OPTIMIZATION OF AGRICULTURAL WATER USE AND TRADE PATTERNS: THE CASE OF IRAN*

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Working Paper 508

December 2009

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* This research has benefited from the financial contribution of ERF as part of the ERF-GDN Regional Research Competition (ERF Research Project No: ERF-05-IR 3002). The content of this publication is the sole responsibility of the authors and can in no way be taken to reflect the views of ERF or GDN.

Abstract

This study addresses the problem of agricultural water use efficiency via optimization of cropping patterns, irrigation strategies and external trade of agricultural products in Iran. Towards this end, comparative advantages of some principal crops are first determined using Policy Analysis Matrix (PAM) at three levels: farm, plain and basin. Due to importance of irrigation water, a new approach is developed for estimating scarcity price or the social price of irrigation water in the selected regions. Then, optimal cropping patterns at basin and farm levels are determined using mathematical programming techniques and considering water supply risk. According to the findings of this study, optimal allocation of water at the farm level is achieved when marginal return to irrigation water is the same not only in all growing stages of a crop but also at different growing stages of competing crops grown in the farm. Finally, the findings indicated that it is possible to direct optimal cropping patterns at basin level to maximize social profits, water-use efficiency and net virtual water import simultaneously. However, in order to draw a definite conclusion with respect to virtual water trade, more data is needed on the quantity of water embedded in each crop imported from and exported to each country. Moreover, it is necessary to design a suitable agricultural external trade plan to be used as a target for directing cropping patterns. The approach used in this study can be considered a first step in this direction.

ملخص

تتناول هذه الدراسة قضية كفاءة استخدام مياه الري من خلال الارتقاء بكفاءة أنماط زراعة المحاصيل الزراعية واستراتيجيات الري والتجارة الخارجية للمنتجات الزراعية في إيران. ولهذه الغاية، تم في البداية تحديد المميزات المقارنة لبعض المحاصيل الأساسية باستخدام مصفوفة تحليل السياسات على ثلاث مستويات: المزارع والسهول والأحواض. ونظراً لأهمية مياه الري، فقد تم تطوير طريقةٍ جديدةٍ لتقدير سعر الندرة أو السعر الاجتماعي لمياه الري في المناطق الإيرانية محل الدراسة، وأعقب ذلك تحديدٌ لأفضل أنماط زراعة المحاصيل على مستوى الأحواض والمزارع باستخدام تقنيات برمجة دقيقة، كما تم أيضاً أخذ المخاطر المتعلقة بالامداد بالمياه في الاعتبار. وطبقاً للنتائج التي خلصت إليها الدراسة فإن التخصيص الأمثل لمياه الري على مستوى المزارع إنما يتحقق حين يظل هامش العائد على مياه الري كما هو ليس في كافة مراحل زراعة المحصول فحسب، بل في مختلف مراحل زراعة المحاصيل المنافسة في المزرعة. وفي الختام، أوضحت النتائج أنه من الممكن لأفضل الأنماط المباشرة لزراعة المحاصيل على مستوى الأحواض أن تضاعف العوائد الاجتماعية، وكفاءة استخدام المياه، وصافي الأهمية الفعلية للمياه في ذات الوقت. غير أنه لا تزال هناك حاجة لمزيدٍ من البيانات حول كمية المياه التي يستهلكها كل محصول يستورد من الدولة أو يصدر إليها وذلك لرسم تصورٍ نهائيٍ محدد فيما يخص تجارة المياه الفعلية. علاوةً على ذلك، لابد من وضع خطةٍ مناسبة للتجارة الخارجية للمحاصيل الزراعية بحيث تستخدم كهدفٍ في توجيه أنماط زراعة المحاصيل. ويمكن اعتبار النهج المتبع في هذه الدراسة بمثابة خطوة أولى في هذا الإتجاه.

1. Introduction

The main source of water in Iran, located in arid and semi-arid regions, is precipitation in form of rainfall or snow, which is estimated to be 429×10^9 m^3. Of this, about 305×10^9 m^3 or 71% is lost as evapo-transpiration, 86×10^9 m^3 or 21% is circulated as surface run-off run-off and about 38×10^9 m^3 is percolated down below soil moisture zone. Out of 75×10^9 m^3 water available from surface and underground sources, about 72.5×10^9 m^3 is allocated to the agricultural sector, 2×10^9 m^3 for domestic and 0.5×10^9 m^3 for industrial purposes. The former amount is used to irrigate 7.6 million hectares of land per year. Of this, 1.4 million hectares are irrigated by regulated flow, and 6.0 and 0.2 million hectares are irrigated by means of traditional and pressurized systems, respectively (Pazira and Sadeghzadeh, 1999). The average annual rainfall of the country in comparison with Asia and the whole world shows that it is 40% less than Asia and about 33% less than the world. Furthermore, rainfall distribution, water resources distribution (both surface and underground) and population distribution are very uneven compared with the area of the country. For example, total potential of Tehran's water resources is less than 2% of the country's total water resources, while 20% of the country's populations live in this city (Vojdani, 2003).

It is estimated that about 87% of renewable water resources (about 113 km^3) can be developed for future use (year 2025) compared to the current 72%.

To provide for domestic water requirements in 2025, estimated at 113 km^3 (assuming groundwater abstraction remaining at 51 km^3 per annum and 2 km^3 from non-conventional water), an additional 60 km^3 of surface water would be needed. With this scenario, the share of ground water resources would decline from 55% at present to 45% and the share of surface water resources would increase from 45 to 58% (Shargh Newspaper: 28/06/05).

Groundwater is supplied through private investment, and surface water is mainly supplied through public investment. The cost of water supplied through reservoir dams has increased 18 fold in the past two decades. Irrigation efficiency is reported to be about 30 to 35% throughout the country (Pazira and Sadeghzadeh, 1999). On the other hand, some macro and sectoral policies such as water pricing — one of the main factor of irrigation inefficiency — and some properties of water have led to over exploitation of underground water. This overuse has resulted in a negative balance of 9 km^3/year for the whole country (Siadat, 2000).

As in most MENA countries, the combined effects of increasing population, urbanization and rising standard of living have led to increasing water demand. The drive for food security for a rapidly growing population, encouraged by low or zero irrigation water prices and limited water use planning have placed heavy pressure on the quantity and quality of water resources.

In order to meet the rising demand, most policies have been focusing on developing water resources and supply management measures — such as constructing dams, irrigation networks and ground water extraction projects — with little attention to the problems of demand management. As a result, the contribution of water development projects to agricultural production has been far below expectations. Both inefficient patterns of irrigation-water-use and insufficient attention to the problem of water allocation have contributed to the poor performance of water development projects.

It should be noted that solutions to the water shortage problem are not only solved by focusing on water supply. Sometimes, more importantly, they can be solved by addressing the demand for water through policies encouraging change in the structure of countries' agriculture strategies, patterns of water use and external trade of agricultural products. In other words, in addressing the problem of water shortage in Iran, along with supply management measures, two complementary approaches are indicated:

1. Increasing the efficiency of water use, particularly in agriculture and,

2. Optimizing agricultural trade patterns.

This study focuses on the agricultural water use efficiency at the farm and basin levels via optimizing cropping patterns, irrigation strategies and trade patterns from the private and social points of views.

2. Issues in Agricultural Water Use and Trade Patterns

At present, irrigation demand in Iran accounts for over 90% of the total amount of water withdrawn from surface and ground resources (Pazira and Sadeghzadeh, 1999). As municipal and industrial water demands increase, and per capita water availability declines with population growth, the agricultural sector will face increasing competition for fresh water resources — particularly given the higher value added and willingness to pay per unit of water in the municipal and industrial sectors. Hence, policies influencing the efficient use of irrigation water are extremely important in the planning of water resources.

Water in many parts of Iran is mainly used for low-value products and consequently water users have neither the willingness nor the ability to pay tariffs that would cover even the operation and maintenance costs for providing water — as willingness and ability to pay are positively related to high-value cropping patterns (Soltani, 1994).

Budgetary limitation is another problem. Increasing cost of water provision and supply has caused supply management policies to be confronted by restrictions. Consequently, more consideration should be given to water management measures, which have historically been ignored in water resources development schemes. Demand management seeks to encourage a more efficient use of available water. Since the agriculture sector is the largest user of water in Iran, irrigation management is particularly important (Soltani, 2005).

Agricultural trade policy is not designed to reduce pressure on the country's water resources. While the underlying foundation of agricultural trade is the notion of comparative advantage, the motivation for agricultural trade is hardly a pursuit of comparative advantage but rather a way to fill the domestic gap of food supply and maintain social and political stability. In other words it is mainly the imperative rather than comparative advantage that drives the agricultural trade patterns in Iran. In any economy, where water is as scarce as it is in Iran and other MENA countries, one would expect exports which contain small quantities of high-value water to replace products embedded with large quantities of low-value water — that is importing "virtual water". This is the exact opposite to the way that Iran’s agriculture is structured. Iran's agriculture uses large quantities of water to produce low-valued products, which simply implies that water in Iran is relatively inexpensive and abundant. Moreover, in recent years, Iran like some other countries of MENA Region (notably the United Arab Emirates, Saudi Arabia and Libya) has been pursuing a deliberate policy of food self-sufficiency through substantial investment in irrigation infrastructure. This policy has intensified pressure on such countries’ water resources.

Another issue to be considered in addressing agricultural water use in Iran is the negative externality of many public irrigation projects. Increasing salinity levels in irrigated soils and in irrigation return flows have driven many irrigated lands out of production. Being under economic and environmental pressure, any further expansion of irrigated agriculture in the region will have to depend increasingly on improved efficiency in the use of existing water supplies (including its re-use) rather than on the development of additional fresh water resources.

In areas where irrigated farming is dependent on groundwater resources, the problem is more serious. The demand on groundwater resources exceeds the recharge rates of aquifers, and groundwater resources are being depleted at an increasing rate with the current rate of extraction exceeding the maximum sustainable yield. Excessive extraction of water is creating external costs in the form of increased pumping costs due to declining water tables, saline water intrusion, land subsidence and damage to irrigation canals and structures.

Reliance on market forces to achieve efficient water use is suggested by some researchers (Rosegrant and Binswanger, 1994). Such a solution can be relied on if property rights are secure and transferable.

Water pricing is another issue to address. Irrigation water in Iran, as well as other countries of MENA region, is heavily subsidized. This has exacerbated the problem of inefficient water use in agriculture. In many irrigation projects, inappropriate pricing has led to low performance on the part of both suppliers and consumers. While pricing could discourage the inefficient use of water and at the same time augment water supply, irrigation water pricing in a developing country is a sensitive issue. To achieve the efficiency objective, irrigation water price should equal the marginal cost of water supply (including external costs). Marginal cost pricing is difficult to implement in practice because of the high implementation costs. Moreover, because of the inelastic demand, to encourage farmers to adopt water saving technology, the water price must increase substantially (Perry, 2001)[1]. Such drastic increase in irrigation water price is politically infeasible in Iran. In most countries of the region, small farmers are unable to pay the full cost of water supply. In these countries governments pursue other objectives which, in many cases conflict with the efficiency objective. In this study, the effect of some distorting policies such as water and fertilizer subsidy, and market failure (externality) on agricultural water use efficiency at the farm and basin levels will be analyzed. Moreover, we attempt to determine the gap between private (farm level) and social profits. To this end, a new approach is developed and used for estimating the social price of irrigation water.

In reviewing irrigation water pricing, Johanson et al (2002) concluded that population pressure, rising standards of living and the increasing demand for environmental quality have forced governments to search for better methods of water management. While marginal cost pricing of irrigation water can enhance the efficiency of water use, implementation of such pricing policy is not politically feasible in many cases. Given the problem, they propose decentralization of water policy reforms and efficient allocation of water resources. Efficient water allocation and marginal cost pricing are effective instruments of demand management. However, they result in increasing the cost of irrigation for farmers. In countries where scarcity price or the opportunity cost of water is high, small farmers may be forced out of business (production). Also, problems relating to the long-run (sustainable) allocation of water between agriculture and other sectors need to be addressed.

Another compelling issue to be considered is the relation between agricultural trade, cropping patterns and farm employment in water stressed countries of the region. When these countries consciously consider agricultural (virtual water) trade to raise water use efficiency and alleviate their water problems, they should also consider altering their cropping patterns in a significant way. This may adversely affect the livelihood of farmers in terms of income and employment. It may require the government to provide some incentives for farmers to change their cropping patterns. Even with the desired changes implemented, it is not clear that the changes are sufficient to ease the pressure on water resources in the arid MENA region.

For example, in addressing water management problems in the water scare regions of India, Satyasai and Wiswanathan (1997) focused on water-use efficiency as well as labor employment. They considered three water management scenarios namely:

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[1] - For example, in determining the potential effects of irrigation water pricing in Zayandaroud of Iran, Perry (2001) suggested that water price must increase 20 fold to persuade farmers to invest in water-saving technologies.

1) Changing cropping patterns from water- intensive crops such as rice and sugarcane to water-extensive crops. 2) Reducing evapo-transpiration (ET) through soil mulching and agronomic practices and, 3) Adopting modern irrigation technologies such as drip and sprinkler irrigation. Given the prevailing conditions they suggested that since the water-intensive crops are also labor-intensive, their omission from cropping plans may result in labor displacement. However, other alternatives can be recommended pending economic feasibility. The impacts of raising irrigation water price and changing cropping patterns on farm labor in Iran cannot be disregarded since such changes may involve social and political costs. For example, about 3.35 million (23 %) of the labor force is engaged in agriculture. Meanwhile, more than 80% of farmers have less than l0 hectares each (Central Bank of Iran, 1996). Time is required to change farmers' perception of water and to develop a diverse economy capable of creating new jobs in other sectors.

On the other hand, changing cropping patterns in favor of more profitable crops at the cost of water-intensive, low-value crops had been successfully implemented in other countries. For example, in market economies farmers are expected to change their cropping patterns when economy and water scarcity demand it. As Hofwegen (2003) indicates, in water scarce areas, Spanish groundwater irrigation farmers have changed their cropping patterns from alfalfa and corn to less water demanding crops as grapes and olives. The regional market of the European Union was an important stimulant for this change. This indicates that if the transition is made successfully, it may not adversely affect employment in the targeted sector. However, if such a transition is not possible, farm unemployment is likely to increase, unless alternative employment opportunities are considered for the unemployed labor.

Another problem with relying on external sources for some basic food item is the fear of dependency. However, some countries like Malaysia, Jordan, Egypt and others have made a conscious choice. The problem with virtual water trade could also be solved through special multilateral trade agreements among regions (such as MENA countries), and even between countries of different relative advantage in water resource endowments.

Finally, the role of economic incentives in relation to water-use efficiency and trade patterns is a problem to be addressed. In addressing the issue of increasing water scarcity and competition for the use of water, Tiwari and Dinar (2003) discuss the role of economic incentives in irrigation management. They argue that, while improved water-use efficiency through demand management instruments appears to be the best available option for water scarce regions, past efforts were more concerned with technical and engineering aspects of the problem. Improving water-use efficiency requires considerations of many factors including technical, economic, institutional and ecological instruments. Despite many studies relating to water-use efficiency, only a few have tried to consider various aspects of water-use efficiency including monetary and non-monetary measures (Soltani, 2005).

Some of the questions addressed by Tiwari and Dinar were:

1. To what extent is there room for policy intervention to improve water-use efficiency at various levels?
2. What is the role of economic incentives for improving water-use efficiency and assisting small farmers in the region?
3. What lessons can be learned from past experience in using economic incentive instruments for increasing water-use efficiency?

Some of the findings and lessons learned from the analysis of the above problems (questions) are:

1. Improvement in water-use efficiency requires an integrated and comprehensive approach. This implies a broader concept of efficiency to encompass technical,

economic and ecological water-use efficiency. Likewise, analysis of water-use efficiency in its various forms should determine the space for policy intervention in each region or project. In other words, the study should clearly specify the specific set of feasible economic incentive instruments necessary for improving water-use efficiency.

2. It is clear that when various economic incentive instruments are complementary, they can have a strong impact. There are some evidence that economic incentives are useful policy instruments which can be used on all levels of water users including consumers, producers and government. Institutional reforms are needed to facilitate the adoption of economic incentive measures in developing countries.
3. Review of projects financed by the financial institutions shows that there has been little use of economic incentive in this area. From the International Financial Institutions' viewpoint, there is a need for linking institutional reforms and the gradual introduction of economic incentives for water management.
4. It is likely that irrigation subsidies will continue to be a useful policy in developing countries in spite of the fact that large and medium sized farms benefit more from them than small farmers. On the same note, previous studies have confirmed that eliminating subsidies and using economic incentives are instrumental in enhancing water-use efficiency and overcoming poverty. While there is consensus among water experts on the need for enhancing agricultural water-use efficiency in MENA, efforts in this direction have not produced the expected outcome in many countries of the region (ICARDA, 2001). In other words, the success of policies aimed at raising water-use efficiency has been limited. There is still a big gap between expected and actual outcomes. This can partly be explained by the fact that water-use decisions at the farm level are not necessarily optimal at the regional or national level. Farmers may lack the needed incentive to move toward the socially desirable outcome. Decisions at the farm level are influenced by a number of technical, economic, social, personal and institutional factors (Soltani, 2005). Unless these factors are identified and addressed appropriately, one cannot take a major step toward achieving the objective of water-use efficiency at the regional (basin) and national levels. As indicated, analysis of the extent of water-use efficiency gap, factors affecting this gap and possible measures designed to reduce this gap are the subject of present study.

Agricultural trade liberalization resulting in a shift in commodity trade and production (cropping patterns) has increased concern over irrigation water subsidies. Analysis have shown that trade reform along with institutional reform in the water sector, such as water pricing reforms or promotion of water market, would prove to be increase welfare more than would an irrigation water subsidy. In other words, reducing water price distortion (elimination of water subsidy) is likely to result in changing water-use and trade patterns, enhancing water-use efficiency and increasing the economic value of irrigation water.

It is clear that the changes in cropping and trade patterns can ease pressure on water resources in arid regions through virtual water trade. Many oil seed and fruit crops in Iran have high water-use efficiency. That is they require less water but give higher income than existing crops. However, how much land can be planted with these crops given domestic and international market potential? This is a problem to be addressed. Likewise, there is a trade-off between the benefits of reduced pressure on water resources and the costs of food imports in terms of possible relocation of rural communities. Hence, considering agricultural trade as an integral part of water management in a country or basin allows for a more rational decision regarding water use patterns and allocation. Overview of the literature dealing with agricultural water-use and trade patterns reveals that these studies have mainly addressed the problem at the macro (sector or basin) levels. In addressing the problem of agricultural trade and comparative advantage in water scare regions, water has been treated like other factors of production or has been disregarded altogether. While water in arid and semi-arid regions plays an integral part in agricultural production, it is surprising that the comparative advantage principle has not been directly applied to the water resource requirements of agricultural production in arid regions. As indicated in this study, optimizing agricultural water use and trade patterns in the MENA region are addressed simultaneously. Furthermore, in applying the comparative advantage principle at the basin level, market prices including water price are corrected for distorting policy (irrigation water subsidy) and market failure.

As indicated, most optimization models have been used to address water management problems and to account for the impact of alternative water-use choices at the regional level. However, water-use decisions are made at both regional and farm levels. Decisions made at these levels may conflict with each other. Optimization of water-use (cropping patterns and irrigation strategy) at the farm level must involve modeling the farmer's decision. In this study, optimization of water use at the farm as well as the basin level will be addressed.

3. Objectives

This study focuses on the agriculture water-use efficiency via optimizing cropping patterns, irrigation strategies and external trade of agricultural products. Thus, the objectives of this study are:

1. Determination of basin's comparative advantages in the production of crops,
2. Determination of optimal cropping patterns and irrigation strategy at the farm and basin levels,
3. Determination of optimal patterns of external trade of agricultural products,
4. Analysis of the effects of selected policies on the social benefits, cropping patterns and water use efficiency.

4. Methodology

In this section methodology including the sampling technique and models is described. The general framework of the research methodology is shown in Figure 1. In this study optimization of agricultural water use and trade patterns are addressed simultaneously. Furthermore, in applying the comparative advantage principle at the basin level, market prices (including water price) are modified for distorting policy and market failure.

Water-use decisions are made at two levels: the regional and farm levels. Optimization of water use at the farm level must involve modeling a farmer's decisions. In this study, optimizations of water use at the farm as well as basin levels are addressed.

Policy Analysis Matrix (PAM) methodology is used to reveal the comparative advantage of crops (Monke and Pearson, 1989, Gotch et al, 2003). Optimal cropping patterns at the basin and farm levels are determined using mathematical programming (Amir & Fisher, 1999; Hazel and Norton, 1986; Patten et al, 1988; Zibaei, 2002; Mainuddin et al, 1997; Dinar et al, 1992 and Diao et al, 2002). Patterns of agricultural trade are determined on the basis of the comparative advantage of basins in producing agricultural products (Yao, 1994 and 1997; Monke and Pearson, 1989 and Nelson and Panggaden, 1993).

Yao (1997) used PAM methodology to study the comparative advantage of three competing crops (Rice, Soybean and Mungbeans) in Thailand. Monke and Pearson (1989) and Yao (1994) presented a detailed description of PAM and the calculation of various measures such as effective protection coefficient (EPC), domestic resource costs (DRC), social benefit-cost ratio and net social profit (NSP), and the economic interpretations of these parameters. In their view, DRC and EPC do not consider all of the parameters needed for determining the comparative advantage. Hence PAM, described below, has been proposed for this purpose.

4.1. Policy Analysis Matrix (PAM)

PAM is a product of two accounting identities, one defining profitability as the difference between revenues and costs and the other measuring the effects of divergences (distorting policies and market failures) as the difference between observed parameters and parameters that would exist if the divergences were removed. Profits are defined as the difference between total sales revenues and costs of production. This definition generates the first identity of the accounting matrix. In the PAM, profitability is measured horizontally, across the columns of the matrix, as demonstrated in Table 1. Profits, shown in the right hand column, are found by subtracting costs, given in the two middle columns, from revenues, indicated in the left-hand columns. Each of the column entries is thus a component of the profits identity-revenue less cost equals profit.

Each PAM contains two cost columns, one for tradable input and the other for domestic factors. Intermediate inputs — including fertilizers, pesticides, purchased seeds, compound feed, electricity, transportation and fuel — are divided into their tradable input and domestic factor components. This process of disaggregation of intermediate goods or services separates intermediate costs into four categories: tradable inputs, domestic factors, transfers (taxes or subsidies that are set aside in social evaluation), and non tradable inputs (which themselves have to be further disaggregated so that ultimately all component costs are classified as tradable inputs, domestic factors, or transfers) (Monke and Pearson, 1989).

According to Table 1 the following definitions can be derived.

Private profits, D = A-B-C,

Social profits, H = E- F- G,

Output transfers, I = A- E,

Input transfer, J = B- F,

Factor transfers, K = C- G and

Net transfers, L = D - H or L = I - J - K.

With regards to Table 1, ratio indicators can be defined as follows for comparison of unlike outputs.

Private costs ratio (PCR), C/(A-B),

Domestic resource cost ratio (DRC), G/(E-F),

Nominal protection coefficient (NPC) on tradable outputs (NPCO); A/E, Nominal protection coefficient on tradable inputs (NPCI); B/F,

Effective protection coefficient (EPC); (A-B)/(E-F),

Profitability coefficient (PC); (A-B-C)/(E-F-G) or D/H and

Subsidy ratio to producers (SRP); L/ E or (D-H)/E.

The data entered in the first row of Table 1, provide a measure of private profitability. The term private refers to observed revenues and costs reflecting actual market prices received or paid by farmers, merchants or producers in the agricultural system. The private or actual market prices thus incorporate the underlying economic costs and valuations plus the effects of all policies and market failures. The second row of Table 1 utilizes social prices. These valuations measure comparative advantage or efficiency in the agricultural commodity system. Efficient outcomes are achieved when an economy's resources are used in the activities that create the highest level of output and income. Determination of inputs and outputs, shadow prices or social values are a prolonged subject and explaining them in detail would make the report lengthy; therefore they are not discussed here. Anyway, if social profits become positive, then the production of those crops has a comparative advantage or the factors of production are used efficiently.

The second identity of the accounting matrix concerns the differences between private and social valuations of revenues, costs and profits. For each entry in the matrix —measured vertically — and the divergence between the observed private or actual market price and the estimated social (efficiency), the price must be explained by the effects of policy or by the existence of market failures. This critical relationship follows directly from the definition of social prices. Social prices correct for the effects of distorting policies — policies that lead to an inefficient use of resources. These policies are often introduced because decision makers are willing to accept some in-efficiencies (thus lower total income) in order to achieve non-efficiency objectives, such as the redistribution of income or improvement of domestic food security. Under these circumstances, assessing the trade off between efficiency and non-efficiency objectives becomes a central part of policy analysis. It is noteworthy that not all policies necessarily lead to non-efficient use of resources. In fact, some policies are enacted explicitly to improve efficiency whenever monopolies or monopsonies, externalities or factor market imperfections prevent the market from the efficient allocation of products or factors. Hence, it is necessary to distinguish between distorting policies, which cause losses of potential income, and efficient policies, which offset market failures and thus create greater income (Monke and Pearson, 1989). Therefore, PAM can be introduced in a more complete form as shown in Table 2.

According to what was explained, PAM is used to determine the comparative advantage of crops in the region of study. Social prices are an estimate based on secondary data and are an approximate estimation at best.

4.2. The Farm Model

Mathematical programming is extensively applied for modeling agricultural systems. Since agricultural production is typically a risky activity therefore, incorporating risk is necessary for considering agricultural systems. However, there is no unique definition of risk among agricultural economists, and in practice, different measures and programming formulations have been used (Anderson et al. 1977, Lambert and McCarl, 1985, Hardaker et al. 1991).

In general, risk modeling using mathematical programming is divided into two categories: risk programming and stochastic programming. In former model, risk is considered in the objective function coefficients, while in the latter model, it appears in the objective as well as constraints and right side coefficients (Anderson et al. 1977).

Risk programming is more developed and consists of expected profits, quadratic, MOTAD; target MOTAD, Mean-Gini, utility maximization and utility-efficient programming. Explaining the advantages and disadvantages of these models is beyond the scope of this study. However, the reasons and structure of two of the applied models are explained.

