cotton is no longer as high as it historically used to be. However, it is worth noting that the land area expected to be allocated to cotton in 2017 is greater than that realized in the cropping pattern of the year 2010.

Due to their high profitability, the FGP model allocates large land areas to the cultivation of horticultural crops. For tomatoes, the FGP model allocates 616 thousand feddans to the cultivation of tomatoes during the cropping year 2017, versus 580 thousand feddans as proposed by the 2017 strategy. Likewise, the FGP model allocates additional 52 thousand feddans to the cultivation of potatoes compared to the land area proposed by the strategy. These results have important policy implications in terms of the importance of penetrating more international markets to increase the exports of Egyptian horticultural crops.

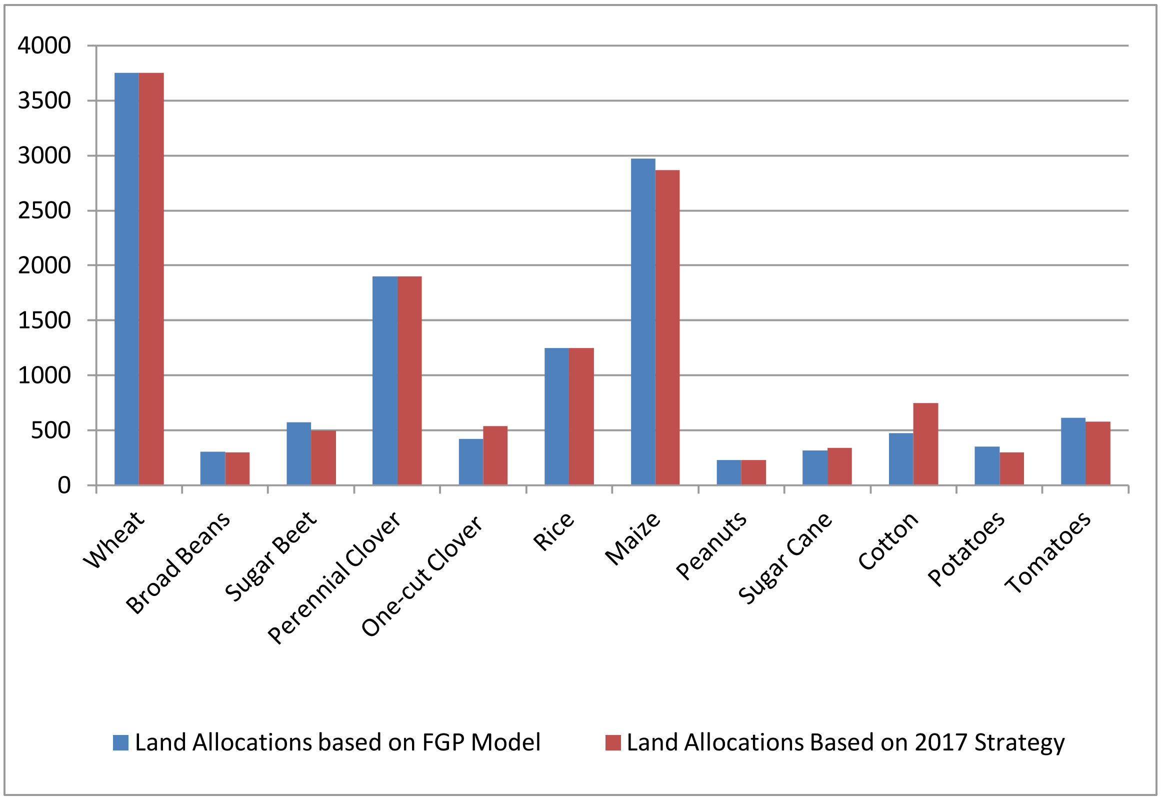

Figure 4: The Cropping Pattern for Egypt in 2017

VI. Sensitivity Analysis

This chapter presents different scenarios for the cropping pattern, considered for sensitivity analysis. The chapter is organized as follows; the first section presents the model results with different weight structures for the five goals considered. While the second section accounts for the potential uncertainty in population growth in 2017. Different figures for the population in Egypt by 2017 shall change the demand for key crops; thus influencing the areas allocated to these crops.

6.1 Weight Structures

Scenarios for changing the weight structure of the model are considered for goals that were fuzzily achieved, in at least one season, in the base scenario presented in chapter (5). The scenarios considered in this section are those related to placing more weight on the profit and fertilizers goals.

6.1.1 Scenario no. 1: Profitability

The weight allocated to the profit goal shall be increased; in an attempt to generate the optimal cropping pattern that places more emphasis on maximizing profitability, while taking into account other fuzzy goals tackled by the model. Therefore, the weight structure suggested is 0.2, 0.4, 0.15, 0.05, 0.05, 0.05, and 0.1 respectively for $\theta_{1,s}^{-}$, $\theta_{2,s}^{-}$, $\theta_{1,s}^{+}$, $\theta_{2,N,s}^{+}$, $\theta_{2,P,s}^{+}$, $\theta_{2,K,s}^{+}$ and $\theta_{3,s}^{+}$. All additional constraints on essential crops were kept the same. The results are shown in the first column of table (26) below.

Changing the weight structure in favor of the profitability goal resulted in the profitability goal being fully achieved for all the seasons with a membership grade of 1. Also, investment and water goals are fully achieved in the three seasons. However, the production, and fertilizers goals were only partially achieved in the winter season, and were fully achieved in the summer and nili seasons. Land allocations changed only in the winter season, whereby less land areas are allocated to broad beans and sugar beet, compared to the initial scenario. Meanwhile, land areas allocated to the relatively more profitable crops, such as one-cut clover and potatoes were increased by 17.54% and 19.36% respectively. It is important to note that the results of the summer and nili

seasons are not sensitive to changing the weight structure in favor for the profitability goal.

6.1.2 Scenario no. 2: Fertilizers Minimization

In an attempt to generate a cropping pattern that requires a level of fertilization that in line with the target level of fertilizers set in the problem, the weight structure shall be modified as follows; 0.2, 0.15, 0.1, 0.15, 0.15, 0.15, and 0.1 shall be assigned respectively for $\theta^{-}_{1,s}$, $\theta^{-}_{2,s}$, $\theta^{+}_{1,s}$, $\theta^{+}_{2,N,s}$, $\theta^{+}_{2,P,s}$, $\theta^{+}_{2,K,s}$ and $\theta^{+}_{3,s}$.Preliminary results indicate that for the winter season, the profitability goal remained fuzzy; and so was the Nitrogenous fertilizer goal. The suggested land allocation for potatoes decreased significantly by 56% compared to the initial scenario; since potatoes is heavy in the use of fertilizers, relative to other winter crops. Larger land areas were allocated to both broad beans and one-cut clover that requires relatively less fertilizers.

Similar to the scenario of changing the weight structure in favor of the profitability goal, the membership grades and land allocations for the summer and nili seasons are not sensitive to changing the weight structure in favor of the fertilizers use minimization goal.

Table 26: Results of Changing the Weight Structure

Variable	**Equal Weights**	**0.2, 0.4, 0.15, 0.05, 0.05, 0.05, 0.1**		**0.2, 0.15, 0.1, 0.15, 0.15, 0.15, 0.1**	
		Land Allocations	*% Change*	Land Allocations	*% Change*
<u>Winter Season</u>					
$\boldsymbol{\lambda^{-}_{1,1}}$	1	0.987		1	
$\boldsymbol{\lambda^{-}_{2,1}}$	0.992	1		0.98	
$\boldsymbol{\lambda^{+}_{1,1}}$	1	1		1	
$\boldsymbol{\lambda^{+}_{2,N,1}}$	0.967	0.967		0.978	
$\boldsymbol{\lambda^{+}_{2,P,1}}$	0.983	0.991		1	
$\boldsymbol{\lambda^{+}_{2,K,1}}$	1	1		1	
$\boldsymbol{\lambda^{+}_{3,1}}$	1	1		1	

Wheat	3750	3750	*0*	3750	*0*
Broad Beans	304.39	300	*-1.44*	324.66	*6.6*
Sugar Beet	571.24	477.54	*-16.40*	565.37	*-1.03*
Perennial Clover	1900	1900	*0*	1900	*0*
One-cut Clover	422.74	496.89	*17.54*	485.4	*14.8*
Winter Potatoes	101.02	120.58	*19.36*	44.2	*-56.3*
Winter Tomatoes	255	255	*0*	255	*0*
Summer Season					
$\lambda_{1,2}^{-}$	1	1		1	
$\lambda_{2,2}^{-}$	1	1		1	
$\lambda_{1,2}^{+}$	1	1		1	
$\lambda_{2,N,2}^{+}$	1	1		1	
$\lambda_{2,P,2}^{+}$	1	1		1	
$\lambda_{2,K,2}^{+}$	0.975	0.975	*0*	0.975	*0*
$\lambda_{3,2}^{+}$	1	1	*0*	1	*0*
Rice	1250	1250	*0*	1250	*0*
Summer Maize	2461.25	2461.25	*0*	2461.25	*0*
Peanuts	230	230	*0*	230	*0*
Sugar Cane	320	320	*0*	320	*0*
Cotton	477.36	477.36	*0*	477.36	*0*
Summer Potatoes	251.40	251.40	*0*	251.40	*0*
Summer Tomatoes	290	290	*0*	290	*0*
Nili Season					
$\lambda_{1,3}^{-}$	1	1		1	
$\lambda_{2,3}^{-}$	1	1		1	
$\lambda_{1,3}^{+}$	1	1		1	
$\lambda_{2,N,3}^{+}$	1	1		1	
$\lambda_{2,P,3}^{+}$	1	1		1	
$\lambda_{2,K,3}^{+}$	1	1		1	
$\lambda_{3,3}^{+}$	1	1		1	
Nili Maize	509.16	509.16	*0*	509.16	*0*
Nili Tomatoes	70.84	70.84	*0*	70.84	*0*
Nili Potatoes	0	0	*0*	0	*0*

6.2 Population Growth

According to the Sustainable Agricultural Development Strategy towards 2030, self-sufficiency ratios of strategic crops are calculated based on population that is expected to reach 92 million (Appendix B). This figure for population was obtained based on a 1.8% annual cumulative rate of population growth. Changing the rate of growth of population will affect the expected needs for crops, and accordingly, the areas required to be reserved to strategic crops. This section presents the response of the cropping pattern and the fuzzy goals to the change in the expected population growth rate.

6.2.1 Scenario no. 3: Higher than Expected Population

Given the fact that the population in Egypt stood at 81 million in 2010 (WDI), increasing the cumulative growth rate to 2.2% will result in a population of 94 million by 2017. This would, in turn, result in a higher demand for the strategic food items; thus affecting the cropping pattern. To maintain the expected self-sufficiency ratios of strategic crops in the case of a higher than expected population growth rate, essential crops constraints shall change as follows:

Winter season:

$$\boldsymbol{x11 \geq 3840}$$

$$\boldsymbol{x21 \geq 307}$$

$$\boldsymbol{x41 \leq 1900}$$

$$\boldsymbol{x51 \leq 540}$$

$$\boldsymbol{x71 \leq 296}$$

Summer Season:

$$\boldsymbol{x12 \leq 1250}$$

$$\boldsymbol{x32 \leq 230}$$

$$x42 \leq 340$$

$$x62 \leq 296$$

Also, an additional constraint shall be imposed on the minimum land area to be allocated to maize to cater for increasing demand on maize; as follows

$$x22 \geq 2450$$

Table 27: Results - Rapid Population Growth

Variable	Base Scenario	Given the New Food Security Constraints	% Change
(1) Winter Season			
$\lambda_{1,1}^{-}$	1	1	*0*
$\lambda_{2,1}^{-}$	0.992	0.991	*(0.10)*
$\lambda_{1,1}^{+}$	1	1	*0*
$\lambda_{2,N,1}^{+}$	0.967	0.973	*0.62*
$\lambda_{2,P,1}^{+}$	0.983	0.976	*(0.71)*
$\lambda_{2,K,1}^{+}$	1	1	*0*
$\lambda_{3,1}^{+}$	1	1	*0*
Wheat	3750	3840	*2.40*
Broad Beans	304.39	307	*0.86*
Sugar Beet	571.24	616.08	*7.85*
Perennial Clover	1900	1900	*0*
One-cut Clover	422.74	302.26	*(28.50)*
Winter Potatoes	101.02	38.65	*(61.74)*
Winter Tomatoes	255	296	*16.08*
(2) Summer Season			
$\lambda_{1,2}^{-}$	1	1	*0*
$\lambda_{2,2}^{-}$	1	1	*0*
$\lambda_{1,2}^{+}$	1	1	*0*
$\lambda_{2,N,2}^{+}$	1	1	*0*
$\lambda_{2,P,2}^{+}$	1	1	*0*
$\lambda_{2,K,2}^{+}$	0.975	0.979	*0.41*
$\lambda_{3,2}^{+}$	1	1	*0*
Rice	1250	1250	*0*
Summer Maize	2461.25	2450	*(0.46)*
Peanuts	230	230	*0*

Sugar Cane	320	340	*6.25*
Cotton	477.36	479.8	*0.51*
Summer Potatoes	251.40	234.17	*(6.85)*
Summer Tomatoes	290	296	*2.07*
(3) Nili Season			
$\boldsymbol{\lambda_{1,3}^{-}}$	1	1	*0*
$\boldsymbol{\lambda_{2,3}^{-}}$	1	1	*0*
$\boldsymbol{\lambda_{1,3}^{+}}$	1	1	*0*
$\boldsymbol{\lambda_{2,N,3}^{+}}$	1	1	*0*
$\boldsymbol{\lambda_{2,P,3}^{+}}$	1	1	*0*
$\boldsymbol{\lambda_{2,K,3}^{+}}$	1	1	*0*
$\boldsymbol{\lambda_{3,3}^{+}}$	1	1	*0*
Nili Maize	509.16	509.16	*0*
Nili Tomatoes	70.84	70.84	*0*
Nili Potatoes	0	0	*0*

According to the results presented in table (27), land allocations for both the winter and summer seasons changed noticeably with changing constraints on essential crops to account for a potentially higher population growth. In the winter season, the profitability, nitrogenous and phosphate fertilizers goals remained only fuzzily achieved. Areas allocated to wheat, broad beans and tomatoes increased by 2.4%, 0.86% and 16% respectively to be in line with the required level of production that would achieve the pre-determined self-sufficiency ratios. Meanwhile, the area allocated to one-cut clover declined noticeably from 423 thousand feddans to 302 thousand feddans. Land allocations during the summer season also changed. Despite imposing an additional constraint on the minimum land area to be allocated to maize, results of the model show that the area allocated to maize after accounting for population growth is less than the area allocated to maize in the initial scenario. The area allocated to summer potatoes decreased by 6.8% compared to the initial scenario. Meanwhile, the land areas allocated to the cultivation of both sugar cane and tomatoes increased, in line with the constraints imposed on the model. Similar to the initial scenario, the potassium fertilizers goal remained partially achieved with a membership grade of 0.979. Results of the nili seasons did not change, compared to the initial scenario, since no additional constraints were imposed on the land allocations during the nili season.

VII. Conclusions and Policy Inferences

7.1 Summary of the Findings

The FGP model was employed to determine the optimal cropping pattern for Egypt, identifying five key objectives. The objectives tackled in the model are: production maximization, profit maximization, investment minimization, fertilizers requirement minimization and water use minimization. Without imposing any constraints on the minimum land area to be cultivated with essential crops, land allocations resulting from the model fully achieves the five objectives in the three cropping seasons. Results of the unconstrained model have a key policy implication; it is not optimal to produce strategic crops, such as wheat and broad beans (in the winter season), and maize and cotton (in the summer season) given the resources available for the agricultural sector in Egypt. On the other hand, results show that Egypt has a strong competitive advantage in the production of clover crops (which provide an important source for nitrogenous fertilizer for the soil), tomatoes, rice and sugar cane. Accordingly, a drawn conclusion is that Egypt can utilize its competitive advantage in producing certain types of crops to export them and generate the necessary funds to finance the importation of other needed agricultural products.

However, the high dependence on imports of food items is unsustainable. In the past few years, the international prices of major food items, including agricultural crops, witnessed sharp fluctuations. Thus, the dependence on international markets to provide necessary food items for a rapidly growing population entails high risks. Accordingly, some government intervention in the agricultural sector is recommended to achieve food security. The model was modified by imposing constraints on the minimum land areas to be allocated to the production of strategic crops, needed to ensure food security. Additionally, limiting constraints on land areas were imposed on exportable crops to ensure the absence of waste, given the international demand for Egyptian agricultural products.

Results of the model indicate that ensuring food security has some costs in terms of profitability and fertilizers utilization. A more balanced cropping pattern was obtained, whereby some land areas were allocated to the cultivation of essential crops, such as wheat, maize and broad beans to achieve the targeted self-sufficiency ratios by the government. The profit goal was fuzzily achieved only during the winter season. The resulting land allocation during the winter seasons resulted in a total level of profit that is lower than the target level by only 0.68%, which indicates that the cost of achieving food security in terms of the profitability of the cropping pattern is very low. As for the fertilizers requirements goals, they were partially achieved in both the winter and the summer seasons. In the winter season, the required level of nitrogenous fertilizer for the suggested cropping pattern exceeded the target level by only 0.093%. While during the summer season, the required level of potassium fertilizer for the suggested cropping pattern exceeded the target level by 3.4%. This indicates that the cost of achieving the targeted self-sufficiency ratios in Egypt is not high. Thus, it is possible for the government to target higher levels of self-sufficiency of strategic items and the costs would still be tolerable.

It is important to note that achieving food security in Egypt does not come at the expense of higher water utilization. During the three cropping seasons, the water requirement goal was fully achieved, with no tolerance required. This is attributed to the fact that the crops identified as “strategic” are not heavy users of water. Furthermore, the limiting constraints on the land areas dedicated to the production of rice and sugar cane, in line with the government’s Sustainable Agricultural Development Strategy, contributed to conserving additional amounts of water, as they are both very heavy users of water.

While the results of the winter season were very sensitive to changes in the weight structure, those of the summer and nili seasons were not at all sensitive to the alteration of the weight structure in the problem. Accounting for the potential of population growth at a faster rate than that projected by the government, results of the model in the different cropping seasons changed to accommodate for the higher demand for essential crops,

captured through the constraints imposed on the model. Figure (5) presents a comparison of land allocations under the different scenarios considered in the study:

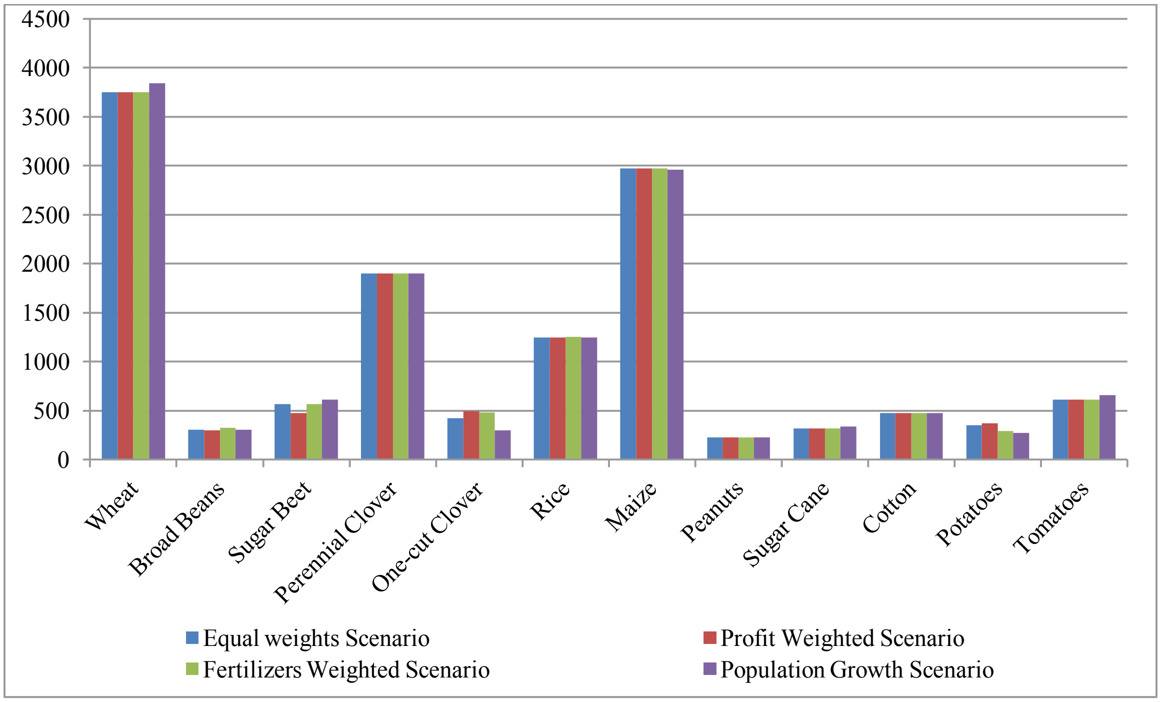

Figure 5: Comparison of Land Allocations under the Scenarios Considered in the Study

7.2 Policy Inferences

- It is crucial for the government to achieve food security by ensuring the domestic production of a certain level of strategic/essential crops;
- Based on the previously presented results, the government can target higher levels of self-sufficiency ratios of the key food items, including wheat, broad beans and maize, since the extra costs associated with fulfilling the self-sufficiency ratios are not high;
- Because the fertilizers requirement goal was not achieved in two cropping seasons, it is important to monitor the fertilizers market in Egypt. Export quotas can be

imposed on fertilizers to ensure the availability of enough quantities of fertilizers to cover domestic demand;

- The optimal cropping pattern proposed by the FGP model allocates more land area to the cultivation of horticultural crops (potatoes and tomatoes) than land areas proposed in the Strategy of Sustainable Agricultural Development Towards 2017, issued by MALR. This result in higher self-sufficiency ratios of horticultural crops, which achieves surplus for exportation. Accordingly, it is important for the government to work on developing new export markets for horticultural crops in order to increase its exports of potatoes and tomatoes.

- There is room to introduce the cultivation of other horticultural crops, especially vegetables that are to be produced for exportation purposes. Examples of these crops include, but not limited to, artichoke, broccoli, aspargus, in addition to different kinds of medical and Aromatic plants.

- It is very crucial to tackle the problem of high losses in the agricultural sector. Losses arise due to the limited attention to proper harvest practices, the inefficient transportation and storage techniques, and poor local marketing.

- **Contract farming**[16] should be further encouraged in Egypt for it is beneficial for both parties involved in the contract. Farmers have a guaranteed market outlet and reduce their uncertainty regarding prices. Thus, it can be considered one way of improving the conditions of small farmers and increasing their direct profits. A study conducted by the International Fund for Agricultural Development (IFAD) concluded that small landlords in Egypt can increase their incomes by about 63% if they engage in the contract farming of organic horticultural produce, and by about 43% if they engage in conventional export crops (IFAD 2007). Meanwhile, buying

[16]Contract farming is defined as agricultural production that is carried out according to an agreement between a buyer and a farmer(s); whereby the farmer agrees to provide agreed quantities of a specific agricultural product. On the other hand, the buyer is committed to purchasing the product and, in some cases, to support production through the supply of farm inputs, land preparation and the provision of technical advice (FAO, 2011).

firms benefit from having a guaranteed supply of agricultural products that meet their specifications regarding quality, quantity and timing of delivery (FAO, 2011). Additionally, contract farming can be one way of overcoming the land fragmentation problem in Egypt. Large buying firms might contract with a large number of small farmers in the same area; thus consolidate agricultural land in order to produce certain crops in different areas.

- Institutional coordination among relevant authorities is highly needed in order ensure food security, environmental preservation, social justice and accordingly sustainable agricultural policy in Egypt.

7.3 Limitations of the Study

7.3.1 Model

As previously stressed, the FGP model used to determine the optimum cropping pattern has numerous advantages. These advantages include (1) the possibility to tackle multiple objectives that are contradicting in nature in the same time, which makes the problem closer to reality; and (2) the possibility of modeling the parameters of the model in a fuzzy sense in order to capture the uncertainties associated with the nature of agricultural production. Nevertheless, a major boundary of the model employed is that it tackles the problem from the partial equilibrium, rather than a general equilibrium perspective. The model focuses only on the supply-side in the agricultural sector. The goals the model tries to achieve are related to maximizing the producers' surplus through either maximizing the profit of farmers and/or minimizing the use of resources. The demand side, including consumers' preferences/utility, is not captured by the model; i.e., the model assumes constant demand.

Yet, consumer demand is accounted for through the imposition of constraints on the land areas to be reserved to the cultivation of essential crops in order to ensure the minimum supply of strategic commodities to meet local demand. However, the consumption pattern and consumers' preferences are yet to be fully captured by the model. The constraints imposed on the model to ensure a minimum level of production of

necessary/strategic food items; and to set a maximum limit on the production of exportable crops are considered to be another drawback for the model. These constraints lead to the cropping pattern being pushed towards the pattern suggested by the Sustainable Agricultural Development Strategy, rather than generating the optimum scenario for the land allocations.

7.3.2 Data

The historical data used on working capital and profitability do not account for additional costs incurred by Egyptian farmers. These costs include the cost of purchasing some inputs, including seeds and fertilizers, from the black market; and the cost of pumping water from major canals to fields. The significance of these costs to the farmer and their effect on his profitability are ambiguous; nonetheless, the exclusion of these costs leads to biased estimates for profitability and working capital in the agricultural sector. Recorded data on the previously mentioned costs are not available. However, these costs could have been approximately estimated through field surveys with farmers in different regions of the country.

Furthermore, the study covers a limited number of crops (7 winter crops, 7 summer crops and 3 nili crops) in order to determine the optimum cropping pattern on a national level. Thus, the study presents a partial picture for the cropping pattern in 2017. The selection of crops was motivated basically by the availability of data on these crops in the year 2017 as part of the Sustainable Agricultural Development Strategy.

7.4 Suggested Future Research

Overall, while the presented study is useful in proposing a new methodology of determining the optimum cropping pattern in Egypt through the utilization of one of the multi-criteria decision making applications while accounting for uncertainty, the model suffers from some limitations as discussed in the previous section. One way to tackle the drawbacks of imposing numerous constraints on the model is to carry out the same model on a governorate level and then aggregate the results to arrive at the optimum cropping pattern on a nation-wide level. Breaking apart the process of determining the optimum

cropping pattern to the level of governorate enables to capture the unique characteristic for each region and the crops that can be cultivated according to the weather and other natural conditions. Thus, there should be less need to impose restrictions on the minimum land areas to be allocated to some crops.