From the policy maker's point of view, the effect of policies (some of which are considered here) on expected profits at the farm level is important. Therefore, the expected profit model is chosen. Also, making a plan at the farm level without taking into consideration risk in the production of crops and farmers' behaviors is imperfect. Thus, risk must be incorporated in agricultural system modeling. The utility-efficient programming is utilized because it is free of any assumption about risk parameter distribution (namely income) or the utility function form. Moreover, it also generates an acceptable efficient set without requiring complete knowledge of target groups' preferences (Lambert and McCarl, 1985).

4.2.1. Expected Profit Model

Linear programming with the objective of maximizing expected profit can be used in a risk programming as follows:

Maximize $E = c'x$

Subject to $Ax \leq b$

and $x \geq 0$

Where E is expected profit; $c_{n\times 1}$ is the vector of activity net revenues; $x_{n\times 1}$ is the vector of activity levels; $A_{m\times n}$ is the matrix of input-output coefficients and $b_{m\times 1}$ is the vector of right-hand-side coefficients. Also, $c=pC$ where $p_{s\times 1}$ is the vector of states probabilities and $C_{n\times 1}$ is the matrix of activity net revenues by state (row) and activity (column). This formulation accounts for risk in activity net revenues across possible states of nature.

Lambert and McCarl (1985), by considering the deficiencies of MOTAD and quadratic programming models, introduced the direct expected maximizing nonlinear programming (DEMP) formulation, which maximized the expected utility of wealth. DEMP was designed as an alternative to quadratic programming and was free from any restriction regarding farmers' utility function and income distribution. DEMP mathematical formula is as follows:

Maximize $E(u) = p'\, u(z)$

Subject to

$Ax \leq b$

$cx - Iz = uf$

and $x \geq 0$

Where u(.) is a monotonic and concave utility function; z is a vector of net revenues; u(z) is a vector of utility of net revenue by state; A is a matrix of input-output coefficients; p is a vector of state probabilities; c is a matrix of activity net revenues; I is an identity matrix; u is a vector of one; x is a vector of activity levels; f is fixed cost and b is a vector of right-hand-side coefficients.

Applying DEMP involves having the risk preferences of the decision maker (farmer) individually. In fact, DEMP can be applied when the preference of an individual farmer is considered. But, in most studies a target group (farmers in a region) is considered. Under these circumstances it is necessary to develop an efficient set of farm plans in accordance with some criteria, such as stochastic dominance with respect to function. This goal can be achieved by using utility-efficient programming introduced by Patten et al (1988).

4.2.2. Utility-Efficient Programming

Utility-efficient programming is a reformulation of DEMP using parametric objective programming. The mathematical form was defined by Patten et al (1988) as follows:

Maximize $E(u) = \Sigma_k\, p_k\, [G(z_k) + \lambda\, H(z_k)]$

Subject to

$Z_k - c'_k x = 0$

$Ax \leq b$

and $x \geq 0$

Where λ is a non-negative parameter; p_k is the probability of state k; G and H are two parts of the utility function u; z_k is the total net revenue for state k; c'_k is the activity net revenue for state k; x is the vector of activity levels; A is the matrix of input-output coefficients and b is the right-hand-side coefficients.

The parameter λ is varied using a parametric objective programming algorithm. At each change of basis, corresponding to a particular level of risk aversion, the expected utility maximizing solution is identified. In the objective function of this model, convenient form of utility function can be used (Patten, et al 1988). We use these models in order to allocate land at the farm level.

4.3. The Plain Model

In this section, applied model at the plain level is described by emphasizing on the optimal use of irrigation water and the maximization of social profits.

Using PAM allows for determining the crops which have comparative advantages. However, in order to find out the combination which maximizes social profits, we need to use mathematical programming.

All related studies reviewed have a common feature; they use observed prices or private prices for calculating revenues and costs of activities. Using social prices for calculating revenues and costs of activities however, some activities may appear to lack the feature of comparative advantage — of production or positive social profits. Therefore, the optimum cropping patterns or optimum allocation of water indicated by previous studies may not be acceptable from a social point of view (meaning that some activities may have negative social profits). In fact, the purpose of these studies was to find a combination of activities or an allocation of scarce water that maximizes total benefit or minimizes total cost, without considering the fact that some of these activities may lack positive social profits and therefore have an adverse effect on social welfare.

This problem can be overcome by integrating PAM and mathematical programming. By using PAM we can determine activities which have the comparative advantage of production (their social profits are positive) and then by applying mathematical programming, the combination of activities that maximize social profits can be specified. In this way we are able to make an objective function which is free of any distorting policies and market failures. However, it is necessary to correct the crop yields for their direct and indirect influences for current distorting policies or market failures. This problem is explained next.

The specification of constraints and technical coefficients is the other problem in making a plain level model. Two constraints, land and water, are considered in the model because they are two principal inputs in agricultural production and very costly for any society.

Since we want to make a model from a social point of view, all parts of such a model should reflect standpoints of the society and the best and most correct use of inputs. Accordingly, technical coefficients at the plain level are different from the farm level model, which are often determined on the basis of averaging the sample's data. This correction can be explained as follows.

As mentioned earlier, distorting policies, such as inputs pricing, affect the amount of utilization of inputs at the farm level and therefore crop yields. As a result, it is necessary to determine technical coefficients and crop yields in a way that is free from any effect of distorting policies or market failures. Correcting crop yield can be done by using the following formula established by Doorenbas and Kassam (1979).

$$\frac{Y_0}{Y_p} = \prod_{i=1}^{4} \left[1 - k_{y_i} (1 - \frac{ET_{ai}}{ET_{pt}}) \right]$$

Where "i" denotes each period in plants growth cycle; y_a is actual yield; y_p is potential yield; k_{yi} is the yield response factor for each stage i of the crops growth cycle; ET_{ai} is the total amount of actual evapo-transpiration during period i and ET_{pi} is the total amount of potential evapo-transpiration during period i. The right-hand-side of the above expression is a number between zero and one often referred to as the crop water stress index. Y_p for each region is calculated by employing the above formula and used in the objective function of the plain model in order to calculate the net social benefit appropriately. It should be noticed that when data needed for calculating y_p is not available, the maximum yield of the sample's data in each region will be used.

Crop irrigation requirements and technical coefficients of the model's water constraints are calculated using the FAO Penman-Monteith method (Allen et al., 1998).

The total crop's water requirement during month t (WRQ_t) is calculated using the formula:

$$WRQ_t = ET_{ot} \times KC_t$$

Where ET_{ot} is the total amount of reference evapo-transpiration during month t and KC_t is the crop coefficient corresponding to the appropriate month of crop growth. The following formula will be used for a crop's total irrigation requirement (TIRQ) during month t:

$$TIRQ_t = \frac{WRQ_t - EP_t}{IE}, \qquad t = 1,2,3,...,12$$

WRQ_t is the crop's water requirement during month t; EP_t is the amount of effective precipitation during month t; and IE is indicative of the level of inefficiency in the system of water distribution.

According to the above explanations we can show our model as fallows:

$$\text{Maximize} \qquad NSB = \sum_{i=1}^{n} (y_{p_{ij}} \times sp_{ij} - sc_{ij}) x_{ij} \qquad \forall j$$

Subject to

$$\sum_{i=1}^{n} \sum_{j=1}^{m} a_{ij} x_{ij} \le x_j$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{t=1}^{12} TIRQ_{ijt} x_{ij} \le GW_{jt}$$

$$\sum_{j=1}^{m} \sum_{t=1}^{12} GW_{jt} \le GW$$

$$pr(\sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{t=1}^{12} TIRQ_{ijt} x_{ij} \le SW_{jt}) \ge a$$

$$X_{ij} \ge 0 \qquad \text{and}$$

Where NSB is the net social benefit from all the crops; y_{pij} is the potential yield of crop i (per hectare) in region j; sp_{ij} is the unit social price (or shadow price) of crop i in region j; sc_{ij} is the social costs of crop i (per hectare) in region j; x_{ij} is the level of crop activity i in region j which has production comparative advantage according to PAM; a_{ij} is the land area coefficient of crop i in region j and equals one if crop i is grown in region j, otherwise zero; x_j is total land available in hectare in region j; $TIRQ_{ijt}$ is the irrigation water required (in m^3/hectare) by crop i in region j, growing in month t with the level of determined inefficiency in the system of irrigation water distribution; GW_{jt} is the permissible withdrawal of underground water (in m^3) in region j and month t; GW is the maximum allowable withdrawal of underground water in basin and SW_{jt} is the amount of surface water available (in m^3) in region j and month t — the availability of surface water is not definite for each month, therefore it is considered stochastically and we use chance constraint programming introduced by Charnes and Cooper (1959).

It is possible to add other constraints to the model. For instance, if we want to take environmental concerns into account, we can add the following constraints:

$$\sum_{j=1}^{m} f_{ig} x_{ij} - n_j = 0$$

$$\sum_{j=1}^{m} n_j - N = 0$$

$$N \leq \text{constant}$$

Where f_{ij} is the quantity of nitrogen (kilogram/hectare) recommended by agricultural experts for crop i in region j; n_j is the total quantity of nitrogen (kilogram) can be used in region j and N is the maximum tolerable quantity of nitrogen (kilogram) in the region under study.

Also, we can change the objective function of the model as follows in order to obtain the social water demand curve in the region under study and provide a quantitative study for water demand at various social prices, and consider their effects on the social and private optimal cropping patterns.

$$\text{Maximize} \qquad NSB = \sum_{i=1}^{n} (y_{py} \times spc_{ij} - pscc_{ij}) - wsp_j \times w_{ij})x_{ij} \qquad \forall j$$

Where $pscc_{ij}$ is the production social costs of crop i (per hectare) in region j excluding social cost of water, wsp_j is the social price of water (Rial/ m^3) in region j, and w_{ij} is the irrigation water applied (m^3/hectare) by crop i in region j. Other parameters were introduced before.

One of the objectives of this study is to consider the effects of some selected policies on social and private profits. We make use of PAM and integrated mathematical programming models at the farm and plain levels. By solving the plain level model, we are able to find a mix of crops that can be viewed as desirable for the society. The farm level model can optimize cropping patterns under circumstances of distorting policies and market failures. Now we are able to consider the effects of some selected policies on social profits, private profits, cropping patterns and water-use efficiency.

Using PAM displays the source of deviations between social and private benefits. Therefore considering the elimination of these deviations gives a package of policies which policy makers are willing to implement practically. In fact, we apply these models in a way that enables agricultural economists, planners and others to directly estimate the effects of some policies — which are objectives — on farmers' revenue, cropping patterns, the amount of inputs used and to consider whether private benefits move towards social profits or not. Also, according to PAM, we are able to calculate the social costs and benefits of using expected profit and utility-efficient programming models by comparing actual and optimum cropping patterns which are indicated by these models.

The effects of the policies below, separately and together, will be considered on cropping patterns, farmers’ revenue and utilization of inputs —especially irrigation water at the farm level — and social profits:

- Increasing irrigation water charges.
- Removing the subsidy on fertilizer.
- Determining the maximum and minimum land areas for crops which have the comparative advantage and disadvantage of production, respectively.
- Considering the effect of different levels of inefficiency in the system of water distribution on optimal cropping patterns and social profits at the plain level.

Farmers' response to a possible change in the price and supply of irrigation water and their possible effects on social and private profits are investigated using positive mathematical programming (PMP) technique. Scenarios considered are: raising water price by 20, 40, 60 and 100% along with 10 and 20% reduction in the available water supply; 80% increase in water price and 50% decrease in water supply reflecting drought conditions; and finally 20% increase in water price and 10% decrease in water supply in Mashhad plain.

Liberalization of sugar beet and fertilizer markets along with a 10% decrease in water supply at the farm level.

The PMP approach uses the farmers' crop allocation in the base year to generate a self-calibrating model of agricultural production and resource use, which is consistent with micro-economic theory. It is more flexible in its response to policy changes. The approach is developed for cases where the empirical constraints set do not reproduce the base year results (see Howitt, 1995).

The risk programming model requires knowledge of the farmers' degree of risk preferences (attitude). Farmers' beliefs can be determined by estimating their subjective probability by using one of three methods: 1) the visual impact method, 2) the judgment fractile method and, 3) the triangular distribution method (Wik and Holden, 1998). Farmers' risk attitudes are estimated by experimenting (based on utility function), econometrics or mathematical programming. In this study triangular distribution and experimental methods are used to determine farmers' subjective probability and risk attitude respectively. Several methods are available for designing questionnaires and deriving farmers' preference functions. Among these methods, the equally likely certainty equivalent (ELCE) method, the Ramsey method and the equally likely but risky outcome (ELRO) are more frequently used (Zibaei, 2002). In this study, the former method is used to estimate farmers' preference function.

4.3.1. Determining the Appropriate Irrigation Strategy

Optimal cropping patterns and irrigation strategies at the basin scale are determined on the basis of deficit irrigation in various growth stages of crops aimed at maximizing social profits. This is because deficit irrigation is consistent with the prevailing conditions in the water scare region selected.

Moreover, most farmers facing water shortage are already practicing deficit irrigation. Their irrigation strategy is based on their beliefs about rainfall distribution and possible intra and inters seasonal allocation of the limited irrigation water. A water allocation model incorporating deficit irrigation requires data on potential yield and water requirements in various growth stages of the crops included. Potential yield data are based on reviewing a 20 years trend of the province’s yield of principal crops (1983-2003) and experts opinions. As indicated, water requirements of crops are calculated by Penman-Montheith formula and studies of meteorological and agricultural departments.

The time period for each crop's growth stage are determined in consultation with crop science department researchers and experienced farmers.

Accordingly, for each irrigated crop, 45 activities corresponding to the number of crop water stresses are considered in the model. Due to the lack of data about deficit irrigation, a random number of less than one and greater than 0.5 for various degrees of water stress in each of the five growth stages are simulated using excel spreadsheets.

Due to the stochastic nature of water supply, the right-hand-sides of the irrigation water constraint are considered to be stochastic. Accordingly, five alternatives of water supply risk are assumed by the model to be 80, 85, 87.5, 90 and 95%. Due to the importance of irrigation efficiency, three efficiency levels are assumed: 35, 45 and 65%.

Social costs of irrigation water are included separately in the objective function of the model by subtracting from the social cost of crop production. Moreover, four alternative discount rates are assumed, leading to four different prices for irrigation water. The mathematical programming model is then solved using GAMS/Minos program.

4.3.2. Estimating Social (Shadow) Prices for Goods and Inputs

Social prices for tradable goods and services in nearest wholesale markets to farm gates are equal to their border price adjusted for the costs of transportation, marketing and processing. General concepts for deriving export and import parity prices are described by Gotsch et al, (2003).

Social prices of non-traded goods are estimated by correcting their private prices from distorting policy and market failure.

Social prices for domestic factors of production (land, water, labor and capital) are based on their social opportunity costs. In the case of some non-traded inputs, social prices of close substitutes in the country or neighboring countries are used. The social price of irrigation water is calculated by following formula:

$$\underset{(\text{per m}^3)}{\text{Social price}} = \begin{matrix}\text{(Private marginal cost of}\\ \text{groundwater extraction or}\\ \text{surface water development)}\end{matrix} + \text{Subsidy} + \begin{matrix}\text{External marginal}\\ \text{cost}\end{matrix}$$

Irrigation water subsidy is determined by PAM. Marginal external costs of ground water extraction are estimated by the following equation:

$$\text{MEC} = \text{a} - \text{bwt} = \text{eht} + \frac{\text{ewt}(1-\theta)}{\text{Asi}}$$

Where:

Wt = volume of water extracted in m^3 per unit of time, a and b are distances from the origin and slope of demand function respectively,

θ = irrigation water return flow to the aquifer ($0 < \theta < 1$)

A = area of aquifer

S = specific yield of aquifer

e = energy cost per m^3 per meter pumping elevation

i = interest (discount) rate

4.4. Optimization of Agricultural Trade Patterns

As indicated, PAM reveals the comparative advantage of various basins and regions in the production of crops. Patterns of agricultural trade are determined by using mathematical programming. When water supply is scare and stochastic, water trade, both actual and virtual, reduces both parties' risk exposure and increases water-use efficiency (Calatvara and Garrido, 2005). In this study, agricultural (water) trade is simulated by developing a mathematical programming model for a representative farm in Mashhad plain of Iran. It is expected that, with external trade, Iran (region) may specialize in products for which it is specially adapted and may trade the surplus of these products for imported ones.

Obviously, since Iran is short on water supplies, it should concentrate on producing agricultural products that generate a high level of income per unit of scare water. To focus on the demand side of the problem, demand management instruments will be selected to achieve this objective. Water requirements per dollar of agricultural output produced is used to determine the manner in which agricultural trade can mitigate domestic water supply restraints. The region's water trade position is shown by the difference between exports and imports of embedded water. The region may export or import water on a net basis, or its water trade may be balanced, depending on the cropping or water use patterns prevalent in the agricultural sector (Kelso et al, 1973). Hence, water requirements for the production of a dollar of each crop are calculated and used as the basis for deterring agricultural trade patterns.

The terms of water exchange is the average trade price of embedded water exported (in dollar/m^3) divided by the average trade price of embedded water imported. A rise in the terms of water exchange means that, the region (country) may import a large quantity of embedded water for each unit of embedded water exported resulting in an increase in economic advantage, at least for a water scare region (country). Hence, optimization of agricultural water-use and trade patterns within a region (country) requires pursuing policies to encourage growth of cropping patterns in which water generates high value per unit of water, among other measures.

Tt should be noted that, agricultural trade between and within countries can be seen as a less costly and more environment friendly alternative to inter-basin water transfers especially since trade in real water between water rich and water poor regions is generally costly due to large distances, bulkiness and associated costs.

While "virtual water" hypothesis predicts a specialization pattern based on exports of water-intensive agricultural products from the water-abundant to water-deficient countries. However, it does not provide an answer to the problem of inefficient water-use and trade patterns in the latter countries. Solutions to the problem of water shortage in the water-deficient countries are not created by just importing water-intensive agricultural products (virtual water), or by just addressing the water supply issues, but often, and even more importantly, they are realized by addressing the demand for water through demand management measures and water policies that encourage and even aid the change in the countries' agriculture structure and patterns of water use, and the external trade of agricultural products (Kelso et al, 1973). In other words, while "virtual water" hypothesis is intended to reveal the comparative advantage of water-deficient countries in the production of commodities, it does not address the problem of inefficient water-use and the choice of appropriate demand management instruments.

The main purpose of this study is to examine the alternative of adopting a conscious agricultural trade policy designed to maximize social returns to scarce water resources by adopting agricultural trade patterns consistent with the country or basin's water resources. Obviously, this approach requires managing irrigation water in order to maximize the economic returns by accessing markets to generate the means for financing the import of food deficit. These markets need not necessarily be global but could be regional or even local.

4.5. Sample Survey and Data

Farm data is collected using a multi-stage random sampling technique. First, a random sample of villages are selected from a list of villages located in the three plains of Harir-reud and Kashafrud basins in Khorasan province using the water corporation's GIS technique. The three plains selected are: Mashad, Narimani and Sangbast. Then, a random sample of 300 farmers in the selected villages is chosen for an interview. Complementary data is obtained by interviewing agricultural experts and researchers in the province.

Departments and institutions contacted for this purpose are:

- Departments of irrigation, crop science and agricultural economics of Ferdowsi University of Mashhad.
- Customs department of province
- A planning and management organization, a sugar factory and farm machinery development
- A tomato processing factory
- The water corporation of the province
- Department of Agricultural Jahad
- A fertilizer and plant chemical distribution unit

5. The Region

The region is located in Khorasan province in the northeast of Iran. With an area of about 313000Km^3, Khorasan is Iran's largest province. Longitudinal and latitudinal specifications of the province are: 55°, 17′ to 61°, 15′ and 30° , 24′ to 38° , 17′ respectively. The average annual precipitation ranges from some 50 mm in the desert areas of the south east to some 800 mm in the northeast of the province. It has a varied climate ranging from a temperate and cold mountainous north with the highest population density and most fertile lands, to an arid and semi-desert climate in the south.

Major agricultural products of the province are: wheat, barley, sugar beet, potato, onion, tomato and saffron.

There are seven hydrological basins forming some 76 plains. Irrigated farming is heavily dependent on groundwater. Over-pumping of ground water resources has led to a substantial decline in the depth of water table.

Groundwater resources are estimated at about 8 billion cubic meters. The current rate of exploitation exceeds groundwater recharge by 1.7 billion cubic meters per annum. Surface water resources are estimated at 3.9 billion cubic meters, with 2.7 billion currently being used up. About 94% of the province's water resources is used in agriculture.

As indicated before, three plains of Harir-rud and Kashafrud basin were selected for this study. The basin has an area of 44000 Km^2. Some properties of the selected plains are shown in Table 3. As indicated, groundwater overdraft prevails in Mashad and Nariman plains. Considering the number of existing villages in each plain, the average number of wells are 6.3, 4.5 and 3.5 in Mashad, Nariman and Sangbast respectively. As shown, Sangbast has the least number of wells and as such, this plain in not currently experiencing groundwater overdraft.

6. Results and Discussion

Farmers make joint water and land-use decisions for economic purposes based on water availability and reliability. In this section, general patterns of land and water use decisions by the farmers in the region are described. Results of PAM and the comparative advantage of agricultural commodities are presented next.

6.1. Cropping Patterns

Using data collected through sample surveys, sample farms were classified into three groups: small (less than 5 hectares), medium (between 5 and 11 hectares), and large farms (more than 11 hectares). There are considerable variations in the patterns of land and water use among these farms. As shown in Table 4, wheat and barley are planted on about 72% of land in small and medium sized farms and 42% of cultivated lands in large farms. Wheat is a dominant crop in small and medium farms (37 and 44% respectively). On the other hand sugar beet is the dominant crop in large farms and occupies about 30% of cultivated area. The lowest area of land is allocated to onion with 0.73, 1.65 and 1.02% in small, medium and large farms respectively. The 20-year trends of yield and cultivated areas of some principal crops show a clear picture of land and water allocation in the province. Table 4 shows the main features of land allocation among major crops (cropping patterns) in the province.

Using the coefficient of variation as a measure of production risk, wheat, barley and sugar beet show lower production risk compared to potato, onion and tomato. Hence, diversification of farming activities adopted by farmers during the 20-year period was focused on reducing fluctuation in their income.

Analysis of yield and cultivated area trends of some principal crops in the province showed that the increase in the production of wheat, onion, potato and sugar beet caused an increase in yield only. But, in the case of tomato and barley the increase in production has been a result of an increase in both yield and cultivated areas. The findings also rejected the hypothesis that "wheat support policy has negative effect on barley production in the long-run".[2] Moreover, results showed that production risk appears to be instrumental for adopting risk-reducing technology in the long-run. Farmers have responded to increasing demand by expanding cultivated area in the short-run and by adopting yield increasing technology in the long-run. Hence, land can be a limiting factor of production in the short run. Increasing the trend of crop yield indicates that government support policies have been successful, to some extent, in enhancing land and water productivities in the region.

As indicated in Table 5, years of maximum yield are not the same across various crops grown in the province. Due to their similar agronomic structure, wheat and barley show similar variation in yield. Since the good cropping year is not the same for all crops grown, farmers have adopted diversified farming as a risk reducing strategy — even in large farms.

Crop patterns during the last two decades have been changing in response to market forces. Tomato and barley have been expanding in acreage while other crops have experienced a declining trend. While productivity of all crops has improved, there is still considerable potential for increasing yield per hectare for most crops.

6.2. Construction of Policy Analysis Matrix (PAM)

The basic data used for the construction of PAM include the level of yields, the variable inputs used and the demand the commodity system places on farm resources especially water. These inputs and outputs are valued at the prevailing prices for the private profitability analysis.

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[2] -According to the statements made by a number of agricultural economists.

The procedures followed for determining social prices vary according to whether the commodities are traded internationally, are non-traded inputs or outputs, or are non-traded domestic factors.

Traded inputs in this study include all kinds of chemical fertilizers, pesticides and herbicides. Domestic inputs are land, labor and capital. Non- Traded inputs are irrigation water, manures, seeds and farm machinery (tractor) services. In the case of agricultural commodities, tomato, onion and potato are export crops, wheat and barley are imported, and sugar beet is considered a non-traded commodity.

Social prices of trade inputs and commodities are estimated using the procedures indicated in the previous section. Deriving realistic social prices (wages) for labor proved to be a problem since prevailing wage rates may be distorted by regulation — such as for minimum wages. However, these are not widely found relative to agriculture in the region studied. Hence, shadow wages for various categories of labor are derived by calculating average wages paid in various stages of crop production such as land preparation, seeding, growing and harvesting. In the case of land (which also embody land-based improvements such as irrigation), it may be appropriate to show returns to land as a residual, thereby limiting the conclusion that can be drawn about social profitability and comparative advantage. However, for the case of this study, average rental prices paid for the sample commodities are used as the opportunity cost of land.

The social price of capital may come from a review of rates calculated across a number of development projects. However, no such estimates were available in Iran. Therefore, four different rates (6, 8, 10, and 12) were used for this purpose.

Social Price of Irrigation Water

To determine the social price of irrigation water, first, the price per cubic meter of water used from each source is calculated. Based on this calculation, the shares of each components of price are specified. Assuming that, price distortion is only due to the cost of energy, the amount of such distortion (subsidy) is added to the price of irrigation water. Moreover, the external cost of groundwater overdraft is also estimated using the formula derived in the methodology. This cost is also added to the price of irrigation water. Estimating private and social prices for irrigation water are shown in Table 6. As shown in Table 6, irrigation water subsidy amounts to 106.8 Rials per cubic meter which is twice the private price of water. Estimated external cost at 4, 6, 8, 10 and 12% interest rates (assuming the decline of the water table to be one meter per annum for the next 20 years) are also shown in the Table. As indicated, the highest social price of irrigation water corresponds to the interest rate of 6%.

Measures of Comparative Advantage

Two measures of net social profit and domestic resource cost coefficient (DRC), were used to determine the comparative advantage of some principal crops of Khorasan province by PAM at three levels (whole basin, basin by farm size and plains). Positive net social profit or DRC of less than one indicate that producing the commodity considered has a comparative advantage.

As mentioned earlier, a new approach is developed and used for estimating the social price of irrigation water. Moreover, due to its better reflection of the negative externality of over-exploitation of the province's scarce water resources, the results of 6% interest rate is used for the analysis.

Summary results of PAM are shown in Table 7. As indicated, the net social profit of an activity varies with the level of that activity.