In addition, an important scenario to be considered is the potential of lifting the energy subsidy in Egypt. Lifting the energy subsidy would increase the cost of agricultural production significantly. The fertilizer industry in Egypt is among the most likely to be affected by the potential decrease in the energy subsidy; due to the high dependency of the sustainability of the fertilizer industry in Egypt on the energy subsidies. Thus, lifting the energy subsidy in Egypt would dramatically change the target values and fuzziness of the goals modeled in the study; and accordingly the optimal cropping pattern.

Finally, determining the optimum cropping pattern can be done through developing a general equilibrium model that captures, in addition to the supply side effects, the demand side. Including the demand side in the model enables it to capture welfare effects related to the consumption of agricultural products either for domestic uses or exportation.

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APPENDIX (A): CROPPING PATTERN IN EGYPT

The Cropping pattern in Egypt by Season (1950 – 2010)

Crop ('000 feddans)	1950 -1954	1955 -1959	1960 -1964	1965 -1969	1970 -1974	1975-1979	1981-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005	2006	2007	2008	2009	2010
Winter Season																	
Wheat	1571	1501	1387	1268	1302	1345	1291	1344	2109	2444	2473	2985	3064	2716	2920	3179	3066
Barely	122	135	128	110	81	103	118	115	177	237	231	248	214	245	182	226	279
Broad Beans	328	353	365	349	283	260	316	348	353	371	314	221	198	235	190	251	202
Lentil	74	80	77	65	64	52	15	20	16	9	5	3	2	2	1	2	3
Sugar Beet	-	-	-	-	-	-	18	40	41	79	141	167	186	248	258	265	386
Clover	2184	2362	2444	2630	2801	2834	2750	2587	2444	2384	2494	2166	2165	2366	2099	1936	2002
Garlic							13	13	15	20	23	17	17	25	28	17	23
Onion	26	36	44	45	33	31	26	28	30	55	68	109	65	87	109	123	134
Linen	8	14	27	30	33	55	36	40	32	21	24	16	16	21	20	13	8
Tomatoes							138	162	154	157	177	215	209	200	218	265	204
Potatoes							81	107	102	74	79	142	102	109	149	154	156
Other Vegetables	70	104	49	170	189	214	139	158	197	295	313	288	289	310	326	391	367
Others	95	126	138	116	122	130	96	105	87	105	124	86	181	83	267	127	90
Total Winter	**4478**	**4711**	**4659**	**4783**	**4908**	**5023**	**5036**	**5065**	**5757**	**6251**	**6465**	**6662**	**6710**	**6647**	**6768**	**6949**	**6920**
Summer Season																	

Rice	505	641	791	1028	1093	1042	1006	947	1202	1428	1500	1459	1593	1673	1770	1369	1094
Maize	29	56	271	1078	1245	1411	1433	1367	1655	1683	1607	1794	1569	1608	1647	1721	1693
Sorghum	386	393	414	462	465	434	365	319	333	358	368	351	368	347	364	333	329
Corn							-	-	13	74	86	150	142	177	217	262	307
Peanuts	28	36	46	47	35	35	27	28	59	111	145	148	132	155	146	152	159
Sesame	37	43	45	32	37	36	33	25	56	67	70	67	73	75	66	99	88
Sunflower							-	-	58	45	38	31	36	27	19	40	35
Soybean							139	110	70	38	18	20	18	19	21	17	36
Sugarcane	96	111	122	145	197	248	249	266	276	299	321	321	327	335	324	317	320
Cotton	1765	1791	1751	1694	1551	1296	1016	1027	858	785	641	657	536	575	313	284	369
Onions							11	13	10	13	13	11	18	15	15	17	19
Tomatoes							97	128	122	180	204	215	241	267	285	270	262
Potatoes							65	78	70	98	73	113	79	86	122	121	134
Other Vegetables	120	200	260	328	356	444	260	358	322	468	661	762	849	825	694	729	825
Others	13	14	46	54	86	123	136	194	193	219	275	286	331	334	318	594	644
Total Summer	**2979**	**3285**	**3746**	**4868**	**5065**	**5069**	**4836**	**4861**	**5298**	**5866**	**6020**	**6386**	**6312**	**6518**	**6321**	**6325**	**6315**
Nili Season																	
Maize	1717	1794	1456	432	348	420	521	457	354	312	295	277	246	243	309	280	274
Sorghum	52	58	55	45	29	21	15	10	12	11	9	9	4	7	3	3	5
Rice							2	1	1	3	1	0	4	3	4	1	1
Corn							0	0	1	12	27	41	36	45	60	85	72
Onion							7	8	7	11	9	6	10	15	11	13	13
Tomatoes							87	105	76	69	74	65	74	70	69	64	49
Potatoes									0	76	49	46	39	62	56	55	45

Other Vegetables	69	91	138	170	216	256	96	86	79	80	88	93	105	126	123	102	70
Others	23	24	18	31	33	56	40	100	82	84	66	69	73	75	65	100	70
Total Nili	**1861**	**1967**	**1667**	**678**	**626**	**753**	**767**	**766**	**611**	**657**	**618**	**606**	**590**	**646**	**701**	**704**	**598**
Fruits	**94**	**114**	**147**	**208**	**255**	**311**	**406**	**567**	**917**	**991**	**1087**	**1164**	**1208**	**1272**	**1350**	**1407**	**1377**
Palm Trees	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**24**	**65**	**74**	**86**	**85**	**87**	**88**	**88**	**100**
Wood Trees	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**15**	**6**	**7**	**23**	**24**
Total Cropped Area	**9412**	**10077**	**10219**	**10537**	**10854**	**11156**	**11045**	**11259**	**12608**	**13831**	**14265**	**14904**	**14920**	**15175**	**15234**	**15496**	**15334**

Source: Data from 1950 – 1980 are obtained from Richards, 1982; while the rest of the data is obtained from the Annual Bulletin of Agricultural Statistical Indicators

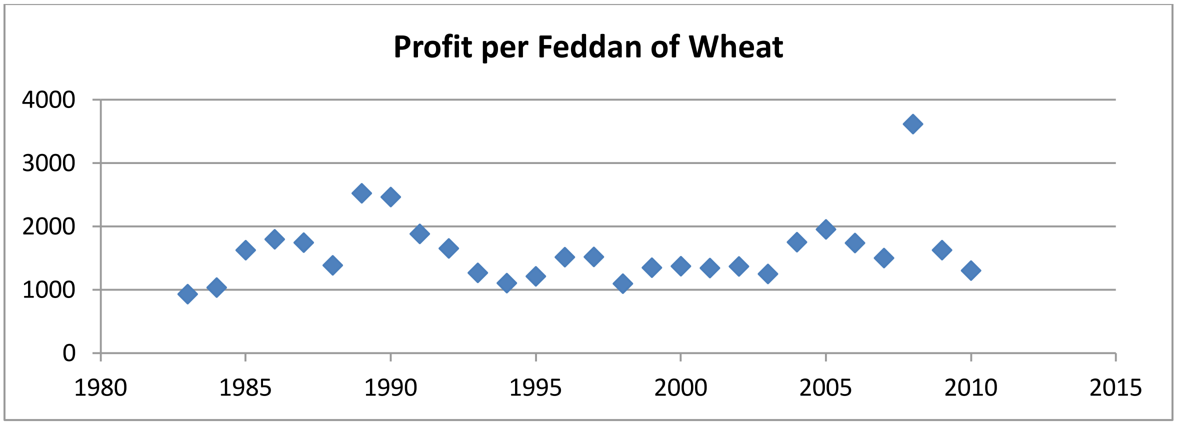
APPENDIX (B): TARGET PRODUCTION AND SELF SUFFICIENCY LEVELS IN 2017

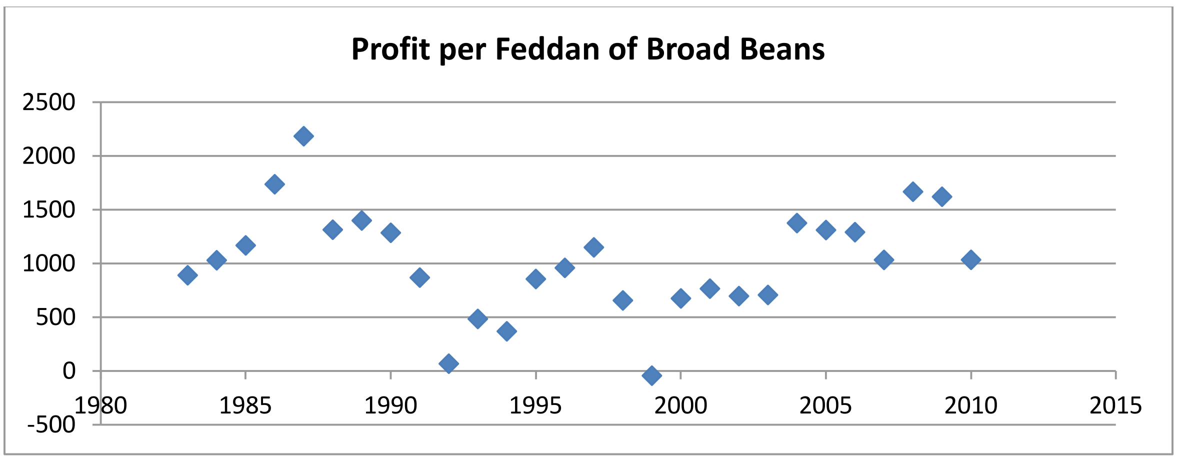
	2007				Estimated 2017			
	Production (000 tons)	**Per Capita Consumption (tons)**	**Total Needs (000 tons)**	**% sufficiency**	**Production (000 tons)**	**Per Capita Consumption (tons)**	**Total Needs (000 tons)**	**% sufficiency**
Wheat	7,388	0.177	13,591	54.4	12,000	0.177	16,238	73.9
Rice	4,553	0.043	3,273	139.1	4,161	0.043	3,956	105.2
Maize	6,300	0.155	11,900	53.2	12,600	0.175	16,100	78.3
Sugar	1,487	0.025	1,933	76.9	2,260	0.030	2,760	81.9
Broad Beans	301	0.008	578	52.1	480	0.008	690	69.6
Potatoes	2,793	0.020	1,548	180.4	3,600	0.022	2,024	177.9
Tomatoes	7,888	0.099	7,623	103.5	11,600	0.10	9,200	126.1
Population	**77 million**				**92 million**			

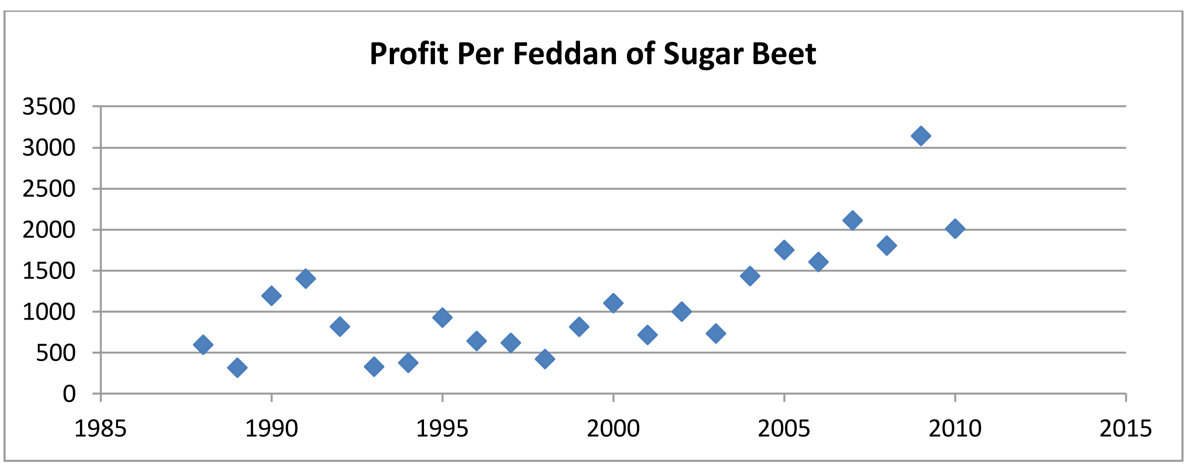
Source: MALR, 2009

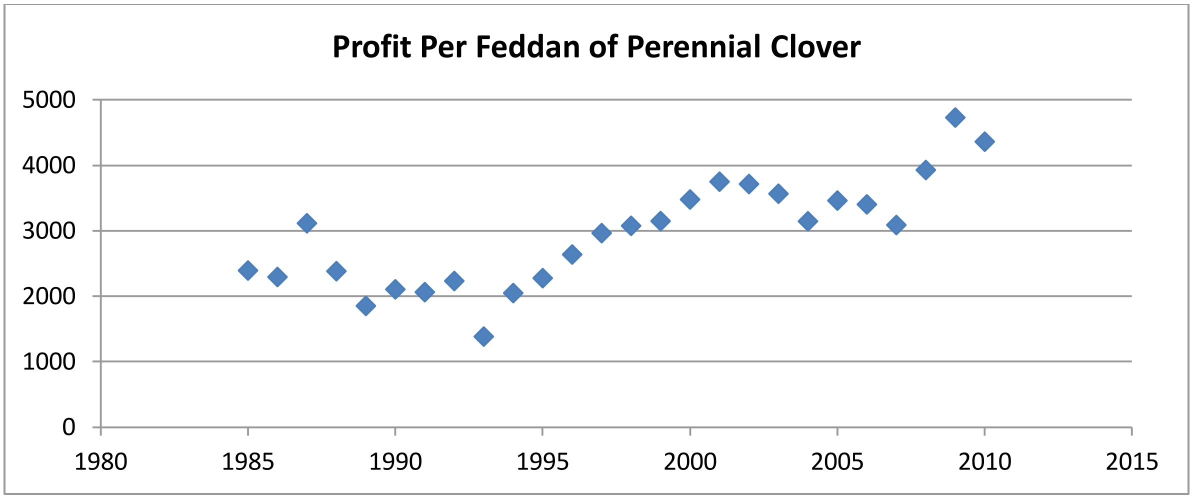
APPENDIX (C)

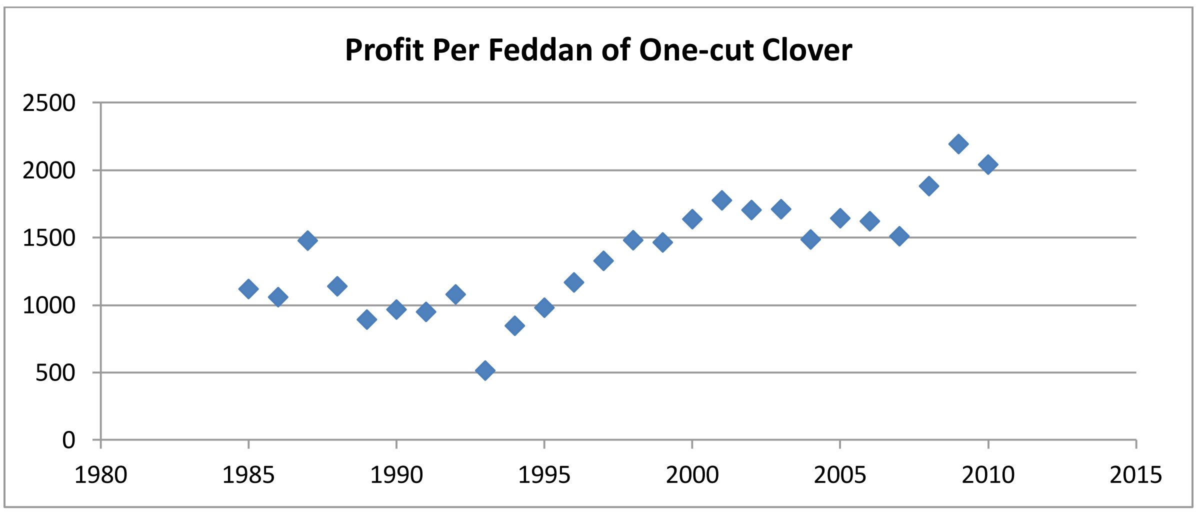
Discounted Profit per Feddan for Selected Crops (1983 – 2010)

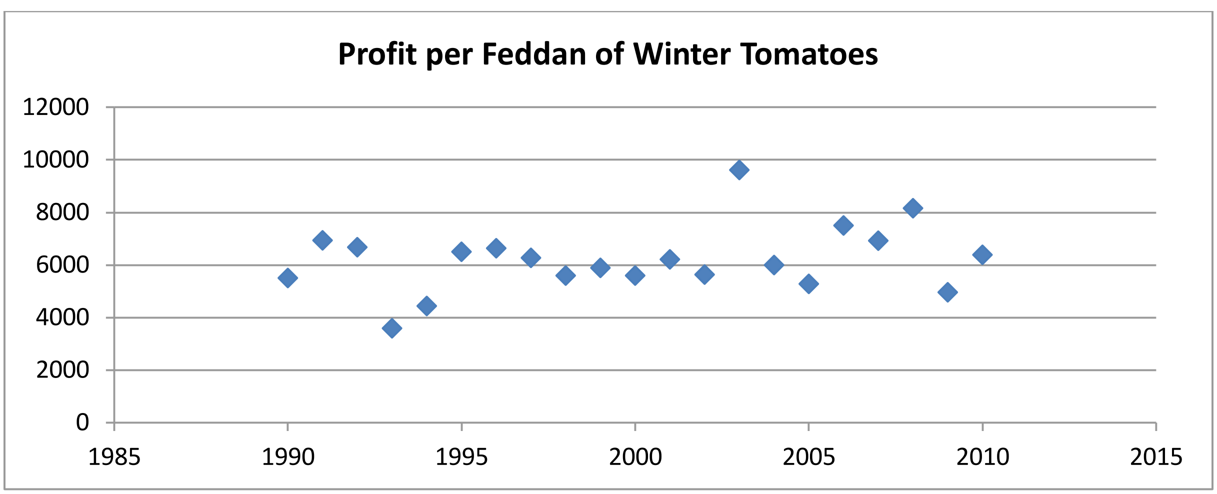


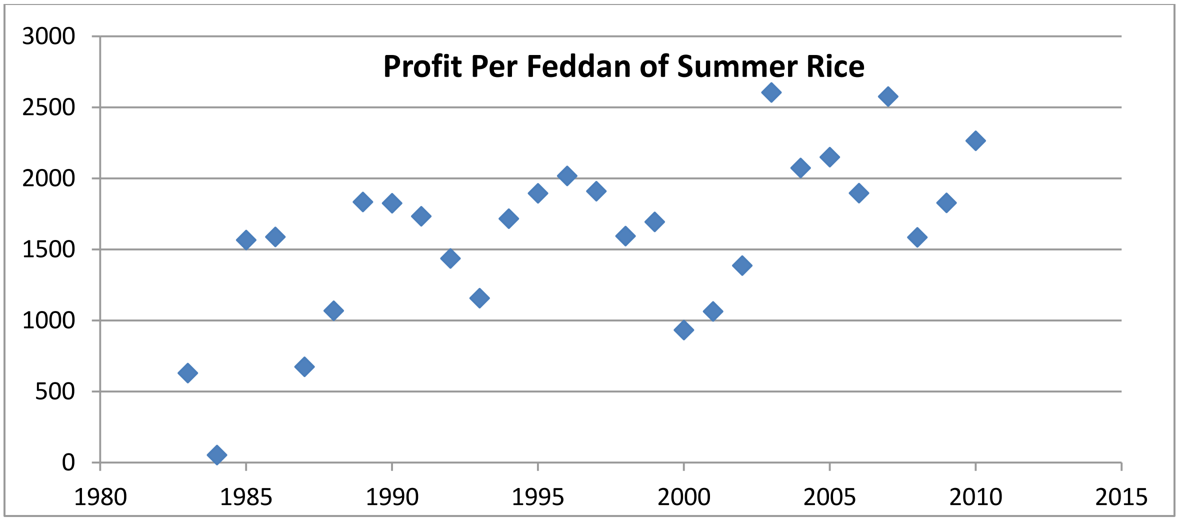


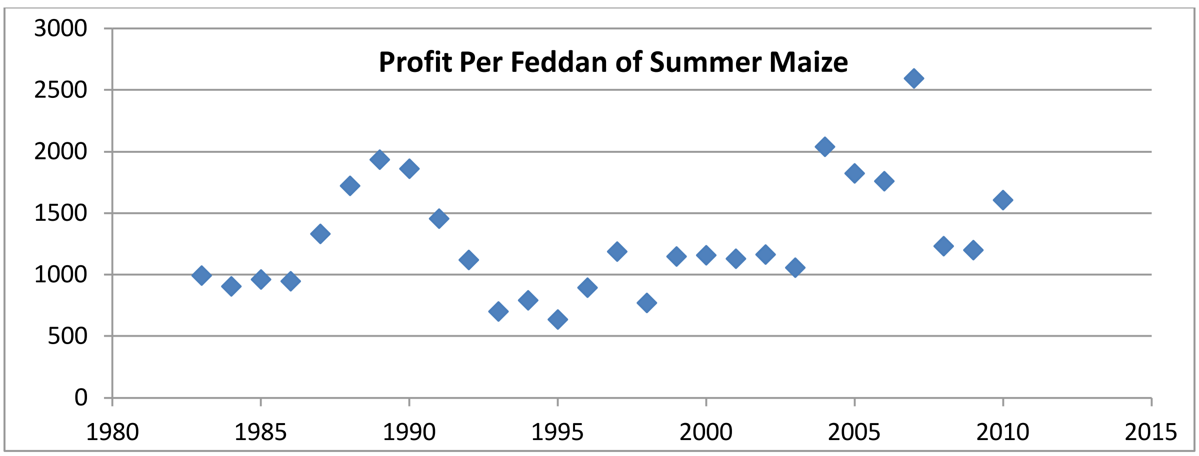


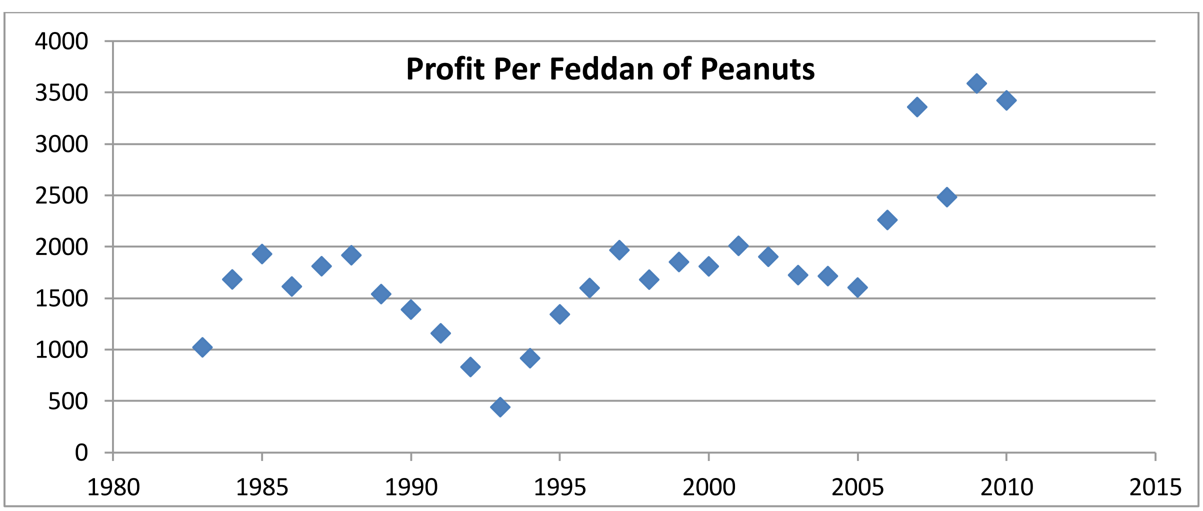

Profit Per Feddan of Perennial Clover
5000
4000
3000
2000
1000
0
1980
1985
1990
1995
2000
2005
2010
2015

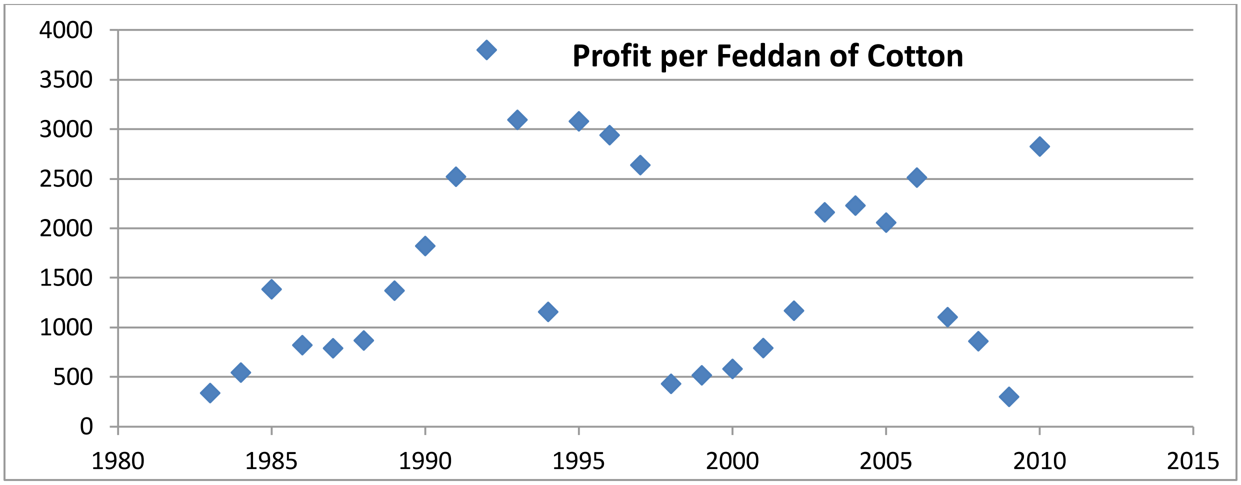

Profit Per Feddan of One-cut Clover
2500
2000
1500
1000
500
0
1980
1985
1990
1995
2000
2005
2010
2015