For example, wheat lacks comparative advantage in Narimani plain, while it generates the highest (1773980 Rials per Ha.) and lowest (9484 Rials per Ha.) social profits in large and small farms respectively. Wheat and barley enjoy a comparative advantage in the whole basin. But, production of barley generates higher social profits than wheat. Sugar beet does not have a comparative advantage in production on all levels, irrespective of the type of seed used. This is mainly due to the low price of sugar in the world market.

Results of PAM at the basin level in relation to farm size showed that social profits of large farms were greater than those of medium and small farms. However, based on the existing cropping patterns, medium sized farms earn more social profit compared to small and large farms. This implies that in the presence of distorting policies and market failure, farmers' cropping patterns have a social loss portion which affects the social profitability of the cropping patterns adopted. Therefore, although supporting large farms seems to be a rational policy for being more efficient in the use of irrigation water, cropping patterns appears to be more important than farm size from a social benefit point of view.

Tomato has a comparative advantage in the whole basin, but its social profit varies at different levels of the analysis. No data was available for tomato in the sample selected in Narimani plain.

Onion production has a comparative advantage on all levels. However, large farms have a more competitive advantage relative to small and medium farms — mainly due to their lower production cost.

Potato has a comparative advantage in the whole basin but its production in the small farms of Mashad plain is not socially feasible. This may be due to the over-use of inputs and the higher cost of production in the small farms considered.

As shown in Table 7, both rain-fed wheat and barley have comparative advantages in all levels of the analysis.

It should be noted that the results shown in Table 7 are based on the interest rate of 6% and that the price of irrigation water is 307.2 Rials per cubic meter. Obviously, changing the interest rate and irrigation water price is likely to affect the results.

Social profits of crops in small and medium farms relative to large farms are shown in Figure 2. For the purpose of comparison, social profits of small and medium farms have been normalized relative to large farms. Comparison of social profits in the three farm size groups shows that the social profits of wheat in medium and small farms are respectively 82 and 53% of large farms. Similarly, those of barley are 70 and 101%, those of tomato are 66 and 13%, those of onion are 613 and 38%, and those of potatoes are 34 and 40%. Also, social costs in medium and small farm relative to large farms are respectively 102 and 111% for sugar beet (multigerm). In the case of the monogerm variety, sugar beet's social cost in medium farms is 106% that of large farms. Monogerm sugar beet is not grown in small farms.

Net social profits and crop hectare in the region's representative farms are shown in Table 8. As indicated, net social profit per hectare in medium farms is twice that of large farms and four times that of small farms. Hence, based on the net social profit per hectare, medium farms have performed better than both the region's larger and smaller farms. The findings in Table 8 indicate that changing cropping patterns of representative farms is a socially desired option to be considered. Such change is especially important with respect to the use of non-priced inputs such as irrigation water. However, it should be noted that the nature and direction of change appears to be more important that the extent of change. Results analyzing the effects of hydrological uncertainty and water prices on agricultural production, cropping patterns, irrigation technology and water use are presented later in this report.

6.3. Optimal Cropping Patterns at Farm Level

As indicated before, PAM was used to determine net social profits and comparative advantage of producing farm products in the region. The next step involves using various mathematical programming models to determine optimal cropping and water-use patterns at the farm level. Towards this end, three representative farms were constructed.

The main features of these farms were presented before. In this section, various patterns of land and water allocations and social profits obtained from the application of mathematical programming models in the three representative farms are analyzed and compared with the existing farms. Four types of models are used in this study: expected profit, mean variance, utility/efficient and nearly optimum linear programming. After validating these models, the results of the latter two are presented hereafter.

To examine the effects of water related policies on cropping patterns, irrigation technology and irrigation water-use, most of the constraints faced by farmers in the region were included in the models. They are: land, irrigation water, four qualities of labor, chemical fertilizers, pesticides and herbicides, manures and machinery services. Due to the importance of irrigation water, crop activities were specified according to the level and timing of irrigation. To reflect the uncertainty in the supply of irrigation water, models were designed with probabilistic water availability and alternative irrigation technologies represented by assuming three irrigation efficiency levels (35, 45, and 65%) Tables 9-12 show optimal and actual cropping patterns for small, medium and large farms. As shown in Table 9, cropping combination in the case of utility efficient programming is not significantly different from the existing patterns.

Also net social profits per hectare in this model are positive but, are about 35% less than those of existing crops in small farms. Optional cropping patterns were also determined using nearly optimum linear programming (MGA) aimed at minimizing crop activities with negative social benefits such as sugar beet and potato. As shown in Table 9, the area allocated to sugar beet (a crop lacking comparative advantage) decreased by 100% relative to the existing cropping pattern.

On the other hand, the land area allocated to wheat, barley, tomato and onion — which have comparative advantages — has significantly increased relative to existing crops in small and medium farms (see Table 12). As a result, net social profits of cropping patterns generated by the MGA model is about 17 times greater than the existing patterns (see Table 9). As shown in Table 10, in the case of UEP, the area allocated to crops with comparative disadvantage has declined compared to other crops. As a result, the net social profit per hectare has increased by about 204% relative to existing farms. In the case of nearly optimum model, resulting cropping patterns generate nearly 424% more profits than existing cropping patterns in medium farms. Omission of sugar beet and increased acreages of wheat and onion are the main reasons for the substantial increase in social profit resulting from the optimal cropping patterns of the MGA model.

As shown in Tables 9 to 11, increasing social profits of both the UEP and MGA models relative to existing cropping patterns are mainly due to changing crop combinations in favor of comparatively advantageous crops and away from crops such as sugar beet with its negative impact on social profits. The results of utility efficient and nearly optimum programming models in large farms show that net social profits per hectare increase by 1985 and 1935% respectively. This is due to increased areas grown with barley and tomato and decreased areas grown with sugar beet and potato (see Table 11).

Graphical demonstration patterns of land (water) allocations resulting from the two mathematical programming models as compared to existing allocations are shown in Figures

3 to 5. These figures clearly demonstrate different patterns of land allocation in various farm-size groups and existing representative farms in the region.

Evaluation of Optimal Cropping Patterns Relative to Farm Size

Based on the net social benefits per hectare in the various farm size groups investigated it can be deduced that when market prices do not reflect the real values of resources and products, application of mathematical programming models does not necessarily result in a socially optimal allocation of resources (land and water in particular). In other words, when land and water use optimization problem are analyzed under the conditions of market failure and distorting policies, programming models' solutions do not necessarily result in reallocating resources to maximize social benefit.

Comparison with alternative programming models indicates that, utility efficient programming results in optimal cropping patterns with positive social profits. However, the magnitude of profits may be greater or smaller than existing cropping patterns.

Among the four different optimization models applied in this study, it is evident that the nearly optimum programming model would be capable of generating cropping patterns which maximize net social benefits if the needed data are available. Model solution indicates that, under conditions of market failure (externality) and distorting policies (subsidizing input and output prices), private and social benefits are in conflict. That is, increasing private profits results in the reduction of social profits and vice versa. Hence, when mathematical programming models are used to reallocate land and irrigation water for maximizing social benefits under conditions of market failure and distorting policy, social (real) rather than market prices of resources and products need to be used. Accordingly, available land for each crop in the model is considered to be equal to the maximum area grown with each crop in the last 20 years.

As mentioned in the methodology, 45 activities were considered for each crop to represent various degrees of water stress. Due to lack of reliable data on the level of deficit irrigation practices by farmers in the region, random numbers of less than 1 and greater than 0.5 for the levels of water stress in each of the five growing stages of sample crops were created using excel spreadsheets.

To determine the effects of water supply uncertainty on cropping and water use patterns, the irrigation water constraint (right-hand-side of programming model) was calculated with and without probabilistic water availabilities.

Due to the importance of irrigation technology relative to water productivity, three irrigation efficiency levels of 35, 45 and 65% were considered to represent different irrigation technologies and their effect on cropping patterns and expected social benefits.

Based on the average irrigation water available (at 35% irrigation efficiency), irrigation water supply was estimated to be about 14300 cubic meters per hectare. This estimate lies between the actual irrigation water used in Narimani plain (14500 cu.m) and Mashhad plain (12000 cu.m.). Obviously, irrigation water supply decreases as uncertainty regarding water availability increases. Since sugar beet lacks comparative advantage, its constraints in the constraint rows of the model were considered as transfer rows to transfer its cultivated area to one of its competing crops. Thus, the level of sugar beet activity in the optimal solution is zero.

It is worth mentioning that social (shadow price) costs of irrigation water were considered separately in the objective function. Social costs of production for each crop were derived from PAM at the basin level excluding social cost of irrigation water.

Four different interest rates were assumed in PAM resulting in four irrigation water costs. However, the basin models were solved considering the 6% interest rate resulting in irrigation water cost of 307 Rials per cubic meter. Moreover, with each irrigation efficiency level considered, water price was changed to determine the price at which net social profit became zero. This is the maximum water price which can be charged at the basin level.

Irrigation water requirements, irrigation water used (the ratio of actual to potential crop yield), current crop yield in the sample and actual crop yield are shown in Table 13. As indicated, the ratios of actual to potential yield for wheat, barley, tomato, onion and potato are 0.88, 0.94, 0.09, 0.70, 0.86 and 0.90 respectively. According to Table 13, irrigation water requirements for optimal cropping patterns are less than the irrigation water used in the existing representative farms, given the level of deficit irrigation selected. The percentage change relative to existing irrigation water used are respectively 10.0, -2.096, -10.8, 16.039 and 16.8 for wheat, barley, tomato, onion and potato respectively. As irrigation efficiency increases the gap between optimal and actual water use is bound to increase. For example, with an irrigation efficiency of 65%, water requirements of optimal cropping patterns are respectively 34, 25, 14 and 42% less than actual water use for barley, tomato, potato and onion.

6.4. Optimal Cropping Patterns at the Basin Level

As indicated before, determination of optimal cropping patterns at the basin level were based on deficit irrigation at the crops' various growing stages with the aim of maximizing net social instead of private benefits. This is because when facing water shortages, deficit irrigation is a logical action to be taken. Moreover, farm data indicated that many farmers with scarce water relative to land base their irrigation strategy on deficit irrigation. In economic terms this means that they make joint land and water use decisions for economic purposes based in part on irrigation water availability and reliability. This strategy is also based in part on farmers' subjective probability of rainfall distribution in the region and possibilities of transferring irrigation water from one crop's growing stage to a competing crop. Rainfall distribution-based irrigation strategy is applied to wheat and barley. While intra-season irrigation water allocation among crops are more practiced in sugar beet and tomato crops.

Constructing a model for implementing deficit irrigation requires data about potential crops yield and their water requirements at various growing stages. Estimation of potential crops yield is based on farmers' experience in the last 20 years and the advice of agricultural researchers in the region. Also, the lengths of each sample crop's growing stage is determined in consultation with the scientists in the Agronomy department of Ferdowsi University in Mashhad.

By examining the 20-year trend of cultivated area of sample crops in the province it is evident that the variation in cultivated areas of these crops in not significant.

As shown in Table 13, the means of deficit irrigation estimated for sugar beet and barley are 20185 and 6040 cubic meters per hectare respectively. Minimum irrigation water requirements calculated for these crops are 17018 and 4708 cubic meters respectively. Accordingly, the range of water requirements per hectare of sugar beet and barley is less than other crops considered in this study. Comparison of water use estimates in deficit irrigations and actual applied water indicate that in the case of wheat and onion, the actual amounts of water used are respectively 10 and 16% more than model estimates. Corresponding figures for barley, sugar beet, tomato and potato are respectively, 2.95, 23.55, 10.86 and 16.39% less than model estimates. Considering crop combination, average irrigation water requirements per hectare in deficit irrigation (model estimate) is 90% more than actual water used in existing farms.

Comparison of actual and estimated crop yields shows that, in the case of wheat, sugar beet, onion and potato, actual (current) yields are respectively 2.5, 5.4, 2.4 and 11.9% less than estimated yields. However, in the case of barley and tomato, current yields are respectively 1.2 and 38.3% more than actual yields estimated. Based on the results shown in Table 13, water application efficiency varies in sample crops and overall efficiency in the whole sample appears to be greater than 35%. This implies that the level of deficit irrigation practiced by farmers in the region is likely to be a bit higher than the level considered in the model. Despite the implied discrepancy, findings at the assumed 35% water application efficiency appear to be very close to the actual situation at the farm level. Accordingly, the approach used in this study can be considered as a practical method for estimating irrigation efficiency at the farm level. It simply involves estimating irrigation water requirements at various levels of irrigation efficiency and crop water stress and resulting crop yields first and then comparing the results with existing water use patterns at the farm level. As indicated, a 9% difference between the irrigation water used in the representative farms and the model appears to be a good indicator of the usefulness of this approach.

Basin model results at three irrigation efficiency levels and water supply certainty are shown in Tables 14, 15 and 16. Results are based on the omission of sugar beet and its substitution by crops with similar growing season.

As shown in Table 14, wheat and barley acreage in the optimal cropping patterns (model result) has declined by 100 and 61% respectively relative to the existing cropping pattern. On the other hand, areas grown with tomato, potato and onion have respectively increased by 44, 358 and 6054 % relative to the actual cropping patterns. According to the results of the table above, net social profits per hectare of optimal cropping patterns is 228% more than the existing one, increasing from 2512000 Rials to 8444260 Rials per hectare assuming irrigation efficiency to be 65%. Also, the irrigation water requirement for the optimal cropping pattern is about 6% less than the existing one. Returns per unit of irrigation water increase from 218 Rial in the existing cropping patterns to about 760 Rials in the optimal cropping patterns. Optimal cropping patterns assuming hydrological certainty and irrigation efficiency of 45% is shown in Table 15. Compared to the results obtained at 65% irrigation efficiency, wheat is not included in the optimal plan. However, the level and stages of deficit irrigation — or the irrigation strategy — for potato and tomato as well as the crop combination have changed as a result of declining irrigation efficiency from 65 to 45%. Water requirements of barley, potato and onion in the optimal plan decrease by approximately 4.4, 19, and 17% respectively relative to the existing cropping pattern while cultivated area remains unchanged. By reducing irrigation efficiency, the level of deficit irrigation (or water application) changes for some crop activities.

Net social profit per hectare at 45% irrigation efficiency has increased from 2572000 Rials in existing cropping patterns to 6649900 Rials in optimal plan. Accordingly, net returns to irrigation water have increased from 218 to 464.4 Rials per cubic meter. Irrigation water requirements per hectare has increased from 11797 cubic meters in the existing cropping pattern to 14818 cubic meters per hectare in the optimal cropping plan (about 21%).

It is to be noted that, with the exception of tomato, water requirements of other crop activities have declined. This shows that, decreasing water use in a given crop does not necessarily lead to decreasing water use in the farm as a whole.

The effects of irrigation efficiency on irrigation strategy are shown in Table 17. As indicated, in the case of barley, tomato, potato and onion, maximum water stress occurs in crop growing stages 5, 1, 1 and 5 respectively at the 65% irrigation efficiency but, remains unchanged in other crops.

Optimal cropping patterns at 35% irrigation efficiency and hydrological certainty are shown in Tables 18 and 19. In contrast to the 45 and 65% efficiency levels, wheat appears in the optimal cropping plan, while potato is omitted. As in the previous cases, the level of deficit irrigation for tomato, barley and onion has remained unchanged. Maximum water stress in wheat, barley, tomato and onion occur at growing stages 4, 5, 2 and 5 respectively.

On the other hand, maximum water stress in tomato occurs at its second growth stage instead of its first which is also observed in the case of efficiency levels 45 and 65%. As expected, water requirement at 35% irrigation efficiency differs from 45 and 65% efficiency levels. Percentage changes relative to the existing plan are -12.67 for wheat. For barley, tomato and onion they are +22.86, +18.91 and +6.44 respectively. Net social profit per hectare in the optimal cropping patterns has increased relative to the existing plan from 2572000 Rials to 4724600 Rials (by 84%).

It is worth mentioning that the changing social profits of optimal cropping patterns at all levels of irrigation efficiency are due to both the yield and acreages of crop activities selected.

Returns to irrigation water in this case have increased to 330 Rials per cubic meter, which is less than the 45 and 65% irrigation efficiency levels, but is about 130 Rials more than the existing situation. On the other hand, irrigation water requirements per hectare of optimal cropping pattern have increased from 11797 cubic meters to 14304 cubic meters relative to the existing cropping pattern.

Optimal Cropping Patterns at Basin Level Assuming Water Supply Uncertainty

By considering water supply uncertainty, the gap between optimal and actual cropping patterns is likely to decrease. Yet as expected, none of the optimal plans require more irrigation water than what is actually used in the representative farms of the basin considered.

Results of the basin model assuming various degrees of irrigation water supply reliability at 65% irrigation efficiency are shown in Table 18. It is evident that optimal cropping varies with the level of water supply risk. At 95% water supply reliability, wheat acreage remains the same but, barley, potato and onion acreages change by -0.1, -100 and +605.3% respectively relative to the existing acreages of sample crops. Tomato appears with two levels of water stress, increasing by about 12% in acreage relative to the existing cropping patterns. Likewise, at 80% irrigation water supply reliability, potato appears in two levels of water stress. With deficit irrigation number 19, potato area decreases by about 25% but, with deficit irrigation number 35 the area grown increases by about 282 % relative to the existing cropping patterns.

As shown in Table 20, increased water supply reliability (reduction of risk) can raise the probability of higher economic returns to irrigation water resulting in more economic use of water in irrigated farming.

Results of the analysis shown in Table 18 indicate that increased water application efficiency can raise social profitability and productivity of irrigation water by substituting lower value crops, such as wheat and sugar beet, by higher value crops such as tomato and onion. Obviously, economic feasibility of raising irrigation efficiency depends on both returns to and cost of irrigation water technology. As shown in the table above, when irrigation efficiency is reduced to 35%, returns to irrigation water are not significantly different from returns in the existing pattern of water use in the basin. Effects of irrigation water supply uncertainty on irrigation strategy in sample crops are shown in Tables 21 and 22.

Evaluation of Optimal Cropping (water-use) Patterns at the Basin Level

Observation of alternative irrigation strategies and optimal cropping patterns derived from mathematical programming models indicate that the range of crop water stress is somewhat limited. Also, in some cropping patterns more than one level of deficit irrigation are observed for some growing stages of crops. This requires some explanation. Based on economic theory, there are two basic water allocation problems at the farm level: seasonal and intra seasonal. Optimal seasonal allocation of irrigation water for each crop is achieved by equating the marginal value of water with its marginal cost. Since timing of irrigation is as (or more) important as the level of irrigation for optimal allocation of water in the various growing stages of each crop, a dated production function (crop-water response function) is needed. Given a dated production function, limited water is allocated to various growing stages of crops in such a way that equates marginal values of irrigation in all growing stages. Application of this rule in the case of a single crop farming system presents no problem. However, in the case of a multiple-crop farming system, which is dominant in the region, various crops grown by farmers have different and/ or overlapping growing seasons. In these cases, farmers, based on their expectation of the effects of irrigation on the farm level rather than on each individual crop's profitability, allocate less (more) water to some crop's growing stages. Obviously, this is an economic decision which can result in maximum farm profit if reduced profit due to reduction of water used in one crop growing stage equals the increased profit resulting from additional water used in another crop's growing stage. For example, when irrigated wheat in the region is in its last growing stage, sugar beet and tomato are grown. According to the above rule, the expected marginal return to irrigation water in the shoot stage of sugar beet or tomato should be equal to the expected marginal return of irrigation water in the mature stage of wheat. Moreover, it is worth mentioning that in each crop's growing stage, the diminishing returns principle applies. That is, the first units of irrigation water applied result in higher returns than the latter units.

Analysis of cropping patterns at the basin level reveal that the maximum social profit are obtained when irrigation efficiency at the farm level is high and water supply uncertainty is not present. Lower irrigation efficiency and higher water supply risk result in lower net social profits. When irrigation efficiency is low, net social profits are more influenced by the environment. For example, irrigation efficiency of 35% and water supply reliability of 80% represent a drought condition in the region. In a region with periodic draught, low irrigation efficiency and poor irrigation management exacerbate the negative impact of drought on farm income.

The above findings were based on an irrigation water price of 307.3 Rials per cubic meter and an interest rate of 6%. For a given water price, interest rate affects net social profit, leaving cropping patterns unchanged.

Pricing Irrigation Water

In the absence of a water market, water resources are allocated by governmental and local institutions. Increasing irrigation water shortage in the region has prompted the government to place renewed emphasis on demand management through pricing structures and non-pricing measures. In this region, water price is mainly used as an instrument for enhancing irrigation efficiency at the farm level. In Table 23, the relation between irrigation efficiency and water prices at which net social profits per hectare becomes zero is presented. The term efficiency here indicates the percentage of applied water effectively used by crops. Prices shown in Table 23 are the maximum prices which can be charged for irrigation water. Higher prices result in negative social profits.

Results of Table 23 indicate that for producing 4377 kilogram of irrigated wheat per hectare, assuming a deficit irrigation number 14 and equal water stress in all growing stages, water requirements per hectare amount to respectively 6759, 5257 and 3639 cubic meters per hectare with irrigation efficiencies of 35, 45 and 65% respectively. As shown in Table 23, when irrigation efficiency is low, the possibility for increasing water price is limited compared to high irrigation efficiency, Therefore, when raising water prices is in the agenda, it is important to consider both the farm level irrigation efficiency and net social profits. According to the law of demand, increasing the price of water results in decreased demand, the magnitude of which depends on the elasticity of demand. One of the objectives of irrigation water pricing is reducing water use at the farm level. The result of price increase is moving along the production curve, increasing marginal and average productivities of irrigation water and decreasing water input and crop output. Based on the definition of irrigation efficiency used here, we can define a production function for each level of irrigation efficiency in contrast to the conventional definition of production function. If we can derive a production function at 100% efficiency; it is also possible to derive a production function at the 35% efficiency. Hence, it is reasonable to first group various farmers according to their efficiency of water application and estimate a production function for each group and then study the impact of the water pricing policy relative to the functions estimated. In this study, wheat crop water response functions were estimated assuming that other inputs remain fixed. The estimated functions at three levels of irrigation efficiency are as follows:

$y_1 = (\text{water requirements at 35\% efficiency})^{1.26}$

$y_2 = (\text{water requirements at 45\% efficiency})^{1.32}$

$y_3 = (\text{water requirements at 65\% efficiency})^{1.39}$

The above coefficients are production elasticities. As seen, higher irrigation efficiency results in higher production elasticity. Wheat yield is the same but water requirements vary with irrigation efficiency. Hence, it can be concluded that, increasing the price of water results in increased marginal and average productivity of irrigation without raising irrigation efficiency, which was the main aim. Hence, water pricing is not a sufficient measure for increasing water-use efficiency at the farm level, and at best it could lead to increased irrigation water productivity. Given the low level of technical irrigation efficiency, irrigation water pricing along with non-pricing measures should aim at reducing water use and leaving saved water unused at the farm level.

6.5. Analysis of Farmer's Response to Selected Water Reform Policies

Policy analysis was mainly undertaken using positive mathematical programming (PMP) technique. Scenarios considered are:

Scenario Number	Measure
1	20% increase in water price along with 10% decrease in water supply
2	60% increase in water price along with 10% decrease in water supply
3	40% increase in water price along with 10% decrease in water supply
4	100% increase in water price along with 10% decrease in water supply
5-8	Similar to above scenarios but along with 20% decrease in water supply
9	80% increase in water price along with 50% decrease in water supply (drought condition)
10	20% increase in water price along with 10% decrease in water supply in Mashad, the largest plain in Harir-rud & Kashafrud Basin
11	Liberalization of fertilizer market (eliminating fertilizer subsidy) along with 10% decrease in water supply
12	Liberalization of the sugar beet market along with 10% decrease in water supply

Positive mathematical programming technique is used to determine the effects of selected policies on the use of inputs, cropping and water-use patterns. This method can be used at both the regional and sectoral levels. Also, it can show the reaction of individual farmers to the selected policies. As indicated before, the CES (constant elasticity of substitution) production function and the quadratic cost function were used in the objective function of the PMP model. Elasticity values were exogenously determined (assigning values between 0.19 and 0.99 and greater than 1.0). In this section, the effects of selected policies on the use of irrigation water, cropping patterns (water and land allocation), and private and social profits at plain level are discussed. For the purpose of policy impact analysis, the three plains were considered separately since farmers' reactions to selected policies may vary depending on the location studied. Results of the analysis are shown in Tables 24 and 25. As seen, in scenarios 1 to 4, by increasing the price of irrigation water, net profit continues to decline from 1221300 Rials in scenario 1 to about 542830 Rials per Ha in scenario 4. Using social prices for inputs and outputs in the policy analysis matrix and increasing water price in scenarios 1 to 4 results in the reduction of net social profit per hectare from 323320 Rials in scenario 1 to about 291160 Rials in scenario 4. Increasing the price of irrigation water does not change cropping patterns in favor of more profitable crops combination. In scenarios 5 to 8 water supplies decrease by about 2295 cubic meters per hectare.

In these scenarios, increasing irrigation water price results in greater reduction in private profits than former scenarios. Also, net social profits per hectare decline from 638750 Rials in scenario 5 to 594390 Rials in scenario 8. In scenarios 1 to 4, the percentage of decline in water supply is less than the percentage of increase in water price. Moreover, results of alternative policy options indicate that farmers are likely to respond to increasing input (water) prices by changing their cropping pattern. Increasing the price of irrigation water does not necessarily result in decreasing the demand for water at the farm level. In other words, farmers react to changing water price by reallocating irrigation water among cropping activities.

Scenario 9 represents drought conditions. In this scenario, irrigation water supply is reduced to 5738 cubic meters per hectare. As a result, net private profit per hectare declines to 1361263 Rials but net social profits increases by 552208 Rials per hectare. While this finding does not appear logical, it can be justified on some grounds. As was indicated in PAM, under conditions of market failure and distorting policy farmers' cropping patterns include crops such as sugar beet which may lack comparative advantage. When drought conditions prevail, the production of these crops is bound to fall, resulting in reduced social cost or increased social benefits. As shown in Table 24, the acreages of sugar beet (a comparatively disadvantaged crop) decrease by about 19 and 62% respectively in Mashhad and Sangbast plains. Obviously, decreasing production of sugar beet results in some loss for the society as a whole (national loss). However, falling production of sugar beet results in less use of inputs, and hence reduced farm subsidy (especially water subsidy) which is beneficial to society. Hence, considering the social costs and benefits of crop output reduction in drought periods may not reduce social benefits of farming significantly.