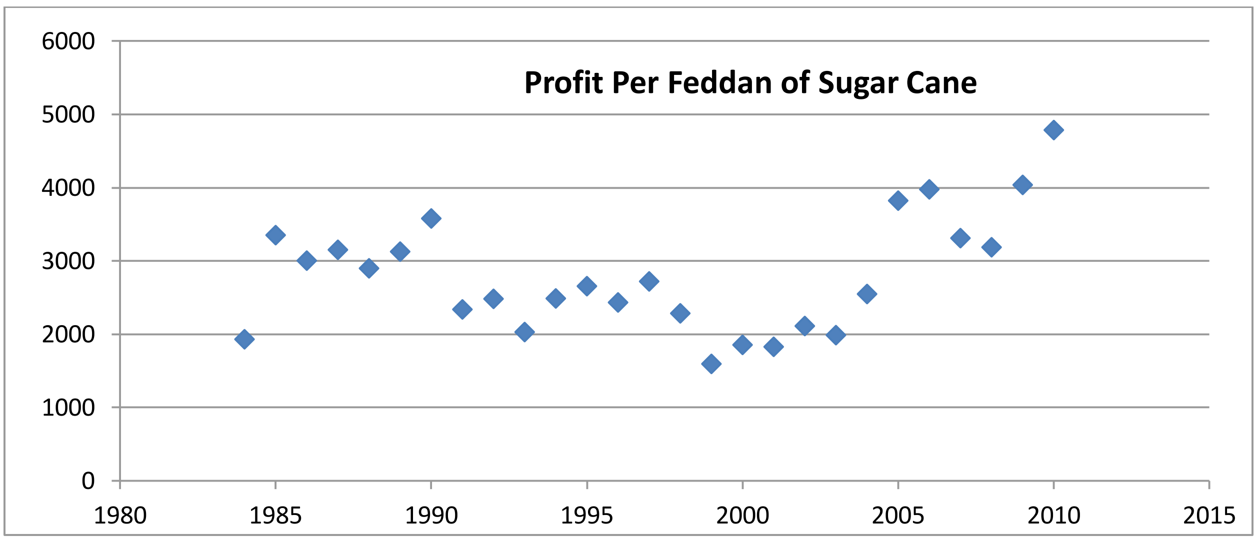

Profit per Feddan of Winter Tomatoes
12000
10000
8000
6000
4000
2000
0
1985
1990
1995
2000
2005
2010
2015

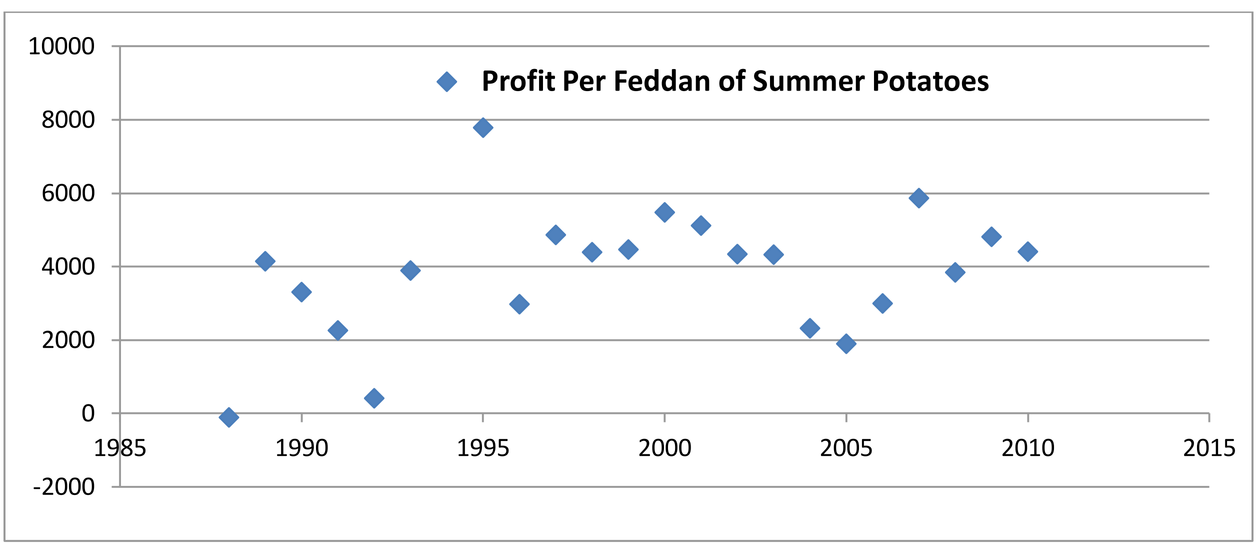

Profit Per Feddan of Summer Rice
3000
2500
2000
1500
1000
500
0
1980
1985
1990
1995
2000
2005
2010
2015

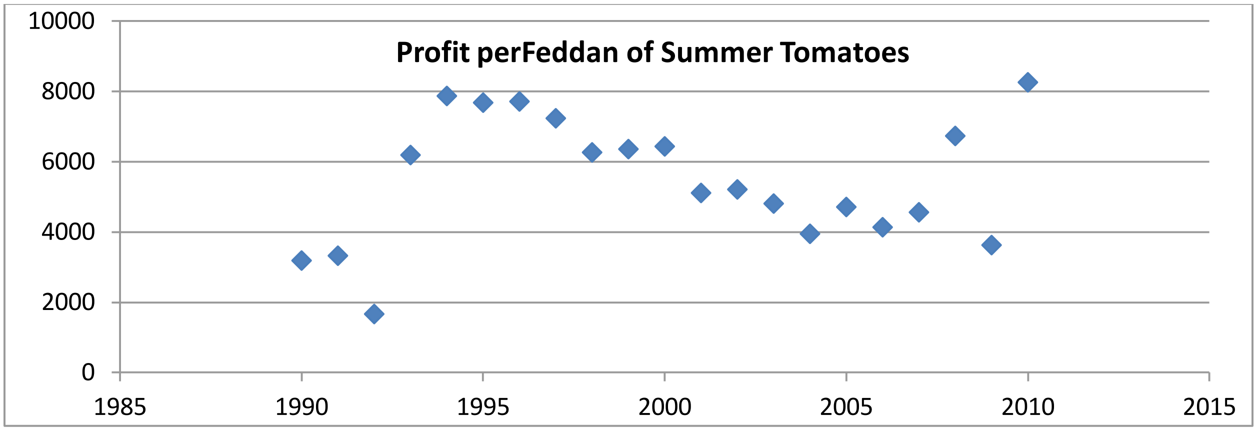

Profit Per Feddan of Summer Maize
3000
2500
2000
1500
1000
500
0
1980
1985
1990
1995
2000
2005
2010
2015


Profit Per Feddan of Peanuts
4000
3500
3000
2500
2000
1500
1000
500
0
1980
1985
1990
1995
2000
2005
2010
2015

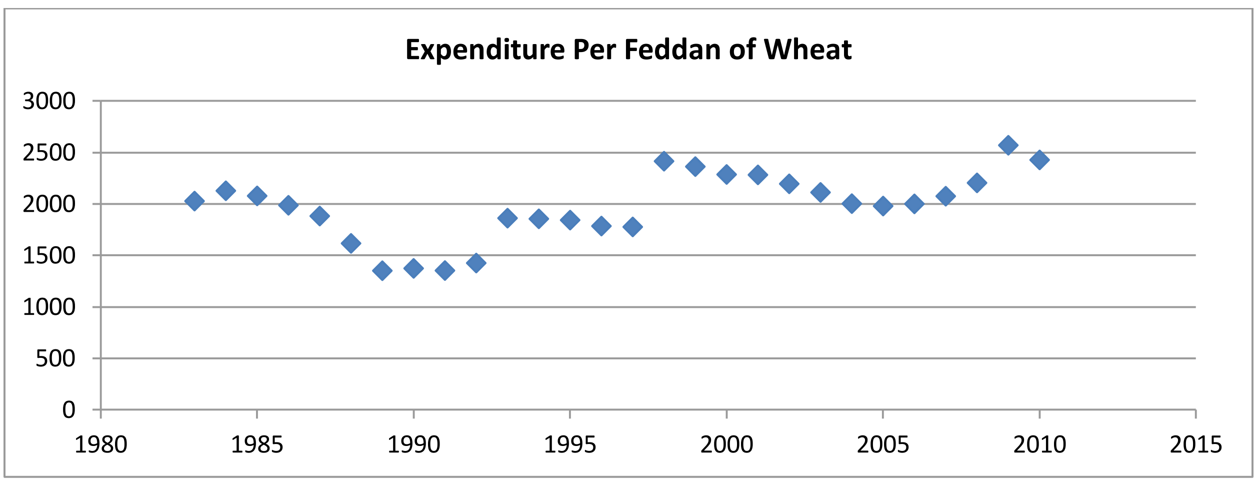

Profit per Feddan of Cotton
4000
3500
3000
2500
2000
1500
1000
500
0
1980
1985
1990
1995
2000
2005
2010
2015

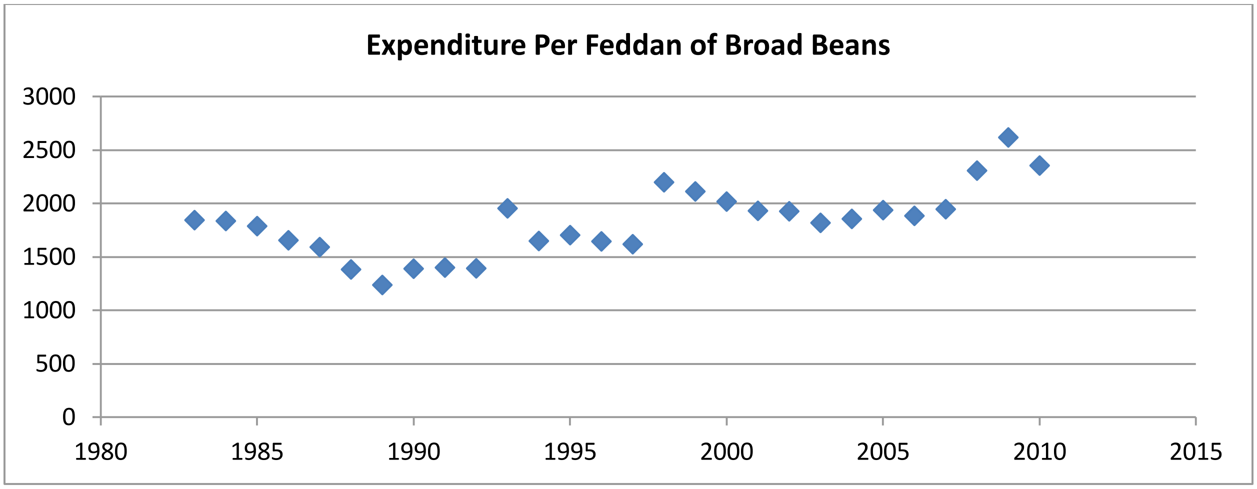

Profit Per Feddan of Sugar Cane
6000
5000
4000
3000
2000
1000
0
1980
1985
1990
1995
2000
2005
2010
2015

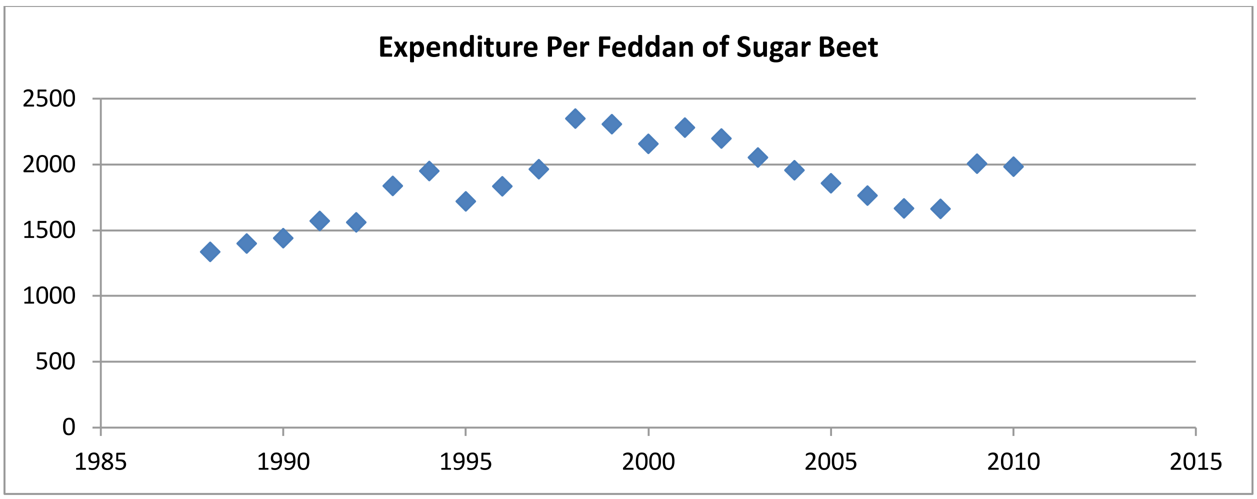

Profit Per Feddan of Summer Potatoes
10000
8000
6000
4000
2000
0
-2000
1985
1990
1995
2000
2005
2010
2015

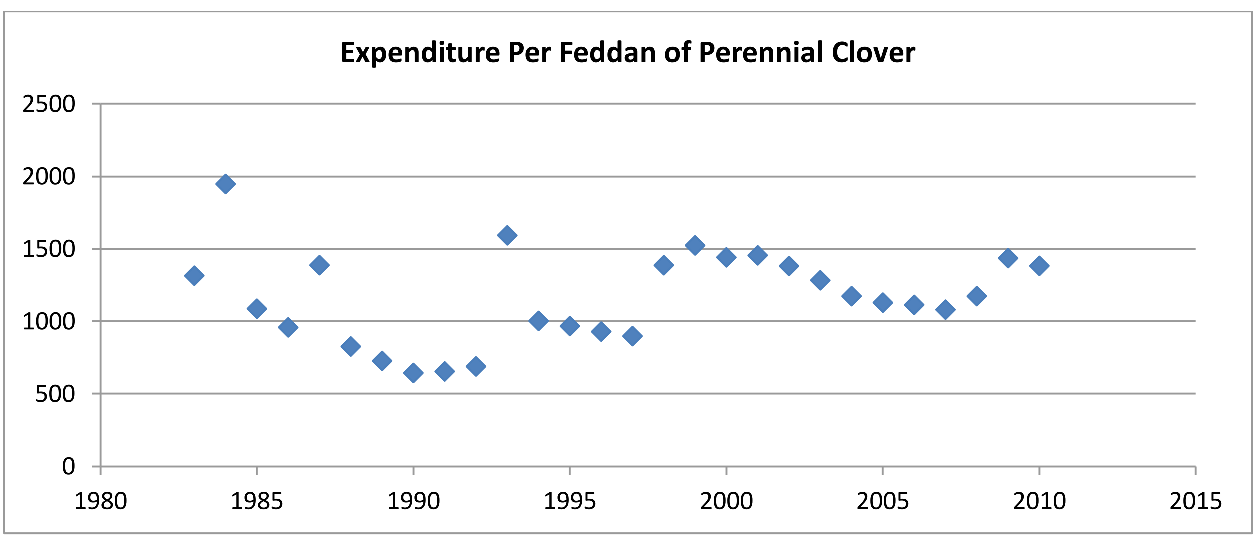


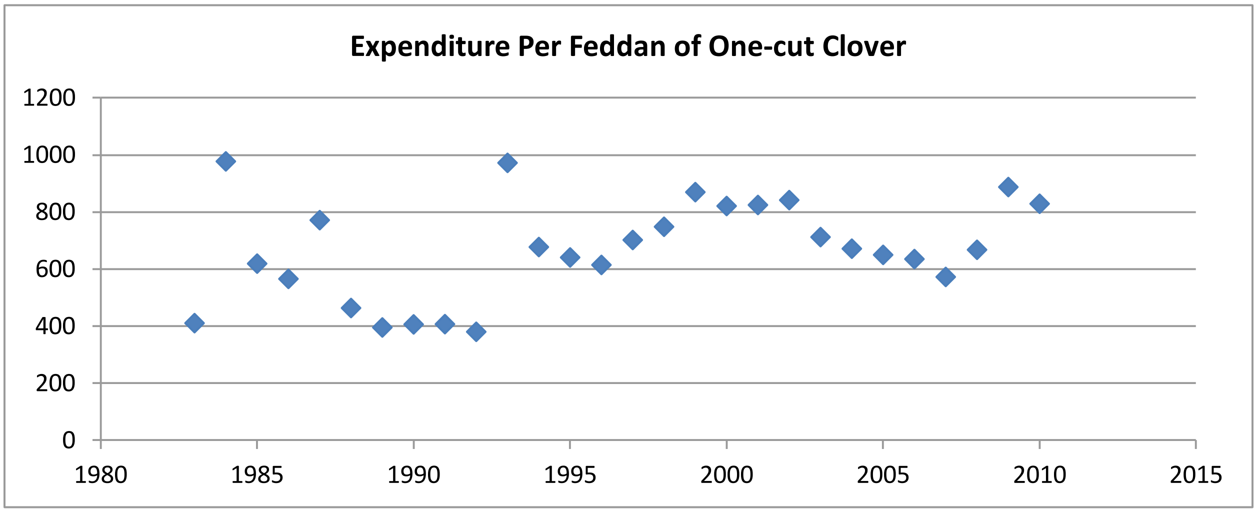
Discounted Expenditure per Feddan for Selected Crops (1983 – 2010)

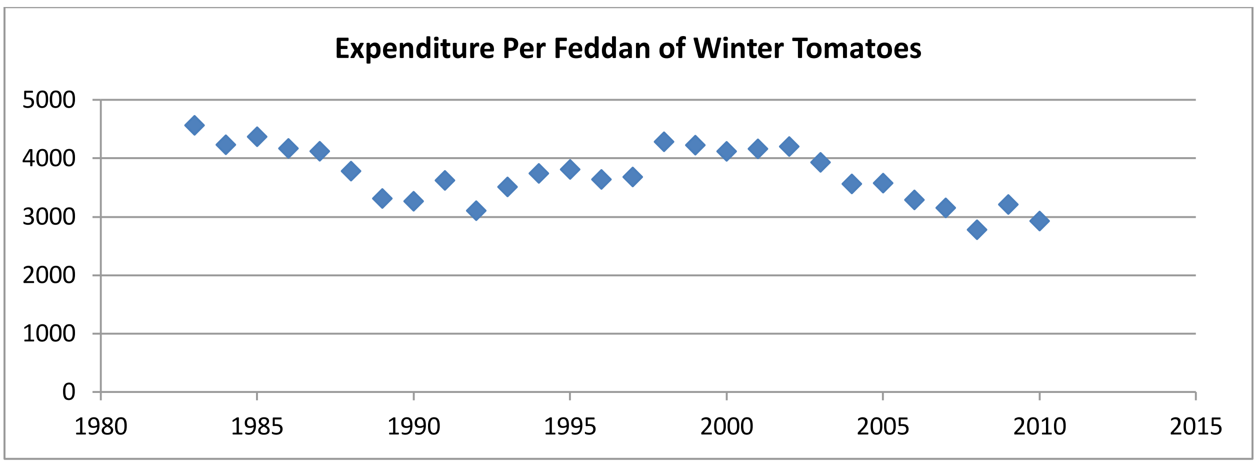


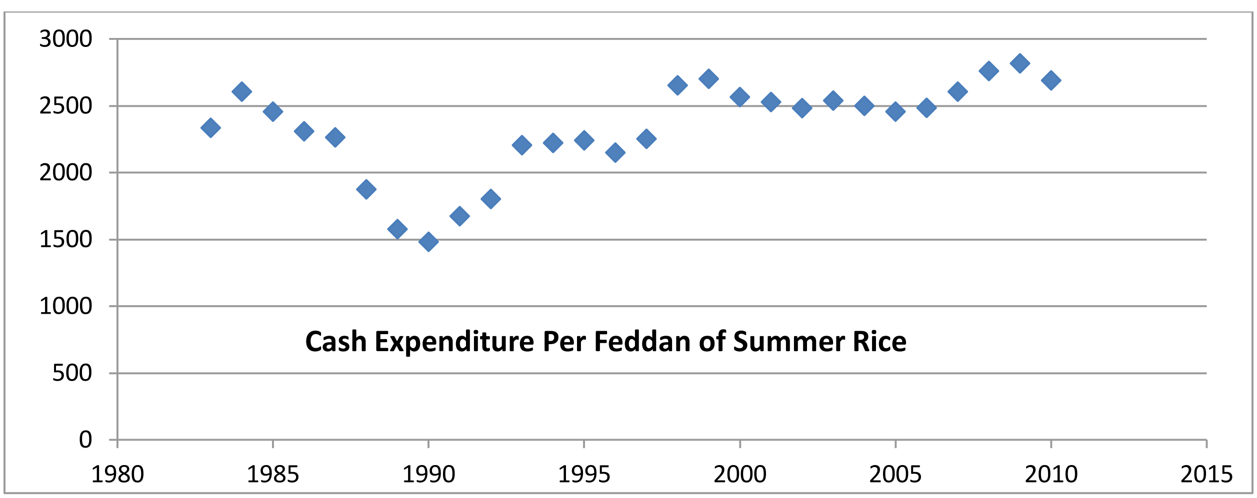

Expenditure Per Feddan of Broad Beans
3000
2500
2000
1500
1000
500
0
1980
1985
1990
1995
2000
2005
2010
2015

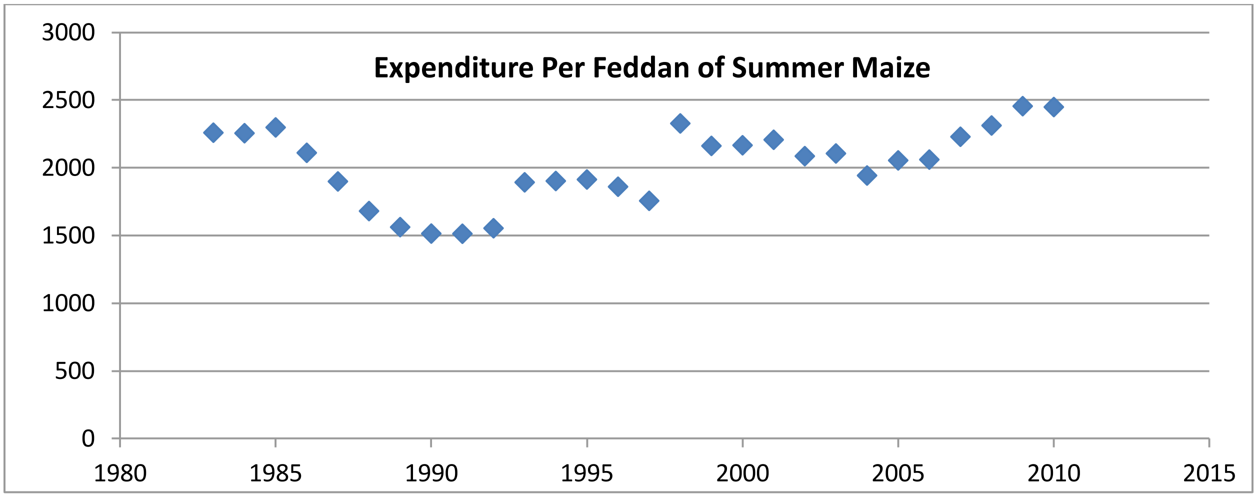

Expenditure Per Feddan of Sugar Beet
2500
2000
1500
1000
500
0
1985
1990
1995
2000
2005
2010
2015

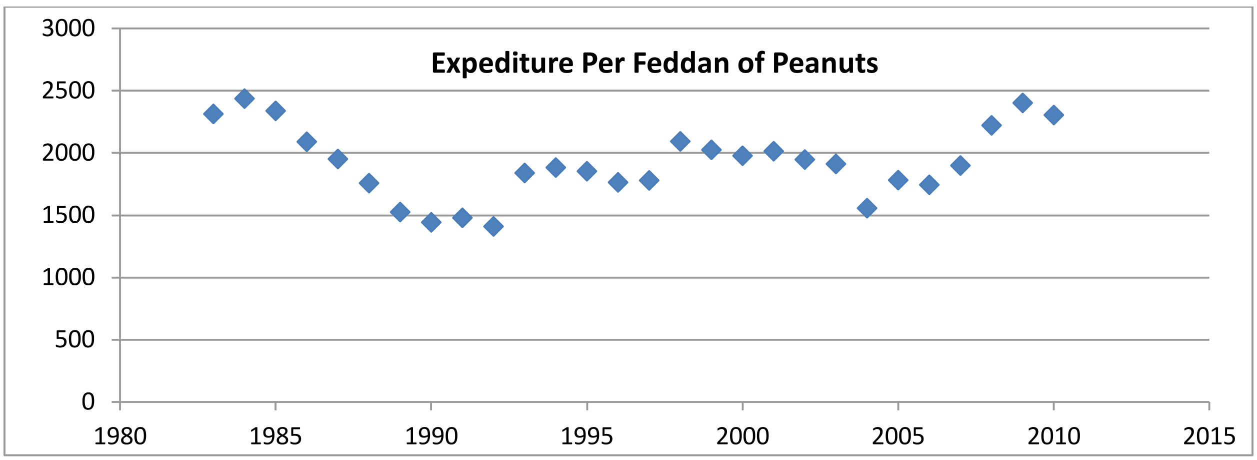

Expenditure Per Feddan of Perennial Clover
2500
2000
1500
1000
500
0
1980
1985
1990
1995
2000
2005
2010
2015

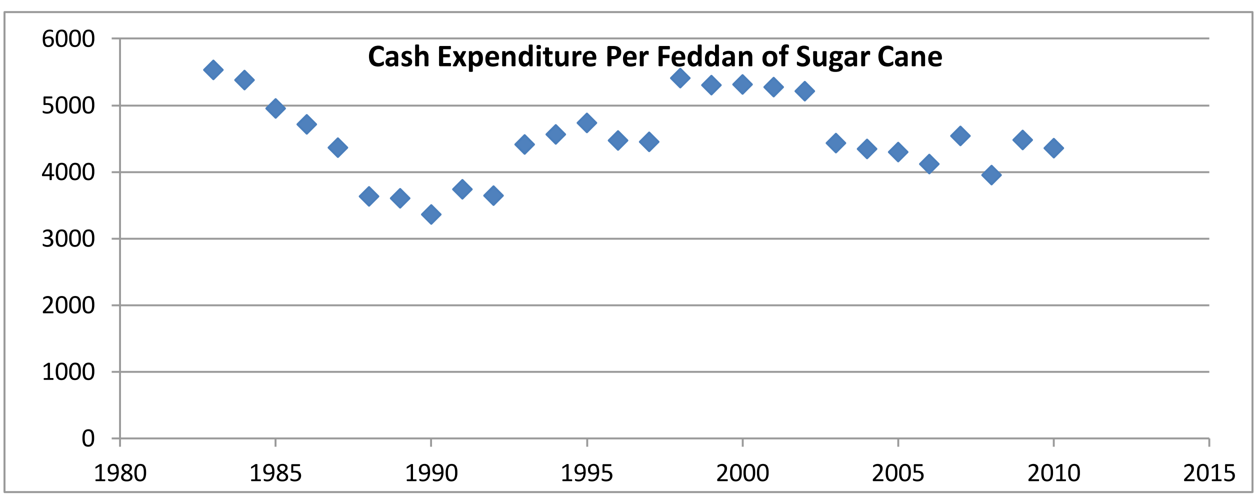

Expenditure Per Feddan of One-cut Clover
1200
1000
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
2015