In scenario 10, only Mashad plain is considered. This scenario consists of a 10% reduction in water supply and a 20 % increase in water price. As shown in Table 24, implementing this scenario is likely to result in 266703 Rials reduction in private profits per hectare and about 500900 Rials increase in social profits per hectare. Sugar beet acreage, which is a major crop in the farmers' cropping patterns (but socially infeasible), decreases by 5% and water use per hectare in both cultivars of sugar beet declines by 20%.

Scenarios 11 and 12 relate to the liberalization of both fertilizers and sugar beet markets along with a 10 % reduction in irrigation water supply. Both policy scenarios are expected to result in the reduction of private profits and an increase in social profits. Moreover, by liberalizing the sugar beet (and sugar) market, the loss incurred by the private sector is likely to outweigh the social gain. The effects of the two policy measures on cropping (water use) patterns are different. As expected, farmers react differently to product and input price policies. Based on the results of this analysis, the effects of decreasing product price on its production appear to be greater than the effects of increased input price. Hence, in the case of water reforms, careful definition of policy objectives appears to be highly important.

6.6. Agricultural Trade Patterns

Agricultural imports and exports of Iran in the last decade (1995-2004) are shown in Tables 26 and 27 respectively. As observed, Iran's major agricultural imports include wheat, barley, rice, maize and sugar. Total cereal imports have declined during the last decade from 6383000 tons in 1995 to 3972153 tons in 2004. However, during the same period imports of barley, soybeans, banana and maize have increased while imports of wheat, rice and sugar beet have decreased. Declining imports of these commodities is the result of the government's self sufficiency policy in the case of the so called strategic crops. It is worth mentioning that rice, sugar beet and sugar cane are water-intensive crops, the increased production of which applies heavy pressure on the country's scarce water resources. Considering exports of agricultural commodities during the same period indicates that agricultural production and trade patterns are changing in favor of water-intensive crops which appears unsustainable from water resources point of view.

Major agricultural exports of Iran include nuts (notably pistachio) raisin, dates, organic materials such as melon, water melon, cucumber, apples and tomato paste. Agricultural exports during the last decade have fluctuated between 0.7 and 1.26 million tons.

Iran enjoys considerable potential comparative advantage in the production of various agricultural products such as pistachios, almonds, walnuts, figs, saffron, garlic, dates, grapes and many horticultural crops. These corps are less water demanding than many of the imported commodities shown in Table 26. Moreover, they produce higher income per hectare than many other commodities produced. Hence, production and export of these crops earn higher returns per unit of scarce water and should be considered for optimizing agricultural trade patterns, since adopting such trade patterns is consistent with the country's water endowments.

As indicated in Table 28, production of wheat as well as the total food production index since the Islamic revolution (1979) has increased considerably.

In general, agricultural production and trade patterns of Iran are hardly consistent with the notion of comparative advantage, but are rather designed to fill the domestic gap of food supply and maintain social stability. In other words, it is mainly the imperative (preventing food price rise) rather than comparative advantage that drives agricultural production and trade patterns in Iran. Increasing oil revenue as a result of the increase in its price has enabled the government to pursue such a lavish import policy in recent years.

A relevant aspect of the agricultural trade pattern is its effects on the net virtual water import to the country. Table 29, shows the effects of agricultural external trade patterns on the net virtual water import of Iran, from 1995 to 2004. Based on the net annual import of agricultural commodities including sugar imports, virtual water imports in the two 5 year periods amount to 5.82 and 5.5 billion cubic meters per annum respectively. This indicates that the net virtual water imports of Iran have declined due to changing agricultural production and trade patterns.

As indicated above, cereal and sugar imports during the period 2000-2004 have declined relative to 1995-1999 period. Some indicators of virtual water relative to agricultural trade patterns in Iran are shown in Table 30.

6.7. Optimization of Agricultural Trade Patterns

Considering water as an economic good, its efficient use can be viewed on three levels: local, basin and international levels. Water use efficiency at the local (farm and household) level can be raised through pricing policy, water saving technology and other demand management measures. At the basin level, the value of water in alternative uses is involved and is more affected by macro-policies. At the global level, water use efficiency can be increased through virtual water trade between water abundant and water stressed regions. It is expected that, with external commodity trade, regions (countries) may specialize in producing commodities for which they are specially adapted and may trade the surpluses of these commodities for imported commodities.

As indicated before, agricultural (virtual water) trade can be simulated by applying mathematical programming models. The approach used in this study is aimed at enhancing water- use efficiency by directing cropping patterns to maximize net virtual import. A programming model is applied for optimizing cropping patterns at the basin level considering virtual water trade, the comparative advantage of the basin for producing crops, and the basin's water resources potential for producing farm products.

6.8. Methodology

Cropping patterns, in which net virtual water use is optimized, are determined using a combination of basin model and nearly optimal programming techniques. This is implemented by changing the level of imported and exported products aimed at maximizing social profits. In estimating virtual water, it is important to distinguish between the quantity of irrigation water applied and the amount of water consumed by a crop. Virtual water is the amount of water embedded in the crops produced irrespective of the efficiency with which it was applied. Obviously, as irrigation efficiency (water application efficiency) increases, the gap between the two quantities declines.

In addition to the above considerations in the construction of the basin model, social (real) rather than market prices were used for factors and products. In other words, the model was implemented in the absence of market failure and government distorting policy. Moreover, sample crops were subjected to various degrees of water stress in their growth stages and net virtual water was considered as an additional source of irrigation water in the region. The structure of original basin model is as follows:

$$Max: \qquad NSB = \sum_{c=1}^{n} \sum_{d=1}^{m} [\ ya_{cd}(sp_c - sc_c) - w_{cd} \times pw) x_{cd}$$

Subject to
$$\sum_{c=1}^{n} \sum_{d=1}^{m} x_{cd} = \bar{X}$$

$$\sum_{d=1}^{m} x_{cd} \le \bar{X}_C \qquad \forall_c$$

$$\sum_{c=1}^{n} \sum_{d=1}^{m} w_{cd} x_{cd} \le \bar{w} + NVWI - Z_a \sigma_w$$

$$x_{cd} \ge 0$$

Where: NSB is the net social benefits from all crops considered, ya_{cd} is actual yield per hectare of crop c with deficit irrigation d. sp_c is the unit social (shadow) price of crop c in the region, sc_c is the social cost of production per unit of crop c in the region excluding the cost of irrigation water. x_{cd} is the level of activity c with deficit irrigation d. $\overline{x}$ = total cropped area. $\overline{x}_c$ = maximum acreage of crop c, w_{cd}= water requirement of crop c in the region, calculated assuming various water stress and irrigation efficiency levels at various growth stages of the crop. NVWI = net virtual water import per hectare in the year studied (shown in Table 30). Irrigation water constraint is considered as a random (stochastic) variable in the framework of chance constant programming developed by Charnes and Cooper (1959).

$\overline{W}$ = average irrigation water supply calculated per hectare. Value of z_a is estimated assuming normal distribution.

Maximum cropped area was assumed to be equal to the existing crop area in the sample on 1 hectare basis. For each crop in the model, 45 activities were used according to the number of deficit irrigation considered. Due to the random nature of irrigation water supply, the level of risk in water supply was set at 80, 85, 87.5 and 95% for z_a in the model. Estimating water supply per hectare was based on the average irrigation water at 35% irrigation efficiency for sample crops plus net virtual water imports per hectare. The amount of water supply, which is bound to decline as uncertainty (risk) increases the social cost of production per kg of crops, was determined by PAM, from which the cost of water supply was deducted.

Modification of the Basin Model

After solving Model 1, the objective functions were added to the constraint of the model in order to provide for the maximum (optimal) use of virtual water. Then, the new model was solved for minimizing the production of imported crops (wheat and barley separately and jointly: objectives 1 to 3) and exported crops (tomato, potato and onion: objective 4) and determining cropping patterns to maximize social benefits and the use of net virtual water import. Accordingly, the modified model is writhen as follows[3]:

Minimize

$$\sum_{d}^{m} x_{wheat,d} \tag{1}$$

$$\sum_{d}^{m} x_{barely,d} \tag{2}$$

$$\sum_{d}^{m} x_{wheat,d} + \sum_{d}^{m} x_{barely,d} \tag{3}$$

$$\sum_{d}^{m} x_{potato,d} + \sum_{d}^{m} x_{tomato,d} + \sum_{d}^{m} x_{onion,d} \tag{4}$$

Subject: $$\left(\sum_{c=1}^{n} \sum_{d=1}^{m} [ya_{cd}(sp_c - sc_c) - w_{cd} * pw] * x_{cd}\right) \geq (1 - .03) * NSB$$

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[3] - In the new constraint, the optimum solution of the original model was reduced by 3 %.

$$\sum_{c}^{n}\sum_{d=1}^{m} x_{cd} = \overline{x}$$

$$\sum_{d}^{m} x_{cd} \le \overline{x}_c \qquad \forall c$$

$$\sum_{c}^{n}\sum_{d}^{m} w_{cd} x_{cd} \le \overline{w} + NVWI - Z_a \sigma_w$$

$$x_{cd} \ge 0$$

7. Results and Discussion

Irrigation water requirements and values per ton of exported and imported crops at the three levels of irrigation efficiency considered are shown in Table 31. As shown, the price (cost) of irrigation water used in producing one ton of exported and imported crops is different. As expected, the social cost of producing crops increases with decreasing irrigation efficiency. Moreover, water requirements for producing one ton of exported crops is lower than imported crops. Considering border prices for the sample crops, returns per cubic meter of irrigation water used are shown in the last row of Table 31. Estimated returns show the relative advantages of sample crops in external trade. Optimal cropping patterns at the basin level, with and without virtual water, at different levels of irrigation water supply reliability and an irrigation efficiency of 65% are shown in Table 32. Comparing alternative cropping patterns indicates that both the amount of irrigation water used and social benefits have increased with virtual water at all water supply uncertainty levels considered. However, the amount of irrigation water used in the virtual water case is less than the available water supply. This shows that in the case of water supply uncertainty reflecting the real situation, virtual water is in fact added virtually.

Observing changing patterns of output produced indicates that in many cases the optimal cropping patterns with virtual water added in the model are advantageous relative to the reference cropping pattern.

Optimal cropping patterns at 45% irrigation efficiency are shown in Table 33. As indicated, social profits and irrigation water used with and without virtual water are different. By considering virtual water in the model, social profits and irrigation water requirements have increased. However, irrigation water used is still less than water supply. By minimizing barley production as an import crop, the model has a solution only with the 80% water supply reliability. In this case, the production of wheat, tomato and potato increases by 838, 1172 and 943 kilograms respectively and the production of barley decreases by 1487 kilogram.

By minimizing the production of both wheat and barley, the model has a solution with the 80 % irrigation water supply reliability. As shown in Table 33a, in this case, barley and onion production decreases by 942 and 604 kilogram respectively but tomato and potato production increases by 50 and 2626 kilogram respectively. With respect to virtual water use, the optimal cropping pattern is not in a better position than the reference one. However, the minimization of export crops production (onion, potato and tomato), results in a more efficient cropping pattern than the reference cropping pattern relative to the use of virtual water (see Table 33b).

Assuming an irrigation efficiency of 35%, the model was solved resulting in an increase in social profit and irrigation water-use efficiency when virtual water was included, relative to the case when virtual water was omitted. Results are shown in Table 34. As indicated, by including virtual water in the model, optimal cropping patterns at different levels of water supply reliability results in increased social profits and irrigation water use compared to the reference model. In addition, resulting changes in the production of sample crops indicates that in more cases, cropping patterns with virtual water are preferred to the reference cropping patterns. In some cases however, it is not possible to make a definite conclusion (see Table 34a).

In summary, the findings showed that it is possible to direct optimal cropping patterns at the basin level to maximize social profit, water-use efficiency and net virtual water import simultaneously. However, in order to derive a definite conclusion, more data about the quantity of water embedded in each crop exported from and imported to each country is needed. Moreover, it is necessary to design a suitable export-import plan to be used as a target for directing cropping patterns. The approach used in this study can be considered as a first step in this direction.

8. Conclusion and Policy Recommendations

This study has focused on the optimization of cropping and water-use patterns, and the external trade of farm products. Towards this end, the comparative advantages of some principal crops in a major agricultural region of Iran were determined using Policy Analysis Matrix (PAM). Comparative advantages were analyzed at three levels, basin, basin versus farm-size, and plain. Due to the importance of irrigation water, a new approach was used to determine its social (real) price, considering the external cost of over-exploitation of provincial water resources. After determining the comparative advantage of sample crops, cropping patterns for representative farms were modeled using various mathematical programming methods for optimizing land and water allocation, and external trade of farm products aimed at maximizing net virtual water import.

The findings showed that the production of a given crop may or may not have comparative advantage, depending on the level of analysis. PAM results revealed that sugar beet does not have a comparative advantage in all levels of analysis irrespective of the cultivar grown. This finding supports the prevailing concern in the region regarding the adverse effects of growing sugar beet on the sustainability of groundwater resources in the province.

PAM analysis at the basin level in relation to farm size showed that social profits of large farms are more than those of medium and small farms. However, based on the existing cropping patterns, medium-sized farms earn more social profits compared to small and large farms. This implies that in the presence of distorting policies and market failure, farmers' cropping patterns have a social loss (cost) portion which affects the social profitability of the cropping patterns adopted. Although supporting large farms appears to be a rational policy because of their lower costs, cropping patterns seem to be more important than farm size from the social point of view.

Results of mathematical programming models revealed that these models are capable of optimizing some objectives and reallocating resources accordingly. However, accepting the solution provided by a specific model largely depends on the nature of data used in these models. When reliable farm level data is not available, or optimization is studied under conditions of market failure and distorting policies, programming models do not result in the reallocation of resources to maximize social benefits.

Optimal cropping patterns resulting from the utility efficient programming model have positive social profits, which may be more (or less) than the currently prevailing (existing) cropping patterns. The findings reveal that when the required data is available, nearly optimum linear programming solutions lead to maximum social profit, and also that in the presence of distorting policies and market failure, private and social profits are in conflict. Thus, a reduction in private profit would increase social profit and vice versa. Hence, when applying mathematical programming models for maximizing the social productivity of resources, social (real) rather than market prices should be used.

Since irrigation water is one of the limitations to agricultural production in the region, water stresses in each crop's growing stages were considered to assess the most efficient use of irrigation water. Accordingly, 45 activities are considered for each crop. Crop yield and irrigation water requirement resulting from various water stress levels at three levels of irrigation efficiency (35, 45 and 65%) are used as basic data in the basin model.

Moreover, in constructing the basin model social prices and costs per kilogram of sample corps output, and social cost per cubic meter of irrigation water are used instead of market prices. The plain model is also solved with and without uncertainty in irrigation water, and with and without including sugar beet, because of it being a main crop that does not enjoy a comparative advantage throughout the region. The findings show that in the multiple cropping systems, farmers tend to reallocate irrigation water among various crops' growing stages based on expected relative effects of irrigation on total farm profits rather than the individual crop's profit. This is an economic decision and results in maximum farm profit only if the reduction of farm profit due to cutting irrigation water from one crop equals to the increase in farm profit resulting from administering the saved water to competing crops.

A review of optimal cropping patterns at the basin level shows that social profits are greatest when farm irrigation efficiency is high (65%) and water supply is reliable (95%). When irrigation efficiency is low (35 %) and irrigation water supply is uncertain (80%), social profits are influenced by the environment.

Low irrigation efficiency and high water supply uncertainty represent the actual conditions in the region. The problem of hydrological uncertainty and its impact on agricultural production, cropping patterns and irrigation water-use efficiency in the region calls for further research.

The irrigation water price at which social profit is zero is estimated by varying irrigation efficiency and assuming the water supply to be certain. Findings show that with higher irrigation efficiency, the possibility of raising water charges to recover costs is greater than at lower irrigation efficiency. In addition, increasing the irrigation water price leads to increased marginal and average water productivities without raising water- use efficiency. Therefore, in irrigation water pricing, both farm irrigation efficiency (technical) and its effects on social profits should be considered.

An approach for estimating farmers' irrigation efficiency is to estimate crop yield and water requirements considering various levels of deficit irrigation (water stress) for each crop first and then comparing the resulting estimates with the actual water used at farm level. The insignificant difference between the irrigation water applied by the sample farmers and model results (9%) is a good indicator for the usefulness of this approach.

Positive mathematical programming techniques were used to determine the effects of some water reform policies on cropping and water-use patterns. Twelve policy scenarios were considered, in 8 of which, irrigation water prices were increased by 20, 40, 60 and 100% along with a 10 and 20% reduction in water supply. One scenario reflected drought conditions. Other policy scenarios included: liberalization of chemical fertilizers and the sugar markets along with a 10% reduction in water supply: a 20% increase in water price along with a 10% reduction in irrigation water supply in Mashad plain. The results of the policy impact study indicate that farmers' responses to the selected water policy reforms depend on the effects of those policies on farm profit. In other words, they respond to price and non-price measures by changing cropping patterns without reducing their total irrigation water. An implication of such water use behavior is that when farmers' objective is to maximize farm profits, irrigation water pricing aimed at reducing water-use at farm level is not an appropriate policy. However, if it is aimed at recovering water supply costs and reducing subsidy, then it may become successful. The findings also indicate that all of the policy options considered are expected to reduce private profits and increase social profits. In addition, results indicate that farmers respond differently to policies aimed at products and inputs. If water policy reform is aimed at reducing the land area allocated to a crop, a product price policy is more appropriate than an input (water) policy. For example, for reducing sugar beet acreage, sugar beet price reduction is likely to be more effective than increasing the price of chemical fertilizers or the price of irrigation water.

In addition, results show that it is possible to increase social profits per hectare by considering sugar beet in the cropping plan. This may be achieved by subjecting the crop to higher degrees of water stress (deficient irrigation), increasing irrigation efficiency from 45%, and reducing water supply risk.

To optimize agricultural trade patterns, the basin model is used along with nearly optimum linear programming. Border prices for import and export crops are used to determine returns per cubic meter of virtual water and the relative advantages of sample crops in external trade.

Based on agricultural trade statistics, the current net virtual water import to Iran is about 5.8 billion cubic meters per annum. However, a new government policy is aimed at expanding domestic production of cereals and sugar beet, which are water intensive products. Hence, changing agricultural trade patterns is likely to result in the reduction of net virtual water import. A further expansion in the production of water-intensive farm products is expected to turn the country from a net importer to a net exporter of virtual water. The findings show that it is possible to direct optimal cropping patterns at the basin level to maximize social profits, water-use efficiency and net virtual water imports simultaneously. However, in order to come to a definite conclusion, more data is needed about the quantity of virtual water imported and exported. Moreover, it is necessary to design a suitable export-import plan to be used as a platform for directing cropping patterns.

Policy Recommendations

Based on the findings of this study, the following policy recommendation can be made:

1. Low water-use efficiency in the region is the result of a number of different factors. The nature and relative impacts of these factors are yet to be investigated thoroughly. Hence, a comprehensive study of the problem and relative impacts of factors affecting irrigation water-use efficiency is recommended. The results of such study can be used as a basis for policies designed for raising water-use efficiency at the farm level.
2. There is a considerable scope for improving water-use efficiency through improved irrigation technology and irrigation strategy. Since most farmers in the region appear to be risk averse, measures for reducing or managing production risk could encourage the adoption of an improved irrigation technology and a more socially profitable cropping and water-use pattern.
3. Since water is the most important factor limiting agricultural production, research and the extension of appropriate deficit irrigation (crop water stress) strategies to be adopted by farmers, particularly in crops lacking comparative advantage, are recommended.
4. According to the findings of this study, irrigation water pricing does not necessarily lead to improved water-use efficiency. Moreover, the existing technical irrigation efficiency determines the feasible range of water price change. Hence, in designing and implementing a water pricing policy, the aim of the policy, the irrigation

efficiency of farms, and the effects of the policy on the net profit of farmers must be determined. It is worth mentioning that a price policy is expected to be more effective in recovering the cost of water supply than in increasing water-use efficiency.

5. One way to control groundwater overdraft in the region is to limit the number of wells. Despite the urgent need for such controls, there are a number of unlicensed wells operating in many farms and the electrical energy supplied to the farmers is heavily subsidized. Hence, a gradual reduction of the energy subsidy should be considered in cases where groundwater overdraft continues to exceed the annual rechargeable capacity of wells. Alternatively, the number of kilowatt hours of electricity used could be limited.
6. This study estimates the economic loss resulting from negative externalities linked to groundwater exploitation and the role of subsidized energy on the sustainability of scarce water resources on a limited scale. Further research as an extension to this subject is recommended.
7. According to the findings of this study, supporting farm sizes is to be based on the effects of selected cropping patterns on the social profitability of various farm sizes. Therefore, a discriminating support policy, such as a discounted energy price for farmers earning higher social profits in the last cropping season, is recommended as an incentive for raising water-use efficiency.
8. Economic water-use efficiency depends, among other things, on two key factors: water application efficiency at the farm level and the reliability of water supplies. Hence, designing and implementing policies for encouraging the adoption of improved irrigation technologies and reducing water supply risk is recommended. Reducing the subsidy on complementary inputs — such as fertilizer price, providing the legal framework for irrigation water trade and providing incentives for forming a local water market are positive steps in this direction.
9. According to farmers and exporters interviewed, the supply management problem is partly responsible for the low water-use efficiency in the region. Hence, studying the efficiency of water supply firms can benefit both water suppliers and water users.
10. Demand management using price and non-price measures and policies encouraging and aiding changes in water-use and trade patterns of agricultural products should be an essential part of the region's water policy.
11. Many fruit and nut crops in Iran have high water efficiency; they require less water but give higher returns than grains such as wheat and rice. Hence, changing cropping patterns can facilitate virtual water trade and ease the pressure on water resources. However, the possible benefits of reduced pressure on the country's water resources should be compared with the possible adverse effects of farm product imports on the rural economy and food security when the country opts consciously for virtual water imports to alleviate its water problem.

9. Implications of the Study for the MENA Region

Most countries of the MENA region (with the exception of Turkey) face the same challenges with respect to water scarcity and there is an urgent need for increasing the efficiency of water-use in agriculture. Case studies in Syria, Iraq, Jordan and Egypt provide similar information regarding the inefficient patterns of water use in agriculture (ICARDA, 2001).

In most MENA countries, irrigation water pricing is based on financial rather than on efficiency considerations. In Egypt, farmers pay no direct charge for irrigation water but they are responsible for the maintenance of common irrigation water. In Jordan, the government policy favors equity over efficiency by charging farmers only 10 to 40% of the actual cost of irrigation water in the five projects considered (Hayward and Kumaar, 1994). Israeli farmers, in irrigating crops for human consumption (rather than animal consumption) show that investment in efficient irrigation technology pays for itself in the form of the water saved (Lant, 2004). Hence, in arid regions, confining irrigation to the highest value, perishable crops is the cornerstone of sustainable water resource management.

As for the agricultural (virtual water) trade, in 2000, Egypt — a highly water-stressed country— imported 8 million tons of grain from the US, thereby saving some 8.5 billion cubic meters of water. Israel and Jordan have formulated policies to reduce the export of water-intensive products. Exports are largely limited to crops that yield a relatively high income per unit of water consumed (Asha, 2004).

Hence, the application of the findings of this research project can be extended to many countries of the MENA region. Optimization of water-use and trade patterns have the potential to mitigate water shortages and reduce the adverse effects of salinity and water logging on the productivity of land, which are caused by inappropriate patterns of irrigation water-use in many countries of the region.

Implications of this study for the MENA region can be summarized as follows:

1. Two complimentary approaches for relieving pressure on the MENA region water resources are:
    A. Increasing the efficiency of water-use particularly in agriculture.
    B. Optimizing agriculture trade patterns.

    The need is first for raising water-use efficiency in the agricultural sector since inefficient use of irrigation water leads to low water productivity — even in crops that have a high water-use efficiency.
2. While the underlying foundation of agricultural trade is the notion of comparative advantage, in some water scarce countries of the region the motivation for importing food is hardly a pursuit of comparative advantage but it is an obligation to fill the domestic gap of food supply and to maintain social and political stability.
3. The economic implications of trade policies designed to maximize social returns to scarce water resources are many. Changing cropping patterns in favor of more profitable crops at the expense of water-intensive low value crops. In market economies, farmers are expected to change their cropping patterns when economy and water scarcity demand it. Moreover, increasing irrigation water prices (when feasible) is likely to provide an incentive for substituting high value cash crops for grains because of the higher marginal returns to water from cash crops.
4. MENA countries can design and implement policies to reduce export or local production of water-intensive crops and replace them by the production of higher value crops to allow for optimization of water use. These are conscious choices made to relieve pressure on their domestic water resources. The net effects of agricultural trade on their domestic water resources balance depends on the cropping or water use patterns prevalent in the agricultural sector.
5. Specifically, food deficient countries of the MENA region can benefit from agricultural trade by importing water-intensive commodities like cereal from exporting countries. Agricultural water saving through trade occurs if production of the exporter is more water efficient than that of the importer.
6. Water requirements per dollar of agricultural output produced in MENA countries can be used to determine the manner in which foreign trade can mitigate domestic water supply shortages.
7. The average trade price (dollar per cubic m.) of embedded water exported divided by the average trade price of embedded water imported determines the relative economic

advantage of a country's agricultural trade pattern. A rise in terms of water exchange means that the country may import a larger quantity of embedded water for each unit of embedded water exported.

8. Agricultural trade in the MENA region aimed at importing "virtual water" should be accompanied by the implementation of a conscious policy for raising water-use efficiency. As indicated, arid countries in the region should better limit their export of water-intensive crops and focus on the crops that generate higher returns per unit of water used. However, some countries do not have less water-intensive products to be exported in return. Fortunately, Iran can produce some high value crops like grapes, dates and vegetable crops which it can trade for some water intensive crops such as grains and sugar beets.
9. Trade reforms, along with institutional reform in the water sector (such as water pricing reforms and the improvement of water markets), have resulted in a shift in commodity trade and production patterns in a number of countries like Spain, China and Chili. The experiences of these countries indicate that the optimization of water use within a country calls for modifying water rights and water transfer policies to encourage the adoption of irrigation strategies and cropping patterns in which water generates higher value per unit of water used.

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Figure 1- The General Framework of Research Methodology

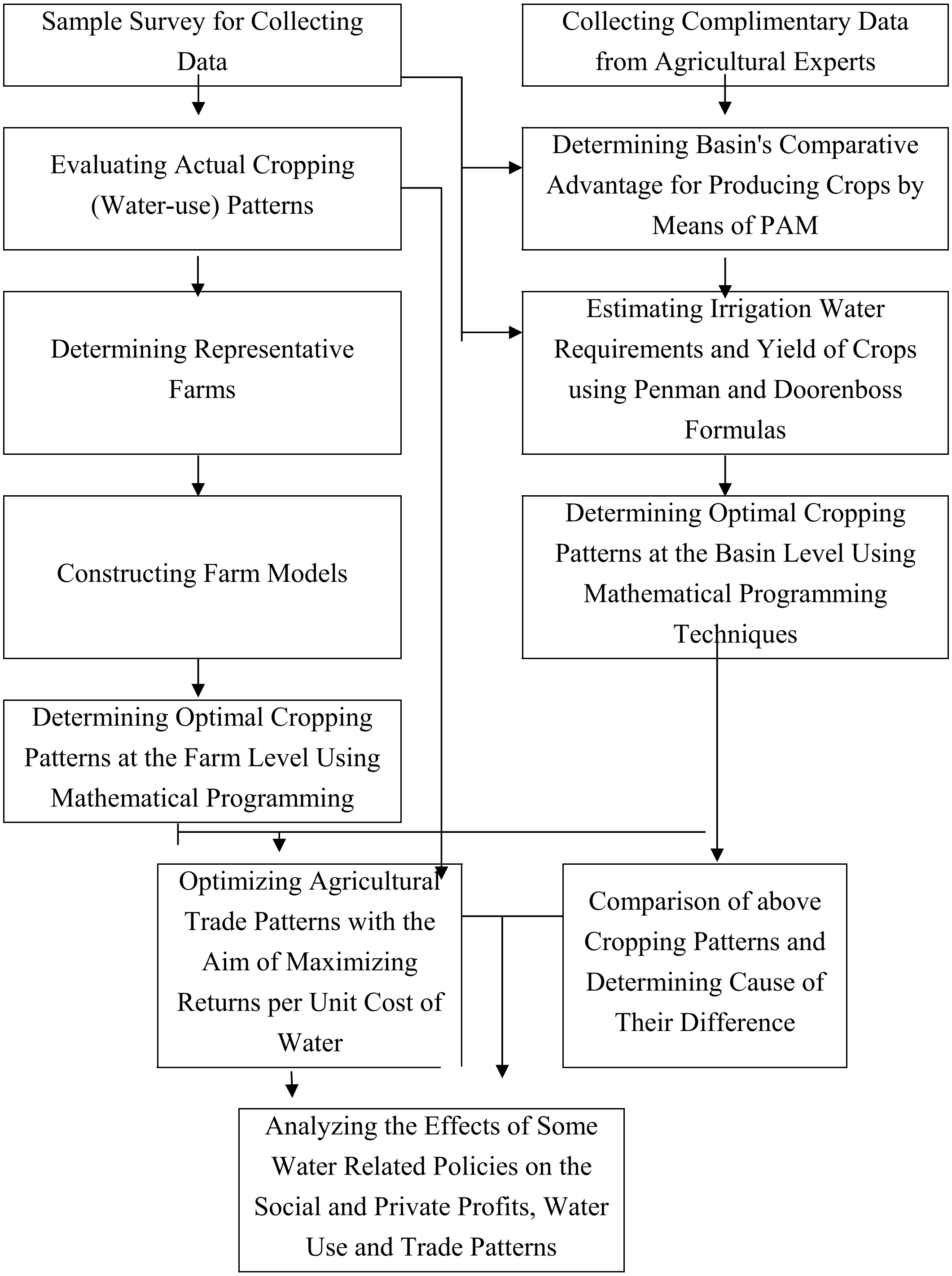


Figure2: Social Profits of Small and Medium Farms Relative to Large Farms

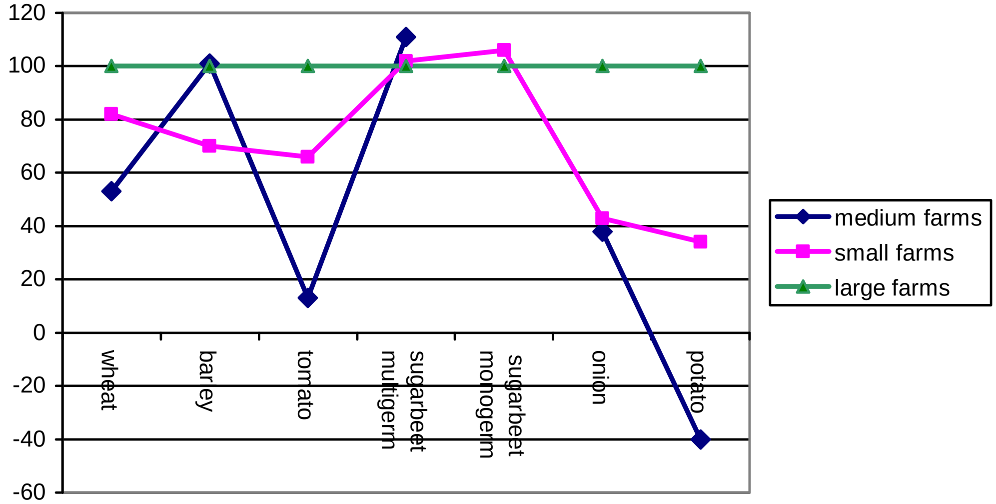


Figure 3: Optimal versus Existing Patterns of Land Allocation-Small Farms

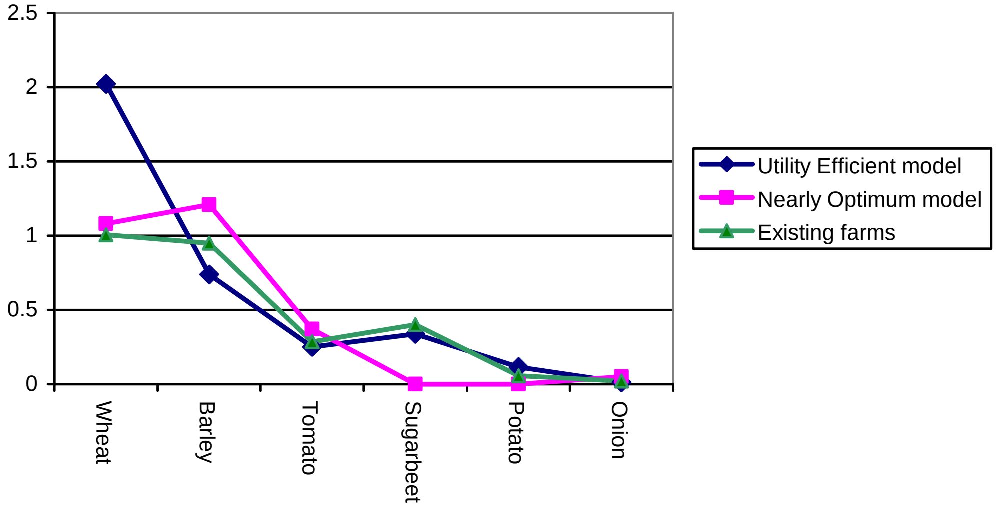


Figure 4: Optimal versus Existing Patterns of Land Allocation-Medium Farms

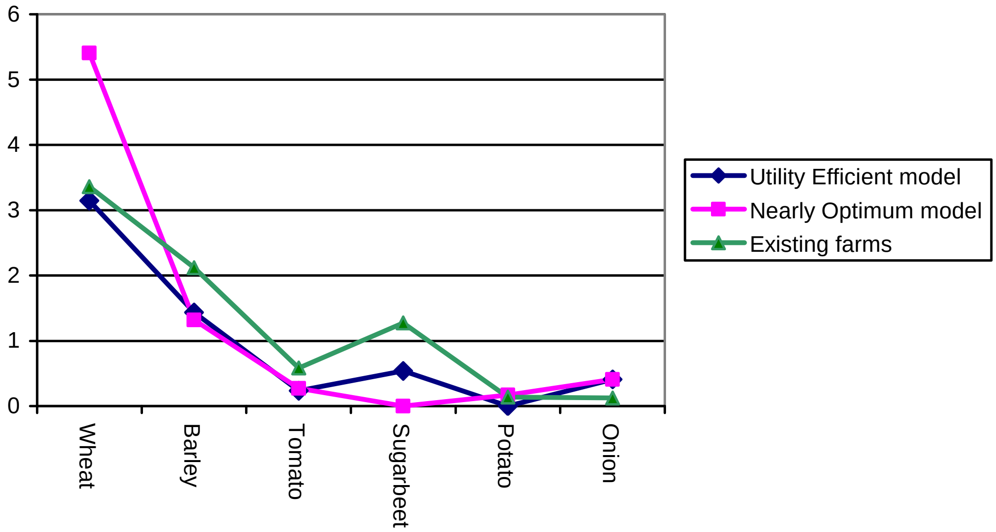


Figure 5: Optimal versus Existing Patterns of Land Allocation - Large Farms

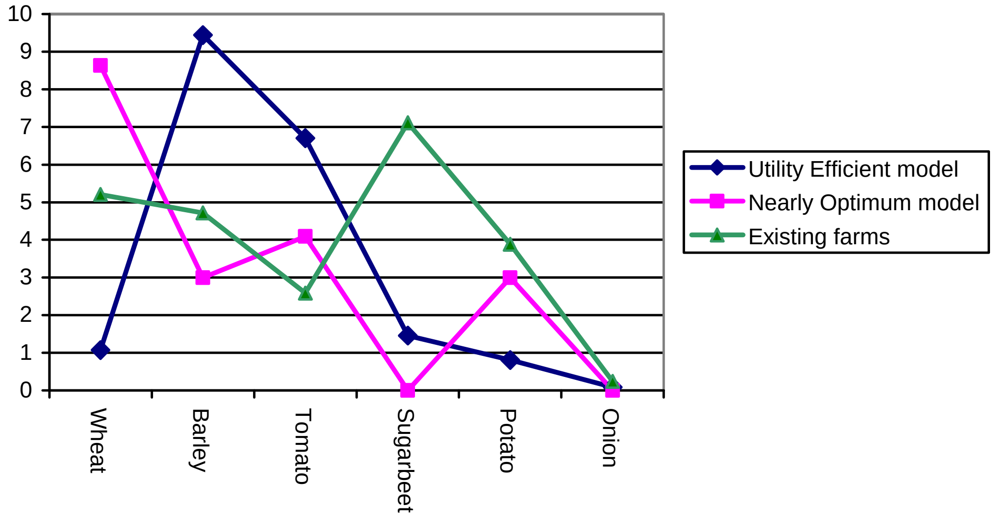


Table 1: Policy Analysis Matrix

	Revenues	Costs		Profits
		Tradable inputs	Domestic factors	
Private prices	A	B	C	D
Social prices	E	F	G	H
Divergence	I	J	K	L

Table 2: Expanded Policy Analysis Matrix

	Revenues	Costs		Profits
		Tradable inputs	Domestic factors	
Private prices	A	B	C	D
Social prices	E	F	G	L
Diverges and efficient policy	M	N	O	P
Effects of market failures	Q	R	S	T
Effects of efficient policies	U	V	W	X

Table 3: Some Properties of Selected Plains

Property	Plain		
	Sangbast	Mashad	Nariman
Average elevation (in meter)	1500	1400	6006
Ground water state	Restricted	Restricted	Restricted
Type of aquifer	Open	Open+ Pressurized	Open
Area of aquifer (Km^2)	134109	990914	296002
No of wells	523	5362	295
Extraction rate (m.cu.m)	6.77	946.35	91.4
No. of qanats	103	825	33
Extraction from qanats	23.72	115.55	9.39
No. of springs	29	419	46
Spring extraction (m.cu.m)	9.58	131.7	9.6
Annual decline of water table (meter)	0	0.99	1.21

Source: Khorasan Management and Planning Organization and Regional water Corporation.

Table 4: Cropping Patterns in Relation to Farm Size

Crop	Cultivated area (%)		
	Small Farms	Medium Farms	Large Farms
Wheat	37.023	44.205	21.931
Barley	34.955	27.908	19.858
Tomato	10.470	7.659	10.879
Sugar beet (multigerm)	14.737	11	20.808
Sugar beet (monogerm)	-	5.745	9.152
Onion	0.726	1.65	1.019
Potato	2.089	1.833	16.535
Total	100.00	100.000	100.00
% of wheat and Barley	71.928	72.112	41.789

Table 5: The Main Features of Crop Yield and Cultivated Areas (1983-2003)

Crop	Annual growth		Year of maximum yield	Coefficient of variation	
	Yield	Acreage		Yield	Acreage
Wheat	5	-0.63	2003	0.232	0.096
Barley	3.86	1.4	2003	0.190	0.128
Sugar beet	2.51	-0.76	1994	0.140	0.133
Potato	3.96	-0.135	1995	0.297	0.259
Onion	13.02	-0.75	1994	0.448	0.418
Tomato	2.01	21.91	2003	0.210	0.645

Table 6: Private and Social Prices of Irrigation Water

Description	Private price (Rials per cubic meter)	Social price (Rials per cubic meter)
Motor operator component	4.860	4.860
Repair and maintenance component	20.764	20.764
Oil Component	1.0933	1.0933
Gas oil component	12.574	71.672
Electricity component	6.452	54.193
Qanat component	2.138	2.138
Surface water (River) component	0.0759	0.0759
Spring component	0.0217	0.0217
Private price of water	47.980	
subsidy+ external costs:		
Subsidy	106.838	
External cost at 6% discount rate	152.4546	307.2741
External costs at 8% discount rate	118.9392	2733.7588
External costs at 10% discount rate	96.5512	251.3768
External costs at 12% discount rate	79.1538	233.9734

Table 7: Comparative Advantage of Agricultural Commodities

Level of study		Selected measures	Wheat		Barley		Tomato
			Irrigated	Rain fed	Irrigated	Rain fed	
Whole Basin		Social profit (per Ha.)	1214269.35	656902.25	1775077.15	512844.46	7267474.45
		Domestic Resource Cost	0.789	0.473	0.663	0.523	0.590
Basin Versus Farm Size	Large	Social profit	1773989.9	-	2013393.38	-	6761647.57
		DRC	0.718	-	0.635	-	0.584
	Medium	Social profit	1453137.15	-	1405276.6	-	4482585.96
		DRC	0.748	-	0.738	-	0.687
	Small	Social profit	941744.67	-	2041976.76	-	904450.61
		DRC	0.821				0.920
Basin Versus Plain	Mashad	Social profit	1694613.82	777778.31	1744390.9	601760.5934.7	6888284.24
		DRC	0.729	0.421	0.691	0.469	0.593
	Narimani	Social profit	-30436.05	381165.76	1699470.92	246-825.84	-
		DRC	1.007	0.615	0.685	0.726	-
	Sangbast	Social profit	973835.84		1440810.09	-	8683467.03
		DRC	0.781		0.680		0.490

Level of study		Selected measures	Sugar beet (1)	Sugar beet (2)	Onion	Potato
Whole Basin		Social profit	-6049853.51	-5601701.89	7898932.89	2589628.99
		DRC	3.124	2.382	0.596	0.867
Basin Versus Farm Size	Large Farms	Social profit	-6563996.90	-6665478.81	8940921.17	3141237.38
		DRC	3.945	2.709	0.543	0.843
	Medium Farms	Social profit	-6680213.98	-7067725.52	3866117.82	1071733.24
		DRC	3.392	3.941	0.759	0.939
	Small Farms	Social profit	-7307777.77	-	3368500.85	-1242448.95
		DRC	4.342	-	0.851	1.084
Basin Versus Plain	Mashad	Social profit	-4840705.91	-5872010.04	8052931.75	-464794.65
		DRC	2.662	2.449	0.589	1.027
	NARIMANI	Social profit	-5680781.09	-	-	-
		DRC	3.964	-	-	-
	SANGBAST	Social profit	-7850606.86	-	-	4592630.02
		DRC	4.337	-	-	0.776

Note: * Social profits of sample commodities are per hectare of cultivated land

Table 8: Net Social Profit and Cropping Patterns in Representative Farms of the Region

	Large farms		Medium farms		Small farms	
Crop	Profit per Ha. (Rial)	Acreage (Hectares)	Profit/ Ha. Rials	Acreage (Ha.)	Profit per Hectare	Acreage Ha.
Irrigated wheat	1773989.9	5.2	1453137.7	3.36	941744.6	1.007
Irrigated barley	2013393.3	4.71	1405276.6	2.12	2041976.7	0.95
Tomato	6761647.5	2.58	4482585.9	0.58	904560.6	0.285
Sugar beet (1)*	-6563996.9	4.94	-6680213.9	0.536	-7307777.7	0.401
Sugar beet (2)**	-6665478.8	2.173	-7067725.5	0.437	-	-
Onion	8940921.17	0.242	3866117.8	0.125	3368500.8	0.02
Potato	3141237.38	3.882	1071733.24	0.139	-1242448.9	0.057
Average size		23.74		7.6		2.72
Net social profit/Ha.	153370		320740		78700	
Gross social profit/Ha.	2129250		1461320		1181600	

Notes: * Sugar beet muligerm; ** Sugar beet monogerm

Table 9: Optimal and Existing Land and Water Allocation Patterns - Small Farms

Crop activity	Utility efficient model	Nearly optimum model	Existing pattern
Wheat deficit irrigation 4	0.191	0	
Wheat deficit irrigation 6	0.581	1.081	1.007
Wheat deficit irrigation 7	0.251	0	
Barley deficit irrigation 3	0.703	1.208	
Barley deficit irrigation 6	0.036	0	0.95
Tomato	0.252	0.371	0.285
Sugar beet deficit irrigation8	0.055	0	0.401
Sugar beet deficit irrigation 13	0.159	0	
Sugar beet deficit irrigation 15	0.123	0	
Sugar beet deficit irrigation 16	0.001	0	
Potato	0.116	0	0.057
Onion	0.012	0.05	0.02
Gross social profit/Ha. (Rial*)	1181680	1181680	1181600
Net social profit Per Ha.	51070	1471860	78700
Percentage change in net social profit	-35	1770	

Note: One U.S. Dollar equals 7920 Rials

Table 10: Optimal and Existing Land and Water Allocation Patterns - Medium Farms

Crop activity	Utility efficient model	Nearly optimum model	Existing patterns
Wheat-deficit irrig.3	0	1.574	3.359
Wheat-deficit irrig.4	0.342	0	
Wheat-deficit irrig.5	2.468	2.541	
Wheat-deficit irrig.6	0.134	0	
Wheat-deficit irrig.7	0.199	0	
Wheat-deficit irrig.8	0	1.294	
Barley deficit irrig.6	0.412	0	2.131
Barley deficit irrig.7	1.022	1.321	
Barley deficit irrig.15	0.233	0.269	0.582
Barley deficit irrig.9	0.531	0	1.273
Barley deficit irrig.15	0.007	0	
Barley deficit irrig.16	0	0	
Potato	0	0.169	0.139
Onion	0.407	0.422	0.125
Gross social profit/Ha (Rial)	8902360	12734830	2435110
Net social profit/ Ha. (Rial)	1547040	1677840	320470
Percentage change in net social profit	204	424	

Table 11: Optimal and Existing Land and Water Allocation Patterns - Large Farms

Crop activity	Utility Efficient model	Nearly optimum model	Existing pattern
Wheat-deficit irrigation 5	0.435	5.43	5.206
Wheat-deficit irrigation 8	0.637	3.201	
Barley deficit irrigation 3	1.168	0	4.714
Barley deficit irrigation 4	1.559	2.993	
Barley deficit irrigation 5	3.112	0	
Barley deficit irrigation 6	3.597	0	
Tomato deficit irrigation 10	1.287	3.633	2.583
Tomato deficit irrigation 12	5.417	0.456	
Tomato deficit irrigation 15	0	0	
Sugar beet deficit irrigation 10	0	0	4.94
Sugar beet deficit irrigation 15	0	0	
Sugar beet (monogerm)	1.456	0	2.173
Potato	0.81	2.993	3.882
Onion	0.088	0	0.242
Gross social profit/ Ha.	59855610	5838790	3640820
Net social profit/Ha.	3059080	3121320	153370
Percentage change in net social profit	1895	1935	

Table 12: Optimal and Actual Crop Combinations in Various Farm Sizes

	Small Farms			Medium Farms			Large Farms		
Crop	Utility efficient model	Nearly optimum model	Existing farms	Utility efficient model	Nearly optimum model	Existing farms	Utility efficient model	Nearly optimum model	Existing farms
Wheat	2.023	1.081	1.007	3.143	5.409	3.359	1.073	8.631	5.206
Barley	0.739	1.208	0.95	1.434	1.321	2.121	9.736	2.993	4.714
Tomato	0.252	0.371	0.285	0.233	0.269	0.582	6.704	4.089	2.583
Sugar beet	0.338	0	0.401	0.530	0	1.273	1.456	0	7.113
Potato	0.116	0	0.057	0	0.169	0.139	0.810	2.993	3.882
Onion	0.012	0.05	0.02	0.407	0.422	0.125	0.088	0	0.242
Tomato	2.481	2.71	2.720	5.754	7.59	7.59	19.567	18.706	23.739

Table 13: Crop Water Requirements and Use, Potential and Actual Yield per Hectare of Sample Crops at an Irrigation Efficiency of 35%

Description	Potato	Onion	Tomato	Sugar beet	Barley	Wheat
Water requirement:						
Average	19368	15178	18097	20185	6039	7027
Maximum	25601	19031	22371	25477	7200	6615
Minimum	14351	11647	13497	17018	4708	5311
Maximum/Minimum	1.784	1.634	1.658	1.497	1.529	1.622
Actual yield:						
Mean	29701	43387	27745	34938	3051	4062
Maximum	41294	59262	43758	50054	3967	5040
Minimum	21288	31527	13092	25344	2225	2923
Maximum actual to potential yield	0.901	0.86	0.70	0.89	0.94	0.88
Minimum actual to potential yield	0.46	0.45	0.21	0.45	0.53	0.51
Current water use	16114	17666	16131	15433	5861	7740
% change relative to mean deficit irrig.	-16.8	16.39	-10.86	-23.54	-2.96	10.14
Current yield in the sample	26534	42372	44989	33145	3089	3964
% Change relative to mean deficit irrig.	-11.9	-2.4	38.3	-5.4	1.2	-2.5
Estimated water use:						
Current			13157 Cubic meters per hectare			
Model			14316 Cubic meters per hectare			

Table 14: Optimal Cropping Patterns at 65% Farm Level Irrigation Efficiency

Description	Crop Wheat	 Barley	 Tomato	 Sugar beet	 Potato	 Onion
Hectares (model)	0	0.12	0.518	0	0.202	0.16
Hectares (existing)	0.129	0.306	0.36	0.157	0.044	0.0626
% change	-100	-60.8	43.7	-100	358	6053
No. of deficit irrigation		17	25		4	6
Estimated yield		3967	43758		4294	59262
Actual yield	3964	3089	44989	33145	26534	42372
Water use (model)		3877	12046		13785	10125
Water use (existing)	7740	5861	16131	15433	16114	17666
Net social profits per Ha. (existing)			2572005			
Net social profits per Ha. (model)			8444269			

Table 15: Optimal Cropping Patterns at 45% Farm Level Irrigation Efficiency

Description	Wheat	Barley	Tomato (1)	Tomato (2)	Potato	Onion	Sugar beet
Hectares (model)	0	0.12	0.365	0.153	0.202	0.16	0
Hectares (existing)	0.129	0.306	0.360	0.360	0.044	0.0026	0.157
% change	-100	-60.8	1.2	-57	358	6053	-100
No. of deficit irrigation		17	25	20	19	6	
Estimated yield		3967	43758	39341	30188	59262	
Actual yield	3964	3089	44989	44989	24534	42312	
Water use (model)		5600	17400	15213	13006	14625	33145
Water use (existing)	7740	5861	16131	16131	16114	17666	15433
Net social profits per Ha.(existing)				2572005			
Net social profits per Ha. (model)				6649909			

Table 16: Optimal Cropping Pattern at 35% Farm Level Irrigation Efficiency

Description	Crop Wheat	 Barley	 Tomato	 Sugar beet	 Potato	 Onion
Hectarage (model)	0.091	0.306	0.442	0	0	0.16
Hectarage (Existing)	0.124	0.3065	0.3605	0.1576	0.441	0.0026
% change	-29.5	-0.1	22.6	-100	-100	6053
No. of deficit irrigation	14	17	19			6
Estimated yield	4377	3967	38686			59262
Actual yield	3964	3089	44989	33145	26534	42372
Water use (model)	6759	7200	19182			18804
Water use (Existing)	7740	5861	16131	15433	16114	17666
Net social profits Per Hectare (Existing) (Rials)			2572000			
Net social profit (model) (Rials)			4724600			

Table 17: Irrigation Strategy as Related to Irrigation Efficiency

Irrigation Efficiency = 65%

Crop growth stage	Wheat water stress	Barley water stress	Tomato water stress	Potato water stress	Onion water stress
1		0.79	0.67	0.61	0.92
2		0.86	0.96	0.97	0.85
3		0.98	0.97		
4		0.97	0.71	0.96	0.98
5		0.55	0.91	0.71	0.78

Irrigation Efficiency =45%

Crop growth stage	Wheat water stress	Barley water stress	Tomato water stress (1)	Tomato water stress (2)	Potato water stress	Onion stress
1		0.799	0.67	0.559	0.83	0.918
2		0.86	0.96	0.67	0.53	0.85
3		0.98	0.97	0.97		
4		0.97	0.71	0.79	0.94	0.98
5		0.55	0.91	0.75	0.82	0.78

Irrigation Efficiency =35%

Crop growth stage	Wheat water stress	Barley water stress	Tomato water stress (1)	Tomato water stress (2)	Potato water stress	Onion stress
1	0.79	0.799	0.67			0.918
2	0.94	0.86	0.65			0.85
3	0.988	0.98	0.91			
4	0.56	0.97	0.81			0.98
5	0.73	0.55	0.84			0.78

Table 18: Irrigated Land Allocation in Relation to Water Supply Risk

Crop Water supply Risk	Wheat	Barley	Tomato	Tomato	Potato	Potato	Onion
95 %	0.129	0.306	0.145	0.259	0	0	0.16
90 %	0	0.242	0.518		0.08		0.16
87.5 %	0	0.132	0.518	0	0.19		0.16
85 %	0	0.12	0.24	0.278	0. 202		0.16
80 %	0	0.12	0.518		0.033	0.169	0.16
Existing allocation	0.129	0.3062	0.3605	Sugar beet 0.157	0.0441		0.0026

Table 19- Effects of Water Supply Risk on Economic Water Use Efficiency

Water supply reliability	Water requirement (cu.m. per hectare)	Net social profit per hectare (Rials)	Social returns per cu.m. (Rials)
80 %	10609 (-10%)	8327430 (+223.7%)	780 (+36%)
85 %	9780 (-17%)	7940590 (+300%)	810 (+370%)
87.5 %	9298 (-22%)	706500 (+300%)	820 (+380%)
90 %	8735 (-26%)	7398420 (187%)	850 (+400%)
95 %	71120	8294000	885
% change relative to existing plan	-40	+114.7	+406

Table 20: Effects of Irrigation Efficiency on Cropping Patterns and Economic Returns to Irrigation Water

Irrigation Efficiency	Crop Area in Hectare						Irrigation Return (Rials)
	Wheat	Barley	Tomato	Tomato	Onion	Potato	
65%	0	0.242	0.145	0.259	0.16	0.08	850
45%	0.129	0.306	0.203		0.154	0.202	457
35%	0.129	0.306	0.203		0.006 0.02 0.014	0.202	242
Existing efficiency level	0.129	0.3062	0.3605		0.0026	0.0441	218

Table 21: Irrigation Strategy as Affected by Water Supply Uncertainty (irrigation efficiency = 65%)

Irrigation Water Supply Reliability = 95%							
Growth stage	**Wheat water stress**	**Barley water stress**	**Tomato water stress(1)**	**Tomato water stress (2)**	**Sugar beet water stress**	**Potato water stress**	**Onion water stress**
1	0.79	0.80	0.55	0.67			0.91
2	0.94	0.76	0.56	0.65			0.85
3	0.98	0.99	0.77	0.91			
4	0.56	0.57	0.94	0.81			0.98
5	0.73	0.71	0.92	0.84			0.78
Water Supply Reliability = 0.90							
1		0.79	0.56			0.83	0.91
2		0.86	0.67			0.53	0.85
3		0.98	0.97				
4		0.97	0.79			0.94	0.98
5		0.55	0.75			0.82	0.78
Water Supply Reliability = 0.87.5							
1		0.79	0.55			0.83	0.91
2		0.86	0.67			0.53	0.85
3		0.98	0.97				
4		0.97	0.79			0.92	0.98
5		0.55	0.75			0.82	0.78

Irrigation Supply Reliability = 0.85							
Growth stage	**Wheat water stress**	**Barley water stress**	**Tomato water stress(1)**	**Tomato water stress (2)**	**Sugar beet water stress**	**Potato water stress**	**Onion water stress**
1		0.79	0.56	0.67		0.83	0.91
2		0.86	0.67	0.96		0.53	0.85
3		0.98	0.97	0.97			
4		0.97	0.79	0.71		0.94	0.98
5		0.55	0.75	0.91		0.82	0.78

Irrigation Supply Reliability = 0.80							
	Wheat water stress	**Barley water stress**	**Tomato water stress**	**Sugar beet water stress**	**Potato water stress (1)**	**Potato water stress(2)**	**Onion water stress**
1		0.79	0.67		0.83	0.52	0.91
2		0.86	0.96		0.53	0.77	0.85
3		0.98	0.97				
4		0.97	0.71		0.94	0.99	0.98
5		0.55	0.91		0.82	0.82	0.78

Table 22: Irrigation Strategy as Affected by Water Supply Uncertainty (irrigation efficiency = 45%)

	Irrigation Water Supply Reliability = 90%						
Growth stage	Wheat water stress	Barley water stress		Tomato water stress	Potato water stress	Onion water stress(1)	Onion water stress (2)
1	0.53	0.93		0.55	0.58	0.67	0.69
2	0.74	0.64		0.56	0.52	0.87	0.72
3	0.57	0.619		0.77			
4	0.50	0.549		0.94	0.54	0.91	0.51
5	0.71	0.57		0.92	0.83	0.50	0.50
Irrigation Water Supply Reliability = 87.5%							
1	0.53	0.93		0.55	0.76	0.72	
2	0.74	0.64		0.56	0.52	0.98	
3	0.57	0.619		0.77			
4	0.50	0.549		0.94	0.76	0.85	
5	0.71	0.57		0.92	0.95	0.67	
Irrigation Water Supply Reliability = 87.5%							
1	0.55	0.90	0.99	0.55		0.91	
2	0.97	0.54	0.71	0.569		0.85	
3	0.84	0.75	0.93	0.77		-	
4	0.52	0.51	0.54	0.94		0.98	
5	0.63	0.88	0.65	0.92		0.78	

	Irrigation Water Supply Reliability = 90%					
Growth stage	Wheat water stress	Barley water stress(1)	Barley water stress(2)	Tomato water stress	Potato water stress	Onion water stress
1	0.79	0.799	0.80	0.67		0.918
2	0.94	0.86	0.76	0.65		0.85
3	0.98	0.98	0.99	0.91		
4	0.56	0.97	0.579	0.81		0.98
5	0.73	0.55	0.71	0.84		0.78

Table 23. Maximum Irrigation Water Charges in Relation to Efficiency Level

Efficiency level (%)	Maximum water charges (Rials per cu.m.)
35	554.8
45	825.4
65	1192.3

Table 24: Effects of Selected Policies on Irrigation Water-use, Private and Social Profits

Description	Policy Scenario											
	1	2	3	4	5	6	7	8	9	10	11	12
Level of water reduction considered (cu.m)	2638615.5	2638615.5	2638615.5	2638615.5	5277231	5277231	5277231	5277231	13193077.6	4045982	2638615.5	2638615.5
Water reduction per Ha. (cu.m)	1147.7	1147.7	1147.7	1147.7	2295	2295	2295	2295	5738.6	2250.3	1467.5	1467.5
Net social profit change per Ha. (Rials)	323320	313768.7	303671.7	291162.4	638754.8	625595.3	612385.2	594391.5	552208	500896.7	278407.3	571868.4
Nets private profit decline per Ha. (Rials)	122130.5	228475.6	334045.6	542830.2	186958.6	298336.3	407842.3	621692	1361262.9	266703.9	619555.5	620222.2

Table 25-1: Effects of Selected Policies on Land Allocation Decisions by Representative Farmers (% change)

Crop vs plain	Policy Scenario											
	1	2	3	4	5	6	7	8	9	10	11	12
Wheat-Mashad	-0.27	-0.35	-0.43	-0.58	-.063	-0.75	-0.89	-1.13	-15.72	-0.83	-1.8	1.85
Wheat- Narimani	0.38	0.49	0.60	0.79	0.77	0.89	1.00	1.17	0.30		-17.15	0.38
Wheat- Sangbast	5.19	6.67	8.05	10.61	11.29	13.3	15.16	18.53	55.55		10.31	50.79
Barley- Mashad	2.76	3.57	-8.45	5.75	6.14	7.29	8.35	10.27	-33.52	7.83	3.33	10.59
Barley- Narimani	-5.28	-6.88	-2.68	-11.4	-12.2	-14.5	-16.89	-21.24	-95.0		16.31	41.2
Barley- Sangbast	-1.34	-1.97	-2.58	-4.28	-4.68	-6.25	-7.94	-11.53	-99.9		-53.87	13.65
Tomato- Mashad	-1.65	-2.13	-2.58	-3.43	-3.66	-4.33	-4.96	-6.09	-18.0	-4.65	-1.35	-0.08
Tomato- Sangbast	-1.67	-2.15	-2.70	-3.38	-3.61	-4.23	-4.80	-5.81	-17.19		0.76	0.38
Sugar beet - Mashad	-1.72	-2.23	-2.16	-3.58	-3.82	-4.53	-5.18	-6.37	-19.2	-4.86	-2.1	-27.42
Sugar beet - Narimani	-1.40	-1.75	-5.90	-2.82	-3.03	-3.56	-4.03	-4.87	-11.09		-5.8	-35.65
Sugar beet - Sangbast	-3.83	-4.91	-1.88	-7.72	-8.22	-9.63	-10.91	-13.18	-35.97		1.42	-34.58
Sugar beet monogerm Mashad plain	-1.20	-1.55	-1.15	-2.50	-2.67	-3.17	-3.63	-4.47	-13.06	-3.41	-3.42	-21.88
Potato- Mashad	-0.73	-0.95	-1.12	-1.43	-1.63	-1.99	-2.22	-2.64	-8.29	-2.09	0.03	-0.04
Potato- Sangbast	-0.72	-0.93	-0.91	-1.45	-1.56	-1.83	-2.08	-2.51	-7.45		0.08	0.16
Onion- Mashad	-0.58	-0.75	-0.91	-1.21	-1.29	-1.54	-1.77	-2.18	-6.95	-1.65	-1.03	0.01

Table 25-2: Effects of Selected Policies on Water Allocation Decisions by Representative Farmers (% change)

Crop vs plain	Policy Scenario											
	1	2	3	4	5	6	7	8	9	10	11	12
Wheat-Mashhad	-9.65	-9.58	-9.49	-9.33	-19.37	-19.25	-19.14	-18.95	-46.97	-19.2	-11.66	-4.64
Wheat- Narimani	-7.5	-6.75	-6.02	-4.63	-14.9	-13.96	-13.0	-11.24	-25.73		-20.24	3.5
Wheat- Sangbast	-2.9	-0.81	1.18	4.93	-5.81	-3.09	-0.53	4.23	11.09		10.31	63.54
Barley- Mashhad	-7.61	-6.93	-6.29	-5.13	-15.38	-14.58	-13.85	-12.59	-63.72	-14.21	-8.81	3.72
Barley- Narimani	-12.8	-13.96	-14.58	-16.3	-25.97	-27.28	-28.57	-31.0	-96.34		16.31	52.85
Barley- Sangbast	-8.93	-8.84	-8.87	-9.2	-19.32	-19.82	-20.48	-22.2	-99.9		-53.87	26.98
Tomato- Mashhad	-10.77	-10.99	-11.19	-11.5	-21.49	-21.76	-22.0	-22.42	-47.13	-21.88	-9.86	-6.38
Tomato- Sangbast	-9.27	-9.68	-9.61	-9.43	-19.46	-19.32	-19.1	-18.9	-44.88			
Sugar beet - Mashad	-10.87	-11.13	-11.37	-11.81	-21.71	-22.02	-22.3	-22.8	-48.19	-22.16	-10.84	-38.85
Sugar beet - Narimani	-9.67	-9.54	-9.41	-9.13	-19.17	-18.94	-18.7	-18.2	-36.97		-7.78	-46.34
Sugar beet - Sangbast	-12.41	-13.0	-13.72	-14.8	-24.62	-25.43	-26.15	-27.43	-62.33		1.9	-44.44
Sugar beet monogerm Mashad plain	-10.10	-10.12	-10.13	-10.16	-20.14	-20.15	-20.14	-20.11	-41.81	-20.15	-12.04	-32.93
Potato- Mashad	-9.46	-9.28	-9.11	-8.6	-18.85	-18.6	-18.35	-17.7	-36.98	-18.48	-7.59	6.14
Potato- Sangbast	-8.60	-8.18	-7.78	-7.02	-17.17	-16.61	-16.0	-15.07	-35.8			
Onion- Mashad	-9.26	-9.03	-8.80	-8.37	-18.45	-18.12	-17.8	-17.2	-35.63	-17.96	-8.89	-6.06

Table 26: Import of Agricultural Commodities during 1995-2004 (metric tons)

Commodity	**1995**	**1996**	**19997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Wheat	3100000	3874000	5941948	3535226	6155936	6577877	6438950	4121983	1153875	222777
Barley	500000	800000	605239	207437	423487	1040226	939348	204061	-	1012583
Rice	1633000	1150000	637498	631292	852000	1129469	778368	848068	945729	972802
Maize	1150000	889000	1510028	806012	1007222	1180692	1695343	1325652	3089731	1763991
Soybean	-	-	-	192500	393985	601955	522133	328993	828000	818628
Sugar	972000	644000	1123000	872221	1279836	1099596	763554	818452	334775	107180
Banana	120000	150000	170000	200000	200000	200000	75586	156725	271539	270949
Total cereal imports	6383000	6713000	8694713	5179967	8438645	9928264	9852069	6499764	5189334	3972153

Source: FAO: www. fao.org/es/ess/toptrade/trade.asp

Table 27: Exports of Agricultural Commodities during 1995-2004 (metric tons)

Commodity	**1995**	**1996**	**19997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Pistachios	128000	140000	57907	124812	101215	101215	115335	135314	184946	138723
Raisins	55000	50000	59703	82920	94328	105129	118013	128626	143634	137919
Dates	100000	200000	59290	73583	101094	107847	119364	113533	120056	94584
Chickpeas	-	-	106440	61576	33487	18866	123522	139716	87111	85223
Apples	100000	190000	117844	176119	157857	133031	89081	92078	108873	120507
Tomato paste	6200	-	64278	31554	74577	87000	52044	24376	98553	51026
Fresh fruits	150000	130000	-	41777	-	-	-	-	-	22576
Apple juice	-	-	19159	43951	42350	27816	27024	26693	-	20461
Melon	-	-	-	204239	172889	118444	111120	99250	-	-
Almond	-	3600	-	-	3263	-	5269	21549	-	-
Potato	100000	100000	-	-	-	-	92068	100918	-	-
Cotton lint	30000	19000	14084	2025	7562	-	-	-	-	-
Macaroni	-	-	111188	62467	38057	23435	-	-	-	-
Pastry	-	-	48873	33371	36563	29190	24426	34132	38763	38763
Oil of soybean	116000	100000	35000	200000	240000	180000	100000	165000	210000	105000
Oil of sunflower	115000	62300	13436	-	-	-	25099	27648	19970	17905
Others (water melon, cucumber, dried fruits)	205716	144500	0	119648	27473	28110	0	0	0	156703
Total	**1195916**	**1139400**	**727202**	**1267102**	**1130715**	**960083**	**1002365**	**1108833**	**1011906**	**989390**

Source: FAO: www.fao.org/es/ess/toptrade/trade.asp

Table 28: Production of Wheat and Food Production Index (1979-2003)

	1979-81	1989-91	2000	2001	2002	2003
Food production Index (1999-01-100	40	65	100	99	111	113
Wheat production (1000 tons)	5843	7605	8088	9459	12450	13440

Source: FAO: www.fao.org

Table 29: Agricultural Trade in Relation to Virtual Water Import

Period	Year 1995-1999	 2000-2004
Annual import (tons)	8054076	7713016
Annual export (tons)	1092067	1014515
Net annual import	6962000	6698500
Annual sugar import	972211	624711
Net annual virtual water import (billion cubic meters)	5.82	5.5

Table 30: Some Indicators of Virtual Water Relative to Agricultural Trade in Iran (1995-1999)

Total virtual water import (billion cu.m.)	29.1
Population	62762116
Water extraction (billion cu.m.)	85.608
Available water resources (billion cu.m.)	117.5
Gross virtual water export per annum (billion cu.m.)	0.85
Gross virtual water import per annum (billion cu.m.)	6.623
Net annual virtual water import (billion cu.m.)	5.82
Water scarcity (%)	72.9
Irrigation areas (million hectares)	7.6
Net virtual water import per hectare (cubic meters per annum)	765

Source: Hoekstra, A.Y. and P. Q. Hung 2002. Virtual Water Trade: A Quantification of Virtual Water Flows between Nations in Relation to International Crop Trade, Value of Water Research Report series No.11, IHE, the Netherlands.

Table 31: Water Requirements and Values of Exported and Imported Crops (cu.m. and Rials)

Topic		65 % irrigation efficiency				
		Export Crops			Import Crops	
	Potato	Onion	Tomato	Barley		Wheat
Water requirements per ton	353	190	372	1073		935
Average water requirement		305			1003	
Irrigation water value (cost) per ton	1083900	584250	1141730	3295230		2872230
Average irrigation water value		1003510			3098240	
			45 % irrigation efficiency			
Water requirements per ton	510	275	537	1549		1351
Average water requirements per ton		440			1550	
Irrigation water value	1566070	843920	1649160	4759780		4148780
Average irrigation value		1449690			4475230	
			35 % irrigation efficiency			
	Potato	Onion	Tomato	Barley		Wheat
Water requirements per ton	655	354	690	1993		1737
Average water requirement		566			1865	
Irrigation water value	2012960	1086270	2118960	6123090		533696
Average irrigation water value		1863100			2756990	
Returns per cu.m. of water	3005	5766	3327	1366		1376

Table 32: Optimal Cropping Patterns under Various Water Supply Risks without and with Virtual Water (irrigation efficiency 65%)

Crop	**Deficit irrigation**	**Without virtual water Water supply risk (%)**					**Crop**	**Deficit irrigation**	**With virtual water Water supply risk (%)**				
		80	**85**	**87.5**	**90**	**95**			**80**	**85**	**87.5**	**90**	**95**
Wheat	14					0.027	Wheat	14					
Barley	17	0.12	0.12	0.132	0.242	0.464	Barley	17	0.12	0.12	0.12	0.12	0.374
Tomato	19					0.348	Tomato	19					0.466
Tomato	20		0.24	0.518	0.518		Tomato	20			0.051	0.425	
Tomato	25	0.518	0.278				Tomato	25	0.518	0.518	0.467	0.093	
Onion	6	0.16	0.16	0.16	0.16	0.16	Onion	6	0.16	0.16	0.16	0.16	0.16
Potato	4						Potato	4	0.202				
Potato	19	0.032	0.202	0.19	0.08		Potato	19		0.055	0.202	0.202	
Potato	35	0.169					Potato	35		0.147			
Social profit (Rials)		**8328690**	**7941578**	**7708940**	**7399210**	**6371071**	**Social profit (Rials)**		**844443**	**829967**	**807774**	**780764**	**689210**
Irrigation water used		10608	9779	9299	8732	7118	Irrigation water used		11106	10545	10065	9498	7884

Yield (kg/Ha)	**Total output at alternative water supply risk**					Yield (kg/Ha)	**Total output at alternative water supply risk**				
	80	**85**	**87.5**	**90**	**95**		**80**	**85**	**87.5**	**90**	**95**
4377.6					118.19	3967.7	476.124	476.124	476.124	476.124	1483.91
3967.7	476.124	476.124	523.739	960.18	1841.01	38686					18027.6
38686					13462.7	39341.8			2006.43	16720.3	
39341.8		9442.03	20379.0	20379.0	0	43758.3	22666.7	22666.7	20435.1	4069.52	
43758.3	22666.79	12164.8			0	59262.1	9481.93	9481.93	9481.93	9481.93	9481.93
59262.1	9481.936	9481.93	9481.93	9481.93	9481.94	41294	8341.54				
30188.3	966.025	6098.03	5735.77	2415.06	0	30188.3		1660.35	6098.03	6098.03	
37734	6377.046				0	37734		5546.89			

Table 32a. Resulting Changes in Crop Output due to Minimizing Barley Activity or Wheat Activity (irrigation efficiency 65%)

Crop	Deficit irrigation			Barley activity			Crop	Deficit irrigation			Wheat activity		
		80	85	87.5	90	95			80	85	87.5	90	95
Wheat	14						Wheat	14	0	0	0		
Wheat	27						Wheat	27					
wheat	40	350.7	458.9	491.7			wheat	40					
Barley	17	-476.	-476	-476			Barley	17	376	0	0		
Tomato	25	-1636	-306	-1532			Tomato	25	0	-2566	-2031		
Onion	6	0	0	0			Onion	6	0	0	0		
Potato	4						Potato	4					
Potato	19						Potato	19					
Potato	35	0	-393	1524			Potato	35	-3923	1134	1717		
Tomato	4						Tomato	4					
Tomato	19						Tomato	19					
Tomato	20						Tomato	20					
As shown, at 80, 85 and 87.5 % water supply reliability for wheat activity level increase by 350, 458 and 491 kg respectively. While barley and tomato activities decrease by the amount indicated, onion activity does not change. Potato output increases by 1524 kg at 87.5 water supply reliability, but it decreases by 393 kg at 85 % water supply reliability.							As indicated at the three levels of water supply reliability, the model has solutions. Barley and potato outputs increase by 376, 1134 and 1717 kg respectively at 80, 85 and 87.5 water supply reliability. Tomato outputs decrease by 2566, 2031 kg respectively and potato output decreases by 3923 kg.						

Table 32b: Resulting Output Changes due to Minimizing Wheat and Barley Activities or Tomato, Onion and Potato Activities (irrigation efficiency 65%)

Crop	Deficit irrigation		Wheat and Barley		Crop	Deficit irrigation		Tomato, Onion and Potato	
		80	85	87.5			80	85	87.5
Wheat	14	0	0	0	Wheat	14	0	0	0
Barley	17	0	0	0	Barley	17	376	376	353
Tomato	4				Tomato	4			
Tomato	19				Tomato	19			
Tomato	20				Tomato	20			
Tomato	25	-1945	-2566	-2031	Tomato	25	0	0	225
Onion	6	0	0	0	Onion	6	0	0	0
Potato	4				Potato	4			
Potato	19				Potato	19			
Potato	35	0	1134	1717	Potato	35	-3925	-2788	-1682
At 90 and 95 % water supply reliability, the model has no solution. As shown, only tomato output has decreased. Other crops' output remains unchanged except potato which has increased by 1134 and 1717 kg respectively at 85 and 87.5 water supply reliability.					At the three levels of water supply reliability, barley and tomato outputs have increased and potato output has decreased by the amounts indicated.				

Table 33: Optimal Cropping Patterns under Various Water Supply Risks with and without Virtual Water (irrigation efficiency 45%)

Crop	Deficit irrigation	Without virtual water Water supply risk (%)				
		80	85	87.5	90	95
Wheat	14		0.079	0.129	0.188	0.032
Wheat	40					0.254
Barley	17	0.458	0.464	0.464	0.464	
Barley	20					0.464
Tomato	8					0.089
Tomato	19	0.382	0.296	0.247	0.188	
Onion	6	0.16	0.16	0.16	0.16	0.16
Social profit (Rials)		**5525644**	**5201735**	**501347**	**4790990**	**4105950**
Irrigation water used		10608	9779	9299	8732	7118
Yield (kg/Ha)		**Total output at alternative water supply risk**				
		80	**85**	**87.5**	**90**	**95**
4377			345.8	564.7	822.9	140.08
4170						1059.38
3967		1817	1841	1841	1841	
3133						1454
3563						3171
38686		14778	11451	9555	7272	
59262		9481	9481	9481	9481	9481

Crop	Deficit irrigation	With virtual water Water supply risk (%)				
		80	85	87.5	90	95
Wheat	14		0.0002	0.05	0.109	0.27
Wheat	40					
Barley	17	0.375	0.464	0.464	0.464	0.464
Barley	20					
Tomato	8					
Tomato	19	0.464	0.375	0.326	0.267	0.1
Onion	6	0.16	0.16	0.16	0.16	0.16
Social profit (Rials)		**5810178**	**5502156**	**5313898**	**5091412**	**4458180**
Irrigation water used		11374	10545	10065	9498	7884
Yield (kg/Ha)		**Total output at alternative water supply risk**				
		80	**85**	**87.5**	**90**	**95**
4377		0	0.979	218.8	477.15	1208.2
3967		1487	1487	1841	1841	1841
38686		17950	17950	12611	10329	3868
59262		9481	9481	9481	9481	9481

Table 33a: Optimal Cropping Pattern with Minimizing Barley and Wheat Activities as Import Crops (irrigation efficiency 45%)

Crop	Deficit irrigation	Barley activity					Wheat activity		
		80	85	87.5	90	95	80	80	80
Wheat	14		0.002					0	0
Wheat	27	0.287					838.9		
Barley	17		0.464	0.354	0.459	0.459	-1487	-942	281
Tomato	4		-0.005						
Tomato	19	0.218	0.378	1.095	0.381	0.381			
Tomato	25			-0.609			1172	506	-2120
Onion	6	0.16	0.16	0.16	0.16	0.16	0	-604	0
Potato	1	0.024							
Potato	9	0.012					943	2626	
Irrigation water		11374	10454	10065	10592	10592			
Model solution		Yes	No	No	No	No			

Table 33b: Optimal Cropping Pattern with Virtual Water Assuming Irrigation Efficiency of 45% and Minimizing Potato, Onion and Tomato Activities

Crop	Deficit irrigation	Water supply risk levels (%)					Changing output at 80% risk
		80	85	87.5	90	95	
Wheat	14			0.004			
Wheat	25	0.05					252
Barley	17	0.464	0.46	0.464	0.459	0.459	253
Tomato	19		0.387	0.459	0.381	0.381	
Tomato	25	0.326					-3685
Onion	6	0.16	0.16	0.16	0.16	0.16	0
Potato	4		-0.008	-0.008			
Irrigation water		10930	10545	10065	10592	10592	

Table 34: Optimal Cropping Patterns under Various Water Supply Risks with and without Virtual Water (irrigation efficiency 35%)

Crop	**Deficit irrigation**	**Without virtual water Water supply risk (%)**					**With virtual water Water supply risk (%)**				
		80	**85**	**87.5**	**90**	**95**	**80**	**85**	**87.5**	**90**	**95**
Wheat	14	0.238	0.287	0.287			0.176	0.243	0.281	0.287	
Wheat	20				0.287						
Wheat	23					0.287					0.287
Barley	7										0.16
Barley	17					0.464	0.464	0.464	0.464	0.114	
Barley	12	0.464	0.31								
Barley	20		0.154	0.464						0.35	
Barley	21				0.317						
Barley	34				0.147						
Tomato	8			0.027	0.089						0.02
Tomato	19	0.138	0.089	0.062			0.2	0.133	0.094	0.089	
Onion	6	0.16	0.16	0.16	0.16		0.16	0.16	0.16	0.16	
Onion	11					0.058					
Onion	24				0.103	0.103					
Potato	24										0.069
Potato	27					0.089					
Social profit (Rials)		**3877772**	**3670163**	**3530464**	**3292721**	**2090937**	**4059161**	**3862827**	**3749161**	**3589215**	**2824651**
Irrigation water used		10608	9779	9299	8732	7118	11374	10454	10065	9498	7884

Table 34a: Resulting Changes in Crop Output due to Minimizing Activities (irrigation efficiency 35%)

Crop	**Deficit irrigation**	**Barley activity**		**Wheat activity**		**Wheat and Barley activities**		**Tomato, Onion and Potato activities**	
		85	**87.5**	**85**	**87.5**	**85**	**87.5**	**85**	**87.5**
Wheat	23	281.9	144.4	-609	-48	-609	-48		
Barley	17	-1269.8	-134.9					0	0
Tomato	25	3201.7	38.6					-3055	-113.49
Onion	6	0	0	0	0	-5432	-5432	0	0
Barley	20			-763.7	-71.9	-763.7	-71.9		
Tomato	19			4021	-386.8	-1021	386.8		
Wheat	25							580.4	26.26
Irrigation water use		10545	10065	10545	10517	10545	10517	10961	10545

Appendix 1: Data Collected and Used in PAM and Mathematical Programming Analysis

Table A1: Deriving Farm-gate Prices from Border Prices (crops)

Description		**Crop**	
	Wheat	**Barley**	**Sugar**
CIF price ($/kg)	0.162864	0.185129	0.215296
Exchange rate ($/Rial)	7920 Rials/$	7920 Rials/$	7920 Rials/$
Exchange fee (%)	0	0	0
Market exchange rate ($/Rial)	7920	7920	7920
CIF price (Rials/kg)	1289.65	1466.22	1705.14
Conversion factor (Weight)	1	1	1
CIF price in Iran (R/kg)	1289.65	1466.22	1705.14
Marketing and transport cost to whale sale market (R/Kg)	294.55	294.55	572.5753
Value before processing	1584.2	1760.77	2277.72
Processing conversion factor	1	1	0.62
Cost of processing (Rial/kg)	1584.2	1760.77	1412.19
Whole sale import parting price (R/kg)	1584.2	1760.77	178.783
Cost of distribution to farm	54.14529	54.14529	35.59686
Import parity price at farm gate (Rails/kg)	1638.34	1814.92	143.186
Description	**Onion**	**Potato**	**Tomato**
Price at the origin ($/kg)	0.131739	0.161547	0.148833
Exchange rate ($/Rial)	7920	7920	7920
Exchange fee	5%	%5	5%
Market exchange rate	8316	8316	8316
Fob price (Rails/kg)	1095.54	1343.42	1237.69
Marketing and transport cost (R/kg)	511.1831	511.1831	784.4036
Price before conversion	584.3553	832.2389	453.291
Conversion factor	1	1	1
Export parity price (whole sale)	584.3553	832.2389	453.291
Transport and storage cost	65.16837	34.30	37.39686
Export parity price at farm gate (Rails/kg)	519.1869	797.942	415.8942

Table A2: Deriving Farm-gate Prices from Border Prices (inputs)

Description	Poisons	Herbicides	Potash	Nitrogen	Phosphate
CIF price ($/kg)	11.31219	7.844271	0.180885	0.160453	0.17981
Exchange rate ($/Rial)	7920	7920	7920	7920	7920
Exchange fee (%)	0	0	0	0	0
Market exchange rate ($/Rial)	7920	7920	7920	7920	7920
CIF price (Rials/kg)	89592.54	62126.62	1432.61	127069	1424.57
Weight conversion factor	1	1	1	1	1
CIF price in Iran (R/kg)	89592.54	62126.62	1432.61	1270.79	1424.57
Transport and marketing cost to whole sale market (Rial/Kg)	488.0333	488.0333	488.0333	488.0333	488.0333
Value before processing (Rial/Kg)	90080.58	62614.6	1920.64	1758.82	1912.6
Processing conversion factor (%)	1	1	1	1	1
Import parity price at whole sale (R/kg)	90080.58	62614.66	1920.64	1758.82	1912.6
Distribution cost to farm (R/kg)	0	0	32.69686	32.69686	32.69686
Import parity price at farm gate (Rails/kg)	90080.58	62614.66	1953.34	1791.52	1945.3

Description	Other Chemical Fertilizers	Sugar beet seed
CIF price ($/kg)	2.445596	36.35489
Exchange rate ($/Rial)	7920	7920
Exchange fee (%)	0	0
Market exchange rate ($/Rial)	7920	7920
CIF price (Rials/kg)	19369.1	287931
Weight conversion factor	1	1
CIF price in Iran (R/kg)	19369.1	287031
Transport and marketing cost to whole sale market (Rial/Kg)	488.0333	543.0423
Value before processing (Rial/Kg)	19857.2	288474
Processing conversion factor (%)	1	1
Import parity price at whole sale (R/kg)	19857.2	288474
Distribution cost to farm (R/kg)	32.69686	36.35489
Import parity price at farm gate (Rails/kg)	19889.8	288510

Table A3: Private and Social Prices of Gas Oil and Electricity in the Agricultural Sector of Iran.

Gas oil price (fob) per liter	$ 0.22696
Gas oil price (CIF) per liter	0.24965
Social price per liter	948.228 Rials
Market (private) per liter	165.00 Rials
Social and market price gap	783.228 Rials
Electricity supply cost (Kilowatt hour)	132.38 Rials
Electricity price for agriculture	15.81 Rials
Electricity subsidy for agriculture	116.57 Rials
Ratio of social to private price of gas oil	5.74684
Ratio of social to private price of electricity	8.373

Table A4: Real Exchange Rate and the Ratio of Price Index in Iran and OECD Countries

Year	Market exchange rate	CPI (Iran)	CPI OECD	CPI (IR) / CPI (OECD)	Real exchange rate index
2002	8008.45 (Rial)	177.9	103.5	1.7188	4659.21
2003	8018.9 (Rial)	206	106.1	1.9415	4130.12
2004	8323.05 (Rial)	238.2	108.7	2.1913	3798.13

Table A5: Gross Income per Hectare of Crops in the Last 15 Years

Year	Wheat	Barley	Tomato	Sugar beet	Potato	Onion
1990	57950.0	62319.0	130567.0	16100.7	200527.0	404063.5
1991	38200	33997.6	641815.0	355575.0	-19091.0	-12318.8
1992	227420	35739	1153063	37853	295784	659178
1993	123170	133579	1068684	389748	484236	-39959
1994	295770	287199	984305	690398	1443285	963126.8
1995	471680	526766	266942	1034848	2535592	1698114.4
1996	494510	435935	7663166	442222	- 4982513	-3306672.9
1997	679980	692920	889050	112.000	-5186420	-420444
1998	477990	600100	-5251660	831650	4871700	1237.7
1999	593840	172340	-5395820	1752820	-5049730	-5052990
2000	580390	431820	1978200	1423580	-5557230	4078080
2001	742800	601130	21415.0	2483300	10491160	16793460
2002	784390	531180	9136.70	2376240	6174290	4189480
2003	2163060	108230	11918360	39535.0	1074.200	10201330
2004	3029990	1688420	7804850	5517400	19446350	18157460

Source: Statistical Division, Agricultural Jihad of Province

Table A6: Prices of Sample Crops in Various Areas (Rials/kg)

Crop		Plain	
	Mashhad	Narimani	Sangbast
Wheat	1496.9	1538.3	1533.1
Barley	1154.0	1089.1	1154.3
Tomato	346.6	-	349.5
Sugar beet (Multigerm)	403.7	414.7	385.2
Sugar beet (Monogerm)	390.4	-	-
Potato	1269.4	-	1062.4
Onion	654.2	-	-

Table A7: Yield of Sample Crops in Various Areas (kg/Ha)

Crop		Plain	
	Mashhad	Narimani	Sangbast
Wheat	4333.3	3248.8	2738.8
Barley	4284.9	3262.4	2791.8
Tomato	42855.0	-	43966.6
Sugar beet (Multigerm)	31739.4	28652.3	32430.9
Sugar beet (Monogerm)	49289.4	-	-
Potato	42372.8	-	28092.59
Onion	23008.4	-	-

Table A8: Use of Inputs (resources) in the Base Year (2004)

Inputs	Crop	Mashhad	Plain Narimani	Sangbast	Total	Standard Deviation
Land (Hectare)	Wheat	226.8	27.0	39.5	293.5	111.92
	Barley	590.35	33.5	72.0	695.85	310.98
	Tomato	690.35	-	127.9	818.25	397.71
	Sugar beet 1*	192.3	39.0	92.35	323.65	77.82
	sugar beet 2*	61.5	-	-	61.5	-
	Potato	30.78	-	69.66	100.44	27.49
	Onion	5.90	-	-	5.90	-
Nitrate (Kilogram)	Wheat	56482.5	77500	7000	71232.5	28354.71
	Barley	134197.5	5684.4	17750	157631.8	70970.9
	Tomato	214529	-	34000	248529	127653.28
	Sugar beet 1*	57400	21790.5	19017.0	98207.5	21404.7
	sugar beet 2*	29936	-	-	29936	-
	Potato	4258	-	15900	20158	832
	Onion	1650	-	-	1650	-
Phosphate (Kilogram)	Wheat	43655	5750	3025	52430	22712
	Barley	57050	5100	11750	73900	28269.8
	Tomato	91575	-	34300	125875	40499
	Sugar beet 1*	39125	11650	16850	67625	14595
	sugar beet 2*	22350	-	-	22350	-
	Potato	3900	-	16650	20550	9015.61
	Onion	1800	-	-	1800	-
Potash (Kilogram)	Wheat	5400	500	100	6000	2951.27
	Barley	18900	350	1800	21050	10316.77
	Tomato	600	-	0.0	600	424.26
	Sugar beet 1*	3085	0.0	650	3735	1626.29
	sugar beet 2*	3750	-	-	3750	-
	Potato	50	-	6450	6500	4525
	Onion	0.10	-	-	0.10	-
Manure (Ton)	Wheat	228	25.3	34	287.33	114.59
	Barley	203	16.5	17	236.49	107.53
	Tomato	530	-	251.5	781.5	196.93
	Sugar beet 1*	320	100	513	933	206.65
	sugar beet 2*	0.0	-	-	0.0	-
	Potato	55	-	800.5	855.5	527.15
	Onion	30	-	-	30	-
Various Poisons (liter, kg)	Wheat	193.8	13.6	21.9	229.3	101.73
	Barley	102.9	7.0	20.0	129.85	51.99
	Tomato	188.5	-	519.5	708.0	234
	Sugar beet 1*	361	82	137.5	580.5	147.69
	sugar beet 2*	116.5	-	-	116.5	-
	Potato	44.0	-	613.5	657.5	402.7
	Onion	15.0	-	-	15.0	-
Herbicide (liter, kg)	Wheat	166.8	1.9	0.0	168.69	95.73
	Barley	600.3	0.0	54.0	654.25	332
	Tomato	18.0	-	9.5	27.5	6.01
	Sugar beet 1*	217.5	45	126	388.5	86.3
	sugar beet 2*	57.0	-	-	57.0	-
	Potato	22.0	-	108.5	130.5	61.16
	Onion	5.0	-	-	5.0	-
Land preparation labor (days)	Wheat	431	23	26.8	480.8	234.47
	Barley	381.5	22.0	8.1	411.6	211.68
	Tomato	807.0	-	3.0	810	568.51
	Sugar beet 1*	284	14	46	344	147.52
	sugar beet 2*	133	-	-	133	-
	Potato	23	-	9.1	32.1	9.83
	Onion	51	-	-	51	-

Table A8: Continued

Inputs	Crop	Mashhad	Plain Narimani	Sangbast	Total	Standard Deviation
Labor (man-days) seeding	Wheat	142.1	20	40.9	203	65.3
	Barley	121.1	24	205	165.6	57.1
	Tomato	13054.2	-	561.5	13615.7	8833.67
	Sugar beet 1*	199.1	73	242.6	514.65	88.08
	sugar beet 2*	6.0	-	-	6.0	-
	Potato	135.2	-	141.8	275.95	5.34
	Onion	50.0	-	-	50.0	-
Labor (man-days) growing period	Wheat	1400.4	199	128.3	1727.7	714.91
	Barley	1506.7	149	230	1885.7	761.56
	Tomato	17823.2	-	2699	20522.15	10694.46
	Sugar beet 1*	5812.5	1319	5257.7	12389.1	2449.89
	sugar beet 2*	2189	-	-	2189	-
	Potato	986.7	-	1016.8	2003.45	21.25
	Onion	197	-	-	197	-
Labor (man-days) harvest	Wheat	219	13.5	28.5	261	114.56
	Barley	222.7	12.5	4.5	239.2	123.89
	Tomato	37266.5	-	5763	43029.5	22276.34
	Sugar beet 1*	2756	824	1566	5146	974.62
	sugar beet 2*	1480	-	-	1480	-
	Potato	1007.5	-	3553	4560.45	1799.9
	Onion	336	-	-	336	-
Irrigation water (cubic meter)	Wheat	1790231.6	199584	228988.8	2218799.4	909992
	Barley	398212.7	229714.3	384545.5	4597072	2123568
	Tomato	10209509.4	-	1944080	12153589.4	5844541
	Sugar beet 1*	2736669.4	445536	1631927.1	4814132.49	1145809
	sugar beet 2*	970581.8	-	-	470581.8	-
	Potato	459776.3	-	1092268.8	1552045.0	447239.7
	Onion	79933.4	-	-	79933.4	-
Tractor services (hours per year)	Wheat	1989.4	348.8	349.2	2687.4	941.1
	Barley	5532	395.2	529.1	6456.19	2927.8
	Tomato	6005.4	-	1172.1	7177.5	3417.6
	Sugar beet 1*	2009.6	522.1	771.9	3303.53	796.5
	sugar beet 2*	944.2	-	-	944.2	-
	Potato	167.7	-	471.1	635.78	216.68
	Onion	49.2	-	-	49.2	-

Note: * Multigerm and monogerm cultivars respectively.

Table A9: Input Prices in Base Year

Inputs	Crop	Plain			S.D.
		Mashhad	Narimani	Sangbast	
Land rent (Rials/Ha.)	Wheat	558796.63	548148.1	410759.5	82567.1
	Barley	430473.4	383582.1	344444.4	4372.7
	Tomato	525574.0	-	924394.1	282000.8
	Sugar beet 1*	684061.4	553846.2	627688.1	65302.6
	sugar beet 2*	844715.4	-	-	-
	Potato	524564.7	-	949110	296663.3
	Onion	756520.0	-	-	-
Nitrate (Rials/kg)	Wheat	505.1	454.9	405.0	49.5
	Barley	367.9	455.8	427.0	44.8
	Tomato	448.2	-	399.7	34.2
	Sugar beet 1*	456	449.8	4200.1	19.2
	sugar beet 2*	463	-	-	-
	Potato	494	-	401.4	65.5
	Onion	419.4	-	-	-
Phosphate (Rials/kg)	Wheat	604.9	553.7	568.9	26.3
	Barley	567.2	556.7	572.5	8.0
	Tomato	538.2	-	511.4	18.9
	Sugar beet 1*	560.2	570.4	548.3	11.0
	sugar beet 2*	471.7	-	-	-
	Potato	582.2	-	532.9	34.8
	Onion	536.1	-	-	-
Potash (Rials/kg)	Wheat	500.6	440	350	75.8
	Barley	436.8	440	420	10.7
	Tomato	400	-	-	-
	Sugar beet 1*	461.4	-	400	43.4
	sugar beet 2*	485.9	-	-	-
	Potato	480	-	491.5	8.1
	Onion	460.8	-	-	-
Manure (Rials/ton)	Wheat	25000	42857.1	56764.7	15923.2
	Barley	47438.4	30000	19411.8	14152.2
	Tomato	39905.7	-	47952.3	5689.8
	Sugar beet 1*	45406.3	36666.7	27347	9031.2
	sugar beet 2*	39433.0	-	-	-
	Potato	14090.0	-	32725.8	13176.9
	Onion	68750	-	-	-
Poisons (Rials/kg. liter)	Wheat	22401	23088.2	18036.5	2739.8
	Barley	23175.6	29142.9	19450	4889.4
	Tomato	28069	-	18052.9	7082.4
	Sugar beet 1*	22838.8	29024.4	19320	4912.9
	sugar beet 2*	25206.4	-	-	-
	Potato	20000.0	-	19559.9	311.2
	Onion	20543.3	-	-	-
Herbicides (Rials/kg. liter)	Wheat	17565.7	26100	36520.1	9492.8
	Barley	15436.2	22973	20000	3796.3
	Tomato	25815.6	-	36105.3	7275.9
	Sugar beet 1*	29671.5	19858.5	39047.6	9595.4
	sugar beet 2*	15312.3	-	-	-
	Potato	37954.5	-	37880.2	52.6
	Onion	13150.0	-	-	-

Table A9: Continued

Inputs	Crop		Plain		S.D.
		Mashhad	Narimani	Sangbast	
Labor Land per pa. (Rials/day)	Wheat	28277.3	29347.8	28134.3	663.2
	Barley	29783.7	28636.4	23963.0	308.3
	Tomato	37298.6	-	25000	8696.4
	Sugar beet 1*	31232.4	40000.0	20434.8	9800.1
	sugar beet 2*	29060.2	-	-	-
	Potato	35217.4	-	30439.6	3378.4
	Onion	33627.5	-	-	-
Labor (seeding) (Rials/day)	Wheat	28226.6	31250	25941.3	2662.9
	Barley	30123.9	30416.7	23902.4	3679.4
	Tomato	29647.1	-	24939.5	3328.8
	Sugar beet 1*	32625	32328.8	24732.1	4473.9
	sugar beet 2*	30000	-	-	-
	Potato	30000	-	26134	2733.6
	Onion	36400	-	-	-
Labor (growing) (Rials/day)	Wheat	30867	30105.5	30202.7	414.4
	Barley	31465.5	29369.1	299978.3	1078.4
	Tomato	25569	-	20386.4	3664.6
	Sugar beet 1*	24415	25246.4	20681.5	2431.4
	sugar beet 2*	21032.4	-	-	-
	Potato	27887.4	-	23414.4	3240.7
	Onion	26116.8	-	-	-
Labor (harvest) (Rials/day)	Wheat	31004.6	30000	28157.9	1443.7
	Barley	29259.8	33371.79	26250	17665.4
	Tomato	30441.9	-	20886.7	6756.6
	Sugar beet 1*	28594	39514.6	23960.7	7985.9
	sugar beet 2*	25027	-	-	-
	Potato	27002.5	-	22567.0	-
	Onion	29207.2	-	-	-

Inputs	Crop		Plain		S.D.
		Mashhad	Narimani	Sangbast	
Irrigation water (Rials/cu.m.)	Wheat	45.2	51.6	49.9	3.3
	Barley	45.2	51.6	49.9	3.3
	Tomato	45.2	-	49.9	3.3
	Sugar beet 1*	45.2	51.6	49.9	3.3
	sugar beet 2*	45.2	-	-	-
	Potato	45.2	-	49.9	3.3
	Onion	45.2	-	-	-
Machinery services (Rials/hour)	Wheat	68507.1	47640	34831.3	16997.8
	Barley	54111.6	33472.9	39769.2	10577.5
	Tomato	28808.7	-	40729.4	-
	Sugar beet 1*	57315.7	37878.6	58805.4	11675.8
	sugar beet 2*	45723.3	-	-	-
	Potato	87870.2	-	109853.8	15544.8

Note: * Multigerm and monogerm cultivars respectively.

Table A10: Net Social Profits of Sample Crops (Rials/Hectare)

Description			Wheat		Barley		Tomato	Sugar beet (1)*
			Irrigated	Rain fed	Irrigated	Rain fed		
Plain	Mashhad	Social profit	1694613.82	777778.31	1744390.9	601764.7	6888284.24	-4840705.9
		DRC Ratio	0.729	0.421	0.691	0.469	0.593	2.662
	Nariman	Social profit	-30436	381165.76	1699470	246825.8	-	-5680781
		DRC Ratio	1.007	0.615	0.685	0.726	-	3.964
	Sangbast	Social profit	973835.84	-	1440810	-	8683467	-7850606.86
		DRC Ratio	0.781	-	0.680	-	0.490	4.337

Description								
			Sugar beet (2)*	Onion	Potato			
Plain	Mashhad		1694613.82	8052931.7	-464794.6			
		-5872010	0.729	0.589	1.027			
	Nariman	2.449	-30436	-	-			
		-	1.007	-	-			
	Sangbast	-	973835.84	-	4592630			
		-	0.781	-	0.776			

Note: * Multigerm and monogerm cultivars respectively.

Appendix 2: Programs Written for Expected Profit Mean Variance Utility Efficient and Nearly Optimum Models Respectively for Small, Medium and Large Farms

Small Farms:

```
$offsymlist
option limrow =0
option limcol =0
set c crops /wheat3*wheat8, barely3*barely7 , tomoto, sugbeet8, sugbeet12
            sugbeet13 , sugbeet15, sugbeet16, potato , onion /
    we(c) /wheat3*wheat8/
    be(c) /barely3*barely7/
    te(c) /tomoto/
    se(c)/sugbeet8, sugbeet12,sugbeet13 , sugbeet15, sugbeet16/
   j constraints / land , water , labour1*labour4, azote , phosphate , potash ,
                 manure , pesticide , herbicide, tracserv /
   t time / 1368*1382/; alias(c,cc);alias(t,tt);
parameter b(j) "quantity of inputs" /land 2.71 ,
                                water 25673.22,
                                labour1 8.782,
                                labour2 12.07,
                                labour3 45.33,
                                labour4 34.57,
                                azote 604.42,
                                phosphate 576.74,
                                potash 11.751,
                                manure 5.81,
                                pesticide 2.654,
                                herbicide 1.79,
                                tracserv 124963/;
Table d(j,c) "input-output coefficients"
        wheat3    wheat4   wheat5   wheat6    wheat7
land       1.0      1.0      1.0      1.0       1.0
water      4350.0   5800.0   7250.0   8700.0    10150.0
labour1    0.8      2.4      3.1      3.0       3.1
labour2    1.9      2.0      2.0      1.0       0.6
labour3    4.5      3.7      4.9      5.9       6.7
labour4    6.5      9.2      0.7      1.1       0.8
azote      190.5    96.4     186.9    250.0     180.0
phosphate   238.1   78.9     189.3    250.0     212.0
potash     0.0      0.0      9.7      0.0       0.0
manure      0.0      1.7      0.0      0.0       1.3
pesticide  0.6      0.5      1.4      0.4       0.8
herbicide  0.4      0.0      0.9      0.6       0.6
tracserv   35523.8  30933.7  52512.1  53250.0  64280.0
+         wheat8    barely3  barely4 barely5  barely6  barely7  tomoto
land       1.0       1.0     1.0      1.0      1.0      1.0      1.0
water      11600.0  4050.0  5400.0   6750.0   8100.0   9450.0   15520.0
labour1    0.8       0.9     1.2      2.9      3.2      2.3      7.4
labour2    0.8       1.3     0.5      2.2      1.5      0.8      20.6
labour3    7.6       3.5     4.9      5.7      5.0      7.5      35.9
labour4    5.2       5.0     0.0      3.1      0.0      1.7      41.4
azote      240.0     80.2    133.9    177.8    187.5    269.2    498.4
phosphate   180.0    106.9   141.8    166.7    200.0    192.3    395.9
potash     0.0       0.0     0.0      0.0      0.0      0.0      0.0
manure      0.0       1.1     0.0      0.0      4.0      0.0      4.0
pesticide  0.3       0.1     0.8      0.1      0.0      0.0      3.0
herbicide  0.8       0.3     1.0      0.0      0.3      0.0      0.4
tracserv   39400.0  2925.7  60436.4  52077.8  49200.0  46592.3  1.0
+         sugbeet8 sugbeet12 sugbeet13 sugbeet15 sugbeet16 potato  onion
land      1.0     1.0       1.0       1.0       1.0       1.0      1.0
water     9600.0 14400.0   15600.0   18000.0   19200.0   15078.0  16150.0
labour1   1.5     3.5       3.9       6.5       1.9       5.1      17.8
labour2   4.3     5.6       1.1       1.7       3.8       29.6     35.6
```

```
labour3    46.0    41.2      43.6      67.5      52.0      54.6     64.4
labour4    19.3    31.3      12.3      29.9      23.3      42.8     241.1
azote      266.7   318.8     237.5     204.1     401.2     405.4    444.4
phosphate   233.3   420.3     250.0     173.5     270.6     405.4    611.1
potash     33.3    14.5      50.0      10.2      11.8      0.0      0.0
manure     4.0     8.4       0.0       1.0       12.9      13.7     23.6
pesticide  2.2     2.2       1.0       0.4       1.4       0.6      5.6
herbicide  0.0     0.3       0.6       6.1       0.2       0.2      0.0
tracserv   38333.3 61739.1   59875.0   22755.1   83882.4   28281.9  47777.8;
Table k(t,c) "states of nature (or reconstructed data)"
         wheat3     wheat4       wheat5      wheat6      wheat7
1368   152963.1   260530.8   116372.6   339970.4  262930.4
1369   141481.5   250841.1   106283.2   327555.8  254698.8
1370   166527.5   271978.2   128292.3   354637.0  272655.2
1371   130157.0   241284.0   96331.8    315311.2  246579.9
1372   134333.0   244808.3   100001.5   319826.5  249573.8
1373   136120.1   246316.4   101571.9   321758.8  250855.0
1374   134609.4   245041.5   100244.4   320125.3  249772.0
1375   132841.5   243549.6   98690.8    318213.8  248504.5
1376   202649.8   302463.0   160034.6   393694.5  298552.6
1377   193856.3   295041.9   152307.4   384186.5  292248.3
1378   -25877.3   109601.8   -40782.8   146598.0  134713.2
1379   -49440.1   89716.4    -61488.5   121120.5  117820.1
1380   -96745.1   49794.3    -103057.6  69971.7   83905.4
1381   250741.7   343049.2   202295.2   445694.2  333031.5
1382   327496.6   407825.1   269743.4   528686.0  388059.9
+        wheat8     barely3      barely4     barely5     barely6      barely7      tomoto
1368  205345.3   214740.0  91101.0    166791.8  174837.1  133616.6  326350.8
1369  197414.2   189831.3  72559.1    146064.5  156052.9  114341.6  252070.9
1370  214715.0   175192.3  61661.9    133882.9  145013.3  103013.6  227279.3
1371  189591.7   180346.4  65498.6    138171.8  148900.1  107002.0  213726.9
1372  192476.3   191121.8  73519.7    147138.3  157026.1  115340.2  255939.9
1373  193710.7   217303.8  93009.4    168925.2  176770.5  135600.6  328746.5
1374  192667.2   210856.2  88209.9    163560.0  171908.2  130611.3  831221.7
1375  191446.0   245602.6  114074.9  192473.5  198111.2  157498.9  507469.0
1376  239666.9   439842.0  258665.3  354106.2  344591.3  307806.3  -323400.6
1377  233592.7   169923.8  57740.1    129498.9  141040.2  98936.8   -241741.5
1378  81809.3    99354.9   5209.1     70776.3   87822.7   44328.7   521380.6
1379  65533.0    105112.0  9494.6     75566.9   92164.2   48783.7   410570.6
1380  32856.5    77911.7   -10753.1  52932.7   71651.9   27735.4   309783.3
1381  272886.9   62702.7   -22074.6  40276.8   60182.4   15966.3   752443.3
1382  325906.2   456338.1  270944.9  367833.1  357031.4  320571.4  -59771.1
+    sugbeet8    sugbeet12  sugbeet13 sugbeet15 sugbeet16 potato        onion
1368 738851.7  502680.2  486459.3  660397.7  505932.2  1920315.2  1150519.7
1369 743692.0  506101.5  488544.5  663298.9  508787.6  1272714.3  913905.5
1370 733417.1  498838.8  484118.0  657140.4  502726.3  1342085.5  865344.5
1371 801826.4  547193.1  513588.7  698142.7  543081.3  1196202.3  877842.4
1372 828571.4  566097.5  525110.4  714172.8  558858.3  1636740.5  1008332.1
1373 858602.4  587324.6  538047.8  732172.5  576573.8  2086789.0  1182607.0
1374 715992.7  486522.6  476611.6  646696.8  492447.6  1198302.6  670050.6
1375 811920.4  554327.9  517937.2  704192.7  549035.8  2202834.5  768329.3
1376 1036133.1 712810.0  614527.8  838578.7  681300.0  2500498.4  2423238.1
1377 1442012.4 999701.0  789380.2  1081849.7 920730.1  -852690.5  133860.6
1378 347322.8  225932.6  317789.0  425727.8  274967.4  2268095.0  926904.0
1379 316636.7  204242.6  304569.5  407335.6  256865.6  2808222.6  1186405.5
1380 76596.1   34572.6   201160.2  263462.9  115264.5  304022.4   583235.2
1381 1030499.0 708827.6  612100.6  835201.8  677976.4  1760741.4  1082217.6
1382 1172632.0 809292.7  673331.4  920391.7  761821.3  1705568.3  1115521.3
parameter mean(c) "mean return to activities x(c)"
        covar(c,cc) "variance covariance matrix of activities";
mean(c)=sum (t,k(t,c)/card(t));
covar(c,cc)=sum(t,(k(t,c)-mean(c))*(k(t,c)-mean(c)))/card(t);
display mean , covar;
```

```
 scalar a "implies variation in absolute risk aversion coefficent" /1/
      rmin " minimum risk aversion coefficient" / 0.000000809/
      rmax " maximum risk aversion coefficient" / 0.0000325/
      rap risk aversion parameter/0.0/
option nlp=minos;
variable x(c) "decision variables"
         u(t)   "utility"
         tou "total utility"
         w(t)
         z
positive variable  x, u ;
Equation obj "objective function for utility efficient programming"
        obj1 "objective function for E-V"
        utility(t) "expected utility"
        const(j) "constraints"
        const1(t) "states of nature";
utility(t) ..  u(t) =e= 1- exp(-((1-a)*rmin+a*rmax)*w(t));
obj ..    tou =e= sum(t, u(t)*(1/card(t)));
obj1 .. z =e= sum(c,mean(c)*x(c))-rap*0.5*(sum(c,sum(cc,x(c)*covar(c,cc)*x(cc))));
const(j) .. sum (c , d(j,c)*x(c)) =l= b(j);
const1(t) .. sum (c ,k(t,c)*x(c)) =e= w(t);
model utefprg /obj,const,const1,utility/
     evsmall / obj1,const/;
solve utefprg maximizing tou using nlp;
solve evsmall using nlp maximizing z;
scalar var "the quantity of variance";
var = sum(cc,sum(c,x.l(c)*covar(c,cc)*x.l(cc)));
set raps risk aversion coefficients /r1*r22,r0/;
parameter risk(raps) risk aversion coefficient
/r1       3.25E-05
r2        3.09E-05
r3        2.93E-05
r4        2.77E-05
r5        2.62E-05
r6        2.46E-05
r7        2.30E-05
r8        2.14E-05
r9        1.98E-05
r10       1.82E-05
r11       1.67E-05
r12       1.51E-05
r13       1.35E-05
r14       1.19E-05
r15       1.03E-05
r16       8.73E-06
r17       7.15E-06
r18       5.56E-06
r19       3.98E-06
r20       2.39E-06
r21       1.58E-06
r22       8.09E-07
r0        0.00E+00/;
parameter output (*,raps) "results from model runs whit varying rap"
loop (raps , rap=risk(raps);
solve evsmall maximizing z using nlp;
var= sum(c,sum(cc,x.l(c)*covar(c,cc)*x.l(cc)));
output("z" ,raps)=z.l;
output("rap" , raps)=rap;
output(c,raps)=x.l(c);
output("mean",raps)=sum(c, mean(c)*x.l(c));
output("var", raps)=var;
output("std", raps)=sqrt(var)
);
```

```
set rraps risk aversion parameter /rr1*rr22/;
parameter risk1(rraps) risk aversion parameter
/ rr1        3.25E-05
rr2         3.09E-05
rr3         2.93E-05
rr4         2.77E-05
rr5         2.62E-05
rr6         2.46E-05
rr7         2.30E-05
rr8         2.14E-05
rr9         1.98E-05
rr10        1.82E-05
rr11        1.67E-05
rr12        1.51E-05
rr13        1.35E-05
rr14        1.19E-05
rr15        1.03E-05
rr16        8.73E-06
rr17        7.15E-06
rr18        5.56E-06
rr19        3.98E-06
rr20        2.39E-06
rr21        1.58E-06
rr22        8.09E-07/;
parameter output1 (*,rraps) "results from model runs whit varying rmax"
loop (rraps , rmax=risk1(rraps);
solve utefprg maximizing tou using nlp;
var= sum(c,sum(cc,x.l(c)*covar(c,cc)*x.l(cc)));
output1("tou" ,rraps)=tou.l;
output1("rmax" , rraps)=rmax;
output1(c,rraps)=x.l(c);
output1("mean",rraps)=sum(c, mean(c)*x.l(c));
output1("var", rraps)=var;
output1("std", rraps)=sqrt(var)
);
display output,output1;
parameter z2, mean2;
z2=output("z","r0");
mean2=output("mean","r0")
display z2;
variable y;
equation const3 new constraint for MGA
        obj4 objective function for MGA;
const3 ..  mean2=g= 0.05*z2;
*const3 .. yy =e= 0.05*output("mean","r0")-rap*0.5*(sum(c,sum(cc,x(c)*covar(c,cc)*x(cc))));
obj4..  y=e=sum(se,x(se))+x('potato');
model mga /const, const3, obj4/;
solve mga minimizing y using nlp;
display x.l;
```

Medium Farms

```
$offsymlist
option limrow =0
option limcol =0
set c crops / wheat3*wheat8 , barely3*barely7 , tomoto10,tomoto15, sugbeet9,
            sugbeet15 , sugbeet16, sugmono, potato , onion /
   we(c) / wheat3*wheat8/
   be(c) / barely3*barely7/
   te(c) / tomoto10,tomoto15/
   se(c) / sugbeet9,sugbeet15,sugbeet16,sugmono/
   j constraints / land , water , labour1*labour4, azote , phosphate , potash ,
                 manure , pesticide , herbicide  , tracserv /
```

```
   t time / 1368*1382/;alias(c,cc); alias(t,tt);
parameter b(j) "quantity of inputs"/ land       7.59
                                water      77434.79
                                labour1    13.92
                                labour2    18.95
                                labour3    106.21
                                labour4    84.261
                                azote      1811.46
                                phosphate  1395.04
                                potash     54.54
                                manure     18.87
                                pesticide  6.41
                                herbicide  3.82
                                tracserv   438405.68/;
Table d(j,c) "input-output coefficients"
        WHEAT3   WHEAT4   WHEAT5   WHEAT6   WHEAT7   WHEAT8   BARELY3  BARELY4
land      1.00     1.00     1.00     1.00     1.00     1.00     1.00     1.00
water     4350.00  5800.00  7250.00  8700.00  10150.00 11600.00 4050.00  5400.00
labour1   1.36     0.19     0.93     1.24     1.78     0.16     1.54     1.70
labour2   1.84     1.41     1.72     0.43     0.00     0.11     0.85     0.45
labour3   2.72     3.44     5.66     5.75     7.20     9.88     2.46     4.15
labour4   3.96     0.63     0.20     0.30     0.25     0.31     5.15     0.30
azote     124.00   150.00   259.46   201.47   233.33   405.88   61.54    150.00
phosphate 76.00    84.38    186.49   160.29   249.38   264.71   61.54    170.00
potash    0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
manure    3.52     3.13     4.11     0.71     0.00     0.00     0.23     0.00
pesticide 0.29     0.31     0.43     0.47     0.66     0.60     0.00     1.12
herbicide 0.00     0.00     1.34     0.65     0.69     0.00     0.31     1.35
tracserv  30520.00 33043.75 59608.11 49867.65 58481.48 71382.35 39076.92 65500.00
+          BARELY5  BARELY6  BARELY7  TOMOTO10 TOMOTO15 sugbeet9
land       1.00     1.00     1.00     1.00     1.00     1.00
water      6750.00  8100.00  9450.00  14500.00 21750.00 10800.00
labour1    1.94     2.67     5.00     5.00     3.13     1.79
labour2    1.36     1.14     1.83     15.14    19.50    2.59
labour3    5.28     5.57     5.17     18.25    30.65    44.21
labour4    1.56     0.00     3.67     68.64    64.39    17.86
azote      183.33   176.19   133.33   375.00   374.00   303.45
phosphate  191.67   114.29   166.67   198.21   360.87   200.00
potash     0.00     33.33    0.00     0.00     0.00     0.00
manure     0.00     2.67     0.00     3.79     5.00     4.83
pesticide  0.29     0.45     0.07     2.54     4.26     2.00
herbicide  0.00     0.05     0.00     0.00     0.13     0.00
tracserv   51927.78 60730.95 42833.33 40035.71 40808.70 56689.66
+         sugbeet15 SUGbeet16  SUGMONO   potato    onion
land      1.00      1.00       1.00      1.00      1.00
water     18000.00  19200.00   17248.00  15782.00  16666.25
labour1   1.26      0.70       3.65      0.44      4.00
labour2   2.39      3.04       0.00      2.39      8.25
labour3   33.20     55.91      35.18     30.17     47.00
labour4   11.11     20.35      17.18     35.56     116.00
azote     437.04    217.39     376.47    106.44    325.00
phosphate 120.37    178.26     305.88    188.89    187.50
potash    6.30      8.70       35.29     88.89     0.00
manure    14.22     8.00       1.00      2.89      2.50
pesticide 0.37      0.96       1.41      2.22      0.75
herbicide 0.00      0.00       0.71      1.00      0.50
tracserv  68370.37  102391.30 92470.59  95555.56   44500.00;
Table k(t,c) "states of nature,(or recunstracted data)"
     WHEAT3    WHEAT4    WHEAT5   WHEAT6   WHEAT7   WHEAT8   BARELY3  BARELY4
1368 212592.9  350948.0  387760.4 305471.8 204615.8 190227.3 58312.7  134198.7
1369 204199.7  339734.7  372961.4 291583.4 197612.9 177761.7 46521.3  117317.7
1370 222508.5  364195.5  405243.8 321879.4 212888.9 204954.1 39591.4  107396.6
1371 195921.4  328674.8  358365.0 277885.1 190705.9 165466.7 42031.2  110889.6
```

```
1372 198974.1  332753.2  363747.6 282936.5 193252.9 170000.6 47132.2  118192.3
1373 200280.5  334498.5  366050.9 285098.1 194342.9 171940.8 59526.3  135936.2
1374 199176.2  333023.1  364103.8 283270.8 193421.5 170300.7 56474.2  131566.6
1375 197883.8  331296.5  361825.1 281132.3 192343.2 168381.3 72922.5  155114.7
1376 248914.1  399473.8  451802.6 365573.6 234920.6 244172.1 164872.5 286753.3
1377 242486.0  390885.8  440468.5 354936.8 229557.3 234625.0 37097.4  103826.1
1378 81859.3   176286.0  157248.8 89143.3  95537.5  -3939.6  3691.1   56000.6
1379 64634.7   153273.7  126878.1 60641.3  81166.1  -29521.8 6416.4   59902.3
1380 30054.4   107074.0  65905.7  3420.4   52313.9  -80880.7 -6459.7  41468.3
1381 284069.6  446442.1  513789.4 423746.4 264252.8 296385.4 -13659.5 31160.9
1382 340178.0  521403.8  612720.6 516590.5 311067.2 379718.3 172681.5 297932.9
+   BARELY5  BARELY6  BARELY7  TOMOTO10  TOMOTO15 sugbeet9 sugbeet15  sugbeet16
1368 111539.3 73706.5  189369.4 505286.3  537351.4 695928.4  573989.9  181568.0
1369 96643.1  57819.5  171118.3 428652.7  471613.6 699993.1  578095.0  185153.9
1370 87888.6  48482.6  160392.0 403075.6  449673.0 691364.7  569380.9  177541.7
1371 90970.9  51769.9  164168.5 389093.8  437679.1 748811.4  627398.1  228222.9
1372 97414.9  58642.6  172063.9 432644.3  475037.6 771270.5  650080.2  248037.0
1373 113072.5 75341.6  191247.9 507757.9  539471.6 796489.1  675549.2  270285.7
1374 109216.7 71229.4  186523.7 1026154.6 984162.6 676732.6  554603.5  164632.8
1375 129996.1 93390.8  211983.0 692143.4  697641.1 757287.8  635958.7  235701.1
1376 246157.0 217278.1 354305.7 -165053.2 -37679.2 945570.4  826111.1  401809.8
1377 84737.9  45122.4  156531.8 -80806.6  34589.2  1286407.5 1170332.9 702506.8
1378 42535.6  113.0    104824.6 706495.9  709952.9 367142.1  241938.4  -108497.5
1379 45978.5  3784.9   109042.9 592174.7  611886.0 341373.5  215913.9  -131231.3
1380 29711.9  -13563.6 89112.8  488193.9  522689.1 139799.4  12338.0   -309066.2
1381 20616.5  -23264.1 77968.9  944880.0  914443.6 940839.2  821332.9  397635.8
1382 256022.2 227799.5 366392.7 106929.7  195633.1 1060195.3 941874.3  502935.5
+    SUGMONO   potato    onion
1368  543839.4  683427.7   1915087.7
1369  547796.2  470527.2   1496398.3
1370  539396.7  426833.1   1541248.5
1371  595319.6  438078.4   1446931.5
1372  617182.9  555490.3   1731750.0
1373  641732.6  712299.1   2022717.0
1374  525152.7  251111.7   1448289.4
1375  603571.2  339540.8   2097743.2
1376  786859.4  1828592.7  2290190.0
1377  1118655.6 -231340.7  122273.6
1378  223774.3  482223.0   2139935.7
1379  198689.2  715716.9   2489141.0
1380  2462.0    172997.1   870116.0
1381  782253.7  621970.9   1811919.5
1382  898443.9  651936.9   1776248.8
parameter mean(c) "mean return to activities x(c)"
          covar(c,cc) "variance covariance matrix of activities";
mean(c)=sum (t,k(t,c)/card(t));
covar(c,cc)=sum(t,(k(t,c)-mean(c))*(k(t,c)-mean(c)))/card(t);
display mean , covar;
 scalar a "implies variation in absolute risk aversion coefficent" /1/
      rmin " minimum risk aversion coefficient" / 0.00000065/
      rmax " maximum risk aversion coefficient" / 0.0000285/
      rap  risk aversion parameter/0.0/;
option nlp=minos;
variable x(c) "decision variables"
          u(t)   "utility"
          tou "total utility"
          w(t)
          z
positive variable  x, u;
x.up('wheat4')=0.3423;
Equation obj "objective function for UEP"
         obj2 "objective function for E-V"
         utility(t) "expected utility"
```

```
     const(j) "constraints"
     const2(c) "Related to total area of wheat"
     const1(t) "states of nature(recunstracted data),net profit";
utility(t).. u(t)=e=1-exp(-((1-a)*rmin+a*rmax)*w(t));
*obj ..  tou =e=(1-sum(t,(sum(tt, exp(-((1-a)*rmin+a*rmax)*w(tt))))/(1/card(t))));
obj ..   tou =e= sum(t, u(t)*(1/card(t)));
const(j) .. sum (c , d(j,c)*x(c)) =l= b(j);
const1(t) .. sum (c ,k(t,c)*x(c)) =e= w(t);
const2(c).. sum(we,x(we)) =l=3.5;
obj2 .. z =e= sum(c,mean(c)*x(c))-rap*0.5*(sum(c,sum(cc,x(c)*covar(c,cc)*x(cc))));
model    utefprg /obj,const,const1,utility, const2/
         evsmall / obj2,const,const2/;
solve utefprg maximizing tou using nlp;
solve evsmall using nlp maximizing z;
scalar var "the quantity of variance";
var = sum(cc,sum(c,x.l(c)*covar(c,cc)*x.l(cc)));
display var;
set raps risk aversion coefficients /r1*r21,r0/;
parameter risk(raps) risk aversion coefficient
/r1     0.0000251
r2      2.39E-05
r3      0.000022655
r4      2.14E-05
r5      0.00002021
r6      1.90E-05
r7      0.000017765
r8      1.65E-05
r9      0.00001532
r10     1.41E-05
r11     0.000012875
r12     1.17E-05
r13     0.00001043
r14     9.21E-06
r15     0.000007985
r16     6.76E-06
r17     0.00000554
r18     4.32E-06
r19     0.000003095
r20     1.87E-06
r21     0.00000065
r0     0/;
parameter output (*,raps) "results from model runs whit varying rap"
loop (raps , rap=risk(raps);
solve evsmall maximizing z using nlp;
var= sum(c,sum(cc,x.l(c)*covar(c,cc)*x.l(cc)));
output("z" ,raps)=z.l;
output("rap" , raps)=rap;
output(c,raps)=x.l(c);
output("mean",raps)=sum(c, mean(c)*x.l(c));
output("var", raps)=var;
output("std", raps)=sqrt(var)
);
set rraps risk aversion parameter/rr1*rr21/;
parameter risk1(rraps) risk aversion parameter
/rr1    0.0000251
rr2     2.39E-05
rr3     0.000022655
rr4     2.14E-05
rr5     0.00002021
rr6     1.90E-05
rr7     0.000017765
rr8     1.65E-05
rr9     0.00001532
```

```
rr10     1.41E-05
rr11     0.000012875
rr12     1.17E-05
rr13     0.00001043
rr14     9.21E-06
rr15     0.000007985
rr16     6.76E-06
rr17     0.00000554
rr18     4.32E-06
rr19     0.000003095
rr20     1.87E-06
rr21     0.00000065/;
parameter output1 (*,rraps) "results from model runs whit varying rmax"
loop (rraps , rmax=risk1(rraps);
solve utefprg maximizing tou using nlp;
var= sum(c,sum(cc,x.l(c)*covar(c,cc)*x.l(cc)));
output1("tou" ,rraps)=tou.l;
output1("rmax" , rraps)=rmax;
output1(c,rraps)=x.l(c);
output1("mean",rraps)=sum(c, mean(c)*x.l(c));
output1("var", rraps)=var;
output1("std", rraps)=sqrt(var)
);
display output;
display output1;
parameter z2, mean2;
z2=output("z","r0");
mean2=output("mean","r0")
display z2;
variable y;
equation const3 new contraint for MGA
        obj4 objective function for MGA;
const3 ..  mean2=g= 0.05*z2;
*const3 .. yy =e= 0.05*output("mean","r0")-rap*0.5*(sum(c,sum(cc,x(c)*covar(c,cc)*x(cc))));
obj4..  y=e=sum(se,x(se));
model mga /const, const3, obj4/;
solve mga minimizing y using nlp;
display x.l;
```

Large Farms

```
$offsymlist
option limrow =0
option limcol =0
*option iterlim=15000
set c crops / wheat5,wheat6,wheat8, barely3*barely6 ,tomoto10,tomoto12,tomoto15,
            sugbeet10,sugbeet15,sugbeet16 , sugbeet19, sugmono, potato , onion /
        we(c)/wheat5,wheat6,wheat8/
        be(c)/barely3*barely6/
        te(c)/ tomoto10,tomoto12,tomoto15/
        se(c)/sugbeet10,sugbeet15,sugbeet16 , sugbeet19, sugmono/
   j constraints / land , water , labour1*labour4, azote , phosphate , potash ,
                  manure , pesticide , herbicide , tracserv /
   t time / 1368*1382/;alias(c,cc); alias(t,tt);
parameter b(j) "quantity of inputs"
  /land         23.74
   water         314189.42
   labour1        105.59
   labour2        92.55
   labour3        527.3
   labour4        592.95
   azote         6951.56
```

```
   phosphate       5744.71
   potash          633.29
   manure          42.22
   pesticide       45.84
   herbicide       13.31
   tracserv        1376074.02/;
Table d(j,c) "input-output coefficients"
        wheat5   wheat6   wheat8   barely3  barely4 barely5   barely6  tomoto10
land      1.00     1.00     1.00     1.00     1.00    1.00      1.00     1.00
water     7250.00  8700.00  11600.00 4050.00  5400.00 6750.00   8100.00  14500.0
labour1   1.58     1.11     3.05     2.45     1.80    0.72      3.67     2.18
labour2   0.32     0.64     0.12     0.64     0.71    1.65      0.22     20.91
labour3   4.75     6.56     7.79     2.86     2.10    4.43      6.50     22.18
labour4   0.19     0.15     0.16     0.17     0.41    0.21      0.18     66.82
azote     342.07   213.89   321.13   184.09   193.50  326.59    88.89    263.24
phosphate 181.13   138.89   235.53   163.64   153.50  228.95    172.22   79.41
potash    18.87    27.78    102.63   0.00     0.00    75.44     0.00     0.00
manure    0.60     0.11     0.00     0.00     0.00    0.00      0.00     2.94
pesticide 1.72     0.60     0.59     0.00     0.44    0.79      0.08     2.76
herbicide 0.92     0.33     0.77     0.95     0.00    0.11      0.00     0.47
tracserv 67177.74 64777.78 71713.16 47636.36 20138.89 49985.75 53083.33 48058.8
+         tomoto12 tomoto15 sugbeet10 sugbeet15 sugbeet16
land      1.00     1.00     1.00      1.00      1.00
water     17400.0  21750.0  12000.0   18000.0   19200.00
labour1   0.23     3.71     3.05      1.90      0.16
labour2   8.59     15.61    0.29      1.41      0.72
labour3   31.73    25.52    26.05     31.76     62.44
labour4   39.86    60.79    15.12     15.85     15.11
azote     268.18   368.75   258.54    277.94    122.95
phosphate 268.18   314.58   218.29    332.35    88.52
potash    0.00     0.00     18.29     14.71     4.92
manure    6.36     2.00     0.49      3.82      0.00
pesticide 1.27     1.79     2.68      1.74      2.85
herbicide 0.09     0.21     0.00      0.18      1.31
tracserv  39181.82 54250.00 64475.61  68636.76  73032.79
+          sugbeet19   sugmono    potato     onion
land        1.00        1.00        1.00        1.00
water       22800.00    15888.00    16041.00    17843.00
labour1     2.10        1.92        0.19        8.64
labour2     1.07        0.11        1.62        8.47
labour3     52.53       35.66       18.64       33.39
labour4     17.93       25.17       45.63       56.95
azote       426.67      504.45      195.35      279.66
phosphate   433.33      372.64      200.63      305.08
potash      0.00        65.09       67.58       0.00
manure      3.33        0.00        8.48        5.08
pesticide   2.00        1.97        6.84        2.54
herbicide   0.00        0.96        1.37        0.85
*seed       16.67       4.50        2756.60     5.59
tracserv    80333.33    66634.91    73136.24    46271.19;
Table k(t,c) "states of nature (recunstracted data)"
     wheat5    wheat6    wheat8    barely3   barely4   barely5   barely6
1368  296405.3  241552.5  213230.0  245601.2  222433.8  172708.8  102663.8
1369  283008.7  227937.6  202935.5  223006.6  206315.7  152349.1  87139.8
1370  312231.9  257637.1  225392.0  209727.5  196843.0  140383.5  78016.2
1371  269795.5  214509.0  192781.9  214402.8  200178.1  144596.4  81228.4
1372  274668.0  219460.9  196526.1  224177.2  207150.7  153403.9  87944.0
1373  276753.1  221580.0  198128.4  247926.8  224092.7  174804.4  104261.7
1374  274990.5  219788.7  196773.9  242078.2  219920.6  169534.3  100243.3
1375  272927.8  217692.3  195188.8  273596.6  242404.5  197935.1  121898.6
1376  354378.7  300471.0  257779.5  449790.5  368094.1  356701.2  242956.0
1377  344118.6  290043.6  249895.2  204948.6  193433.9  136077.3  74732.7
1378  87737.7   29483.5   52880.1   140935.7  147769.7  78396.1   30751.4
```

```
1379  60245.1   1542.7    31753.5   146157.9  151495.0  83101.8   34339.4
1380  5050.6    -54551.5  -10660.6  121484.7  133894.1  60869.0   17387.2
1381  410491.4  357498.3  300899.2  107688.6  124052.6  48437.5   7908.3
1382  500047.6  448514.4  369718.4  464754.0  378768.5  370184.7  253237.0
+     tomoto10   tomoto12  tomoto15  sugbeet10  sugbeet15  sugbeet16
1368  789698.9   601897.1  676699.9  714172.1   714205.1   465662.1
1369  701408.9   539038.5  614673.6  718770.1   718251.1   468656.8
1370  671941.3   518058.9  593971.8  709009.6   709662.2   462299.6
1371  655832.8   506590.4  582655.2  773994.0   766846.0   504625.1
1372  706007.6   542312.6  617904.4  799400.1   789202.4   521172.4
1373  792546.5   603924.4  678700.4  827927.7   814305.6   539752.9
1374  1389794.5  1029138.3 1098284.2 692457.5   695097.1   451519.0
1375  1004978.1  755166.3  827939.7  783582.7   775283.7   510870.3
1376  17396.7    52052.4   134135.5  996570.6   962704.7   649592.8
1377  114457.6   121155.4  202323.6  1382130.3  1301982.1  900714.0
1378  1021513.7  766938.8  839556.4  342244.3   386923.2   223419.5
1379  889803.5   673167.1  747026.3  313094.5   361272.5   204433.8
1380  770006.6   587877.0  662865.5  85071.1    160620.8   55918.4
1381  1296157.5  962473.0  1032501.6 991218.6   957995.1   646106.9
1382  330749.8   275145.8  354275.0  1126236.0  1076805.1  734045.9
+      sugbeet19     sugmono