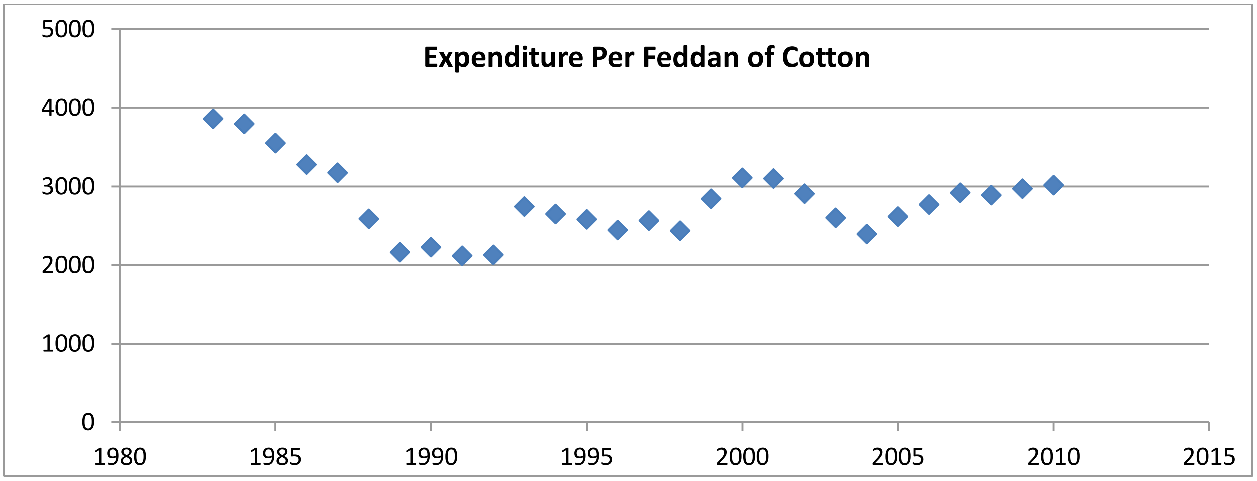

Expenditure Per Feddan of Winter Tomatoes
5000
4000
3000
2000
1000
0
1980
1985
1990
1995
2000
2005
2010
2015

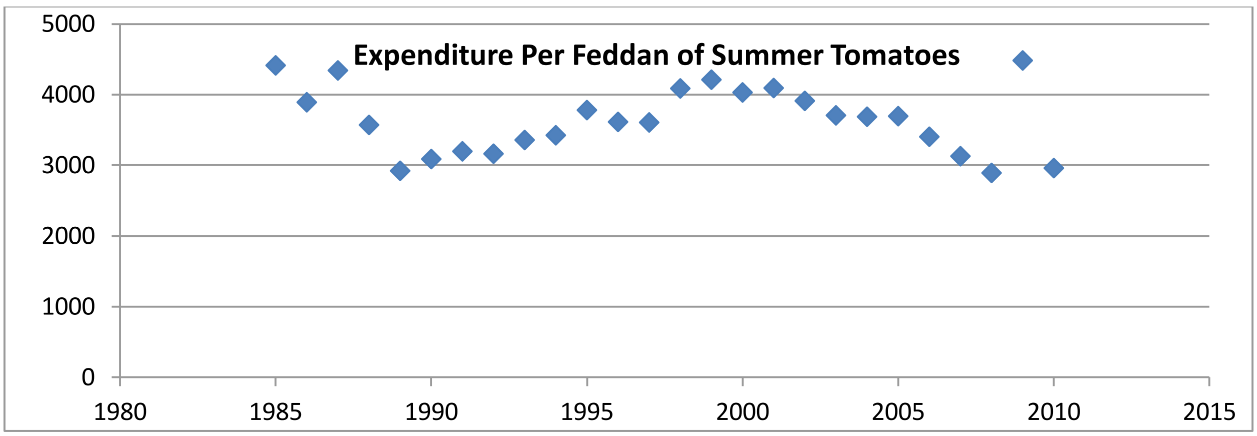

3000
2500
2000
1500
1000
Cash Expenditure Per Feddan of Summer Rice
500
0
1980
1985
1990
1995
2000
2005
2010
2015

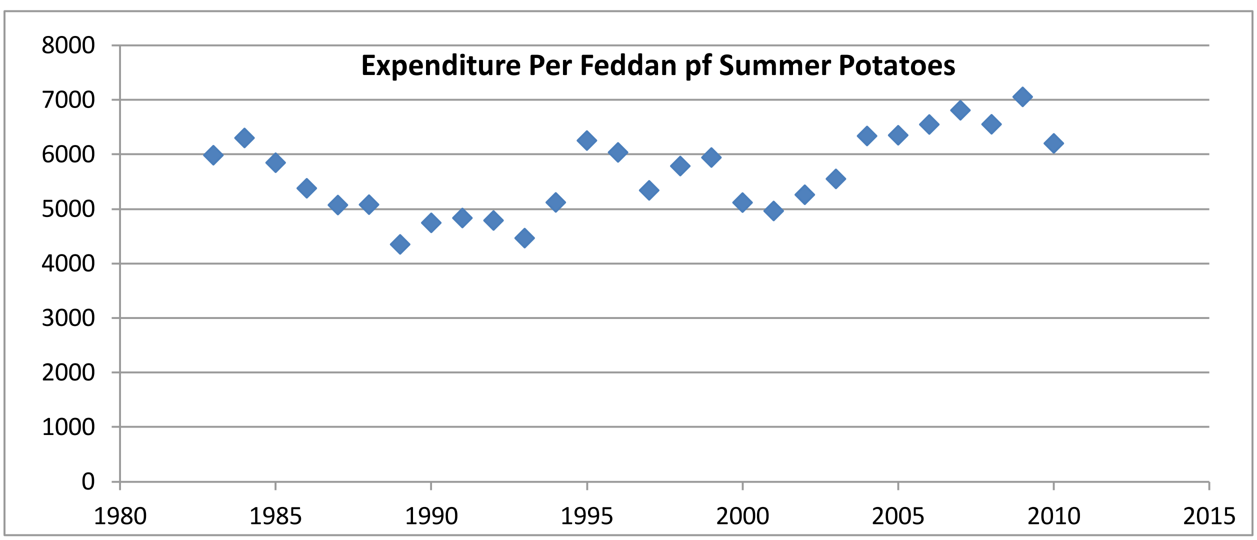

Expenditure Per Feddan of Summer Maize
3000
2500
2000
1500
1000
500
0
1980
1985
1990
1995
2000
2005
2010
2015


Expediture Per Feddan of Peanuts
3000
2500
2000
1500
1000
500
0
1980
1985
1990
1995
2000
2005
2010
2015


Cash Expenditure Per Feddan of Sugar Cane
6000
5000
4000
3000
2000
1000
0
1980
1985
1990
1995
2000
2005
2010
2015


Expenditure Per Feddan of Cotton
5000
4000
3000
2000
1000
0
1980
1985
1990
1995
2000
2005
2010
2015


Expenditure Per Feddan of Summer Tomatoes
5000
4000
3000
2000
1000
0
1980
1985
1990
1995
2000
2005
2010
2015


Expenditure Per Feddan pf Summer Potatoes
8000
7000
6000
5000
4000
3000
2000
1000
0
1980
1985
1990
1995
2000
2005
2010
2015

APPENDIX (D): DATA USED FOR THE MODEL

Crops	P_{cs} Tons/ Feddan	N_{cs} EGP/ Feddan	I_{cs} EGP/ Feddan	F f_{cs}			W_{cs} '000 m^3/ Feddan
				N Kg/ Feddan	P Kg/ Feddan	K Kg /Feddan	
Winter Season (1)							
Wheat	3.20	1510.15	2003.35	75	15	24	1200
Broad Bean	1.60	1030.66	1840.36	15	22.50	0	920
Sugar beet	28	931.18	1856.00	80	30	24	1429
Perennial Clover	35	3082.57	1152.45	15	22.5	0	1937
One-cut Clover	13.5	1473.43	669.73	15	22.5	0	725
Potatoes	12	4328.21	5669.68	174	60	115	2061
Tomatoes	20	6205.41	3711.78	102	60	96	2160
Summer Season (2)							
Rice	4.5	1704.64	2454.92	69	15	0	4000
Maize	4.4	1158.75	2073.78	120	30	24	1795
Peanuts	2	1722.98	1903.82	30	30	24	2645
Sugar cane	56.6	2660.02	4465.60	210	60	28	6000
Cotton	1.6	1269.94	2757.46	62	22.50	24	2170
Potatoes	12	4328.21	5669.68	174	60	115	2061
Tomatoes	20	5207.69	3651.20	102	60	96	2160
Nili Season (3)							
Maize	4.4	553.33	1882.47	120	30	24	1795
Tomatoes	20	6892.76	3670.54	102	60	96	2160
Potatoes	12	1002.67	4844.83	174	60	115	2061

APPENDIX (E): EQUATIONS USED IN THE MODEL AND THEIR TRANSFORMATION INTO LINEAR CONSTRAINTS

Winter Season

Production Equation

$$3.2\ X_{1,1} + 1.6\ X_{2,1} + 28\ X_{4,1} + 35\ X_{5,1} + 13.5\ X_{6,1} + 12X_{9,1} + 20\ X_{10,1} \gtrsim \mathbf{106,994}$$

Net Profit Equation

$$1510.15\ X_{1,1} + 1030.66\ X_{2,1} + 931.18\ X_{4,1} + 3082.57\ X_{5,1} + 1473.43\ X_{6,1} + 4328.21X_{9,1} + 6205.41\ X_{10,1} \gtrsim \mathbf{20,818,914}$$

Expenditure Equation

$$2003.35\ X_{1,1} + 1840.36\ X_{2,1} + 1856\ X_{4,1} + 1152.45\ X_{5,1} + 669.73\ X_{6,1} + 5669.68\ X_{9,1} + 3711.78\ X_{10,1} \lesssim \mathbf{9,632,676}$$

Fertilizers Equations

N:

$$75\ X_{1,1} + 15\ X_{2,1} + 80\ X_{4,1} + 15\ X_{5,1} + 60\ X_{6,1} + 174\ X_{9,1} + 102\ X_{10,1} \lesssim \mathbf{409,563}$$

P:

$$15\ X_{1,1} + 22.5\ X_{2,1} + 30\ X_{4,1} + 30\ X_{5,1} + 0\ X_{6,1} + 60\ X_{9,1} + 60\ X_{10,1} \lesssim \mathbf{154,915}$$

K:

$$24\ X_{1,1} + 0\ X_{2,1} + 24\ X_{4,1} + 0\ X_{5,1} + 0\ X_{6,1} + 115\ X_{9,1} + 96\ X_{10,1} \lesssim \mathbf{139,807}$$

Water Equation

$$1200\ X_{1,1} + 920\ X_{2,1} + 1429\ X_{4,1} + 1937\ X_{5,1} + 725\ X_{6,1} + 2061\ X_{9,1} + 2160\ X_{10,1} \lesssim \mathbf{11,607,224}$$

Using the tolerance values, these fuzzy goals were transformed into linear constraints as follows:

Production goal

$$3.2\, X_{1,1} + 1.6\, X_{2,1} + 28\, X_{4,1} + 35\, X_{5,1} + 13.5\, X_{6,1} + 12X_{9,1} + 20\, X_{10,1} + 106{,}422\, \theta_1^- \geq \mathbf{106,994}$$

Net profit goal

$$1510.15\, X_{1,1} + 1030.66\, X_{2,1} + 931.18\, X_{4,1} + 3082.57\, X_{5,1} + 1473.43\, X_{6,1} + 4328.21X_{9,1} + 6205.41\, X_{10,1} + 9{,}158{,}221\theta_2^- \geq 20{,}818{,}914$$

Investment Goal

$$2003.35\, X_{1,1} + 1840.36\, X_{2,1} + 1856\, X_{4,1} + 1152.45\, X_{5,1} + 669.73\, X_{6,1} + 5669.68\, X_{9,1} + 3711.78\, X_{10,1} - 13{,}228{,}182\, \theta_1^+ \leq 9{,}632{,}676$$

Fertilizers goal

N:

$$75\, X_{1,1} + 15\, X_{2,1} + 80\, X_{4,1} + 15\, X_{5,1} + 60\, X_{6,1} + 174\, X_{9,1} + 102 - 589{,}813\theta_{2,N}^+ \leq 409{,}563$$

P:

$$15\, X_{1,1} + 22.5\, X_{2,1} + 30\, X_{4,1} + 30\, X_{5,1} + 0\, X_{6,1} + 60\, X_{9,1} + 60\, X_{10,1} - 213{,}415\theta_{2,P}^+ \leq 154{,}915$$

K:

$$24\, X_{1,1} + 0\, X_{2,1} + 24\, X_{4,1} + 36\, X_{5,1} + 24\, X_{6,1} + 115\, X_{9,1} + 96\, X_{10,1} - 147{,}007\theta_{2,K}^+ \leq 139{,}807$$

Water Goal

$$1200\, X_{1,1} + 920\, X_{2,1} + 1429\, X_{4,1} + 1937\, X_{5,1} + 725\, X_{6,1} + 2061\, X_{9,1} + 2160\, X_{10,1} - 12{,}369{,}820\theta_{3,1}^+ \leq \mathbf{11,607,224}$$

Summer Season

Production Equation

$$4.5\,X_{1,2} + 4.4\,X_{2,2} + 2\,X_{3,2} + 56.6\,X_{5,2} + 1.6\,X_{6,2} + 12\,X_{7,2} + 20\,X_{8,2} \gtrsim \mathbf{43,143}$$

Net Profit Equation

$$1704.64\,X_{1,2} + 1158.75\,X_{2,2} + 1722.98\,X_{3,2} + 2660.02\,X_{5,2} + 1269.94\,X_{6,2} + 4328.21\,X_{7,2} + 5207.69\,X_{8,2} \gtrsim \mathbf{12,915,266}$$

Expenditure Equation

$$2454.92\,X_{1,2} + 2073.78\,X_{2,2} + 1903.82\,X_{3,2} + 4465.60\,X_{5,2} + 2757.46\,X_{6,2} + 5669.68\,X_{7,2} + 3651.20\,X_{8,2} \lesssim \mathbf{11,154,142}$$

Fertilizers Equations

N:

$$69\,X_{1,2} + 120\,X_{2,2} + 30\,X_{3,2} + 210\,X_{5,2} + 62\,X_{6,2} + 102\,X_{7,2} + 174\,X_{8,2} \lesssim \mathbf{579,871}$$

P:

$$15\,X_{1,2} + 30\,X_{2,2} + 30\,X_{3,2} + 60\,X_{5,2} + 22.5\,X_{6,2} + 60\,X_{7,2} + 60\,X_{8,2} \lesssim \mathbf{166,732}$$

K:

$$0\,X_{1,2} + 24\,X_{2,2} + 24\,X_{3,2} + 24\,X_{5,2} + 24\,X_{6,2} + 96\,X_{7,2} + 115\,X_{8,2} \lesssim \mathbf{137,092}$$

Water Equations

$$4000\,X_{1,2} + 1795\,X_{2,2} + 2645\,X_{3,2} + 6000\,X_{5,2} + 2170\,X_{6,2} + 2061\,X_{7,2} + 2160\,X_{8,2} \lesssim \mathbf{22,003,921}$$

The fuzzy goals were transformed into linear constraints as follows:

Production goal

$$4.5\, X_{1,2} + 4.4\, X_{2,2} + 2\, X_{3,2} + 56.6\, X_{5,2} + 1.6\, X_{6,2} + 12\, X_{7,2} + 20\, X_{8,2} + 42{,}110\, \theta_1^- \geq \mathbf{44,607}$$

Net profit goal

$$1704.64\, X_{1,2} + 1158.75\, X_{2,2} + 1722.98\, X_{3,2} + 2660.02\, X_{5,2} + 1269.94\, X_{6,2} + 4328.21\, X_{7,2} + 5207.69\, X_{8,2} + 5{,}627{,}860\theta_2^- \geq \mathbf{12,915,266}$$

Investment Goal

$$2454.92\, X_{1,2} + 2073.78\, X_{2,2} + 1903.82\, X_{3,2} + 4465.60\, X_{5,2} + 2757.46\, X_{6,2} + 5669.68\, X_{7,2} + 3651.20\, X_{8,2} - 13{,}832{,}087\, \theta_1^+ \leq 11{,}154{,}142$$

Fertilizers goal

N:

$$69\, X_{1,2} + 120\, X_{2,2} + 30\, X_{3,2} + 210\, X_{5,2} + 62\, X_{6,2} + 102\, X_{7,2} + 174\, X_{8,2} - 681{,}724\theta_{2,N}^+ \leq 579{,}871$$

P:

$$15\, X_{1,2} + 30\, X_{2,2} + 30\, X_{3,2} + 60\, X_{5,2} + 22.5\, X_{6,2} + 60\, X_{7,2} + 60\, X_{8,2} - 172{,}357\theta_{2,P}^+ \leq 166{,}732$$

K:

$$0\, X_{1,2} + 24\, X_{2,2} + 24\, X_{3,2} + 24\, X_{5,2} + 24\, X_{6,2} + 96\, X_{7,2} + 115\, X_{8,2} - 161{,}892\theta_{2,K}^+ \leq 137{,}092$$

Water Equations

$$4000\ X_{1,2} + 1795\ X_{2,2} + 2645\ X_{3,2} + 6000\ X_{5,2} + 2170\ X_{6,2} + 2061\ X_{7,2} + 2160\ X_{8,2} - 24{,}655{,}197\ \theta^{+}_{3,2} \leq \mathbf{22,003,921}$$

Nili Season

Production Equation

$$4.4\ X_{1,3} + 20\ X_{2,3} + 12\ X_{3,3} \gtrsim \mathbf{2,962}$$

Net Profit Equation

$$553.33\ X_{1,3} + 6892.76\ X_{2,3} + 1002.67\ X_{3,3} \gtrsim \mathbf{1,128,254}$$

Expenditure Equation

$$1882.47\ X_{1,3} + 3670.54\ X_{2,3} + 4844.83\ X_{3,3} \lesssim \mathbf{665,413}$$

Fertilizers Equations

N:

$$120\ X_{1,3} + 102\ X_{2,3} + 174\ X_{3,3} \lesssim \mathbf{73,326}$$

P:

$$30\ X_{1,3} + 60\ X_{2,3} + 60\ X_{3,3} \lesssim \mathbf{21,478}$$

K:

$$24\ X_{1,3} + 96\ X_{2,3} + 115\ X_{3,3} \lesssim \mathbf{23,921}$$

Water Equation

$$1795\ X_{1,3} + 2160\ X_{2,3} + 2061\ X_{3,3} \lesssim \mathbf{1,354,214}$$

The fuzzy goals were transformed into linear constraints as follows:

Production goal

$4.4\ X_{1,3} + 20\ X_{2,3} + 12\ X_{3,3} + 2817\ \theta_1^- \geq \mathbf{2962}$

Net profit goal

$553.33\ X_{1,3} + 6892.76\ X_{2,3} + 1002.67\ X_{3,3}\ + 584{,}336\theta_2^- \geq \mathbf{1,128,254}$

Investment Goal

$1882.47\ X_{1,3} + 3670.54\ X_{2,3} + 4844.83\ X_{3,3} - 975{,}450\ \theta_1^+ \leq 665{,}413$

Fertilizers goal

N:

$120\ X_{1,3} + 102\ X_{2,3} + 174\ X_{3,3} - 81{,}923\ \theta_{2,N}^+ \leq \mathbf{73,326}$

P:

$30\ X_{1,3} + 60\ X_{2,3} + 60\ X_{3,3} - 21{,}478\ \theta_{2,P}^+ \leq \mathbf{21,478}$

K:

$24\ X_{1,3} + 96\ X_{2,3} + 115\ X_{3,3} - 23{,}921\theta_{2,K}^+ \leq \mathbf{23,921}$

Water Equations

$1795\ X_{1,3} + 2160\ X_{2,3} + 2061\ X_{3,3} - 1{,}734{,}033\theta_{3,3}^+ \leq \mathbf{1,354,214}$

APPENDIX (F): GAMS CODE

Winter Season

```
Variables z, t1, t2, t3, t4, t5, t6, t7, x11, x21, x31, x41, x51, x61, x71;

Positive Variables t1, t2, t3, t4, t5, t6, t7, x11, x21, x31, x41, x51, x61, x71;

Equations Obj, constr1, constr2, constr3, constr4, constr5, constr6, constr7, constr8, constr9,
constr10, constr11, constr12, constr13;

Obj.. z =E= 0.2*t1 + 0.2*t2 + 0.2*t3 + 0.067*t4 + 0.067*t5 + 0.067*t6 + 0.2*t7;

Constr1.. 3.2*x11 + 1.6*x21 + 28*x31 + 35*x41 + 13.5*x51 + 12*x61 + 20*x71 + 106422*t1 =g=
106994;

Constr2.. 1510.15*x11 + 1030.66*x21 + 931.18*x31 + 3083.57*x41 + 1473.43*x51 +
4328.21*x61 + 6205.41*x71 + 13139853*t2 =G= 15112100;

Constr3.. 2003.35*x11 + 1840.36*x21 + 1856*x31 + 1152.45*x41 + 669.73*x51 + 5669.68*x61 +
3711.78*x71 - 13579338*t3 =L= 13172000;

Constr4.. 75*x11 + 15*x21 + 80*x31 + 15*x41 + 60*x51 + 174*x61 + 102*x71 - 589813*t4 =L=
409563;

Constr5.. 15*x11 + 22.5*x21 + 30*x31 + 30*x41 + 0*x51 + 60*x61 + 60*x71 - 213415*t5 =L=
154915;

Constr6.. 24*x11 + 0*x21 + 24*x41 + 0*x51 + 0*x61 + 115*x91 + 96*x101 - 147007*t6 =L=
139807;

Constr7.. 1200*x11 + 920*x21 + 1429*x31 + 1937*x41 + 725*x51 + 2061*x61 + 2160*x71 -
12369820*t7 =L= 11607224;

Constr8..x11 + x21 + x31 + x41 + x51 + x61 + x71 =e= 7300;

constr9..x11 =g= 3750;

constr10..x21 =g= 300;

constr11..x41 =l= 1900;

constr12..x51 =l= 540;

constr13 ..x71 =l= 255;
```

```
t1.up= 1;

t2.up= 1;

t3.up= 1;

t4.up= 1;

t5.up= 1;

t6.up= 1;

t7.up= 1;

Model FGP1 /All/;

Solve FGP1 Using LP Minimizing z;
```

Summer Season

```
Variables z, t1, t2, t3, t4, t5, t6, t7, x12, x22, x32, x42, x52, x62, x72;

Positive Variables t1, t2, t3, t4, t5, t6, t7, x12, x22, x32, x42, x52, x62, x72;

Equations Obj, constr1, constr2, constr3, constr4, constr5, constr6, constr7, constr8, constr9,
constr10, constr11, constr12;

Obj.. z =E= 0.2*t1 + 0.2*t2 + 0.2*t3 + 0.067*t4 + 0.067*t5 + 0.067*t6 + 0.2*t7;

Constr1.. 4.5*x12 + 4.4*x22 + 2*x32 + 56.6*x42 + 1.6*x52 + 12*x62 + 20*x72 + 42110*t1 =g=
44607;

Constr2.. 1704.64*x12 + 1158.75*x22 + 1722.98*x32 + 2660.02*x42 + 1269.94*x52 +
4328.21*x62 + 5207.69*x72 + 6242055*t2 =G= 9434800;

Constr3.. 2454.92*x12 + 2073.78*x22 + 1903.82*x32 + 4465.6*x42 + 2757.46*x52 +
5669.68*x62 + 3651.20*x72 - 16438144*t3 =L= 14296126;

Constr4.. 69*x12 + 120*x22 + 30*x32 + 210*x42 + 62*x52 + 102*x62 + 174*x72 - 681724*t4 =L=
579871;

Constr5.. 15*x12 + 30*x22 + 30*x32 + 60*x42 + 22.5*x52 + 60*x62 + 60*x72 - 172357*t5 =L=
166732;

Constr6.. 0*x12 + 24*x22 + 24*x32 + 24*x42 + 24*x52 + 96*x62 + 115*x72 - 161892*t6 =L=
137092;

Constr7.. 4000*x12 + 1795*x22 + 2645*x32 + 6000*x42 + 2170*x52 + 2061*x62 + 2160*x72 -
24655197*t7 =L= 22003921;

Constr8..x12 + x22 + x32 + x42 + x52 + x62 + x72 =e= 5280;

Constr9..x12 =l= 1250;

constr10..x42=l= 320;

constr11..x32 =l= 230;

constr12..x72 =l= 290;

t1.up= 1;

t2.up= 1;
```

```
t3.up= 1;

t4.up= 1;

t5.up= 1;

t6.up= 1;

t7.up= 1;

Model FGP1 /All/;

Solve FGP1 Using LP Minimizing z;
```

Nili Season

```
Variables z, t1, t2, t3, t4, t5, t6, t7, x13, x23, x33;

Positive Variables t1, t2, t3, t4, t5, t6, t7, x13, x23, x33;

Equations Obj, constr1, constr2, constr3, constr4, constr5, constr6, constr7, constr8;

Obj.. z =E= 0.15*t1 + 0.2*t2 + 0.4*t3 + 0.05*t4 + 0.05*t5 + 0.05*t6 + 0.1*t7;

Constr1.. 4.4*x13 + 20*x23 + 12*x33 + 2817*t1 =g= 2962;

Constr2.. 553.33*x13 + 6892.76*x23 + 1002.67*x33 + 455337*t2 =G= 770000;

Constr3.. 1882.47*x13 + 3670.54*x23 + 4844.83*x33 - 1492618*t3 =L= 1399426;

Constr4.. 120*x13 + 102*x23 + 174*x33 - 81923*t4 =L= 73326;

Constr5.. 30*x13 + 60*x23 + 60*x33 - 21478*t5 =L= 21478;

Constr6.. 24*x13 + 96*x23 + 115*x33 - 23921*t6 =L= 23921;

Constr7.. 1795*x13 + 2160*x23 + 2061*x33 - 1734033*t7 =L= 1354214;

Constr8..x13 + x23 + x33 =e= 580;

t1.up= 1;

t2.up= 1;

t3.up= 1;

t4.up= 1;

t5.up= 1;

t6.up= 1;

t7.up= 1;

Model FGP1 /All/;

Solve FGP1 Using LP Minimizing z;
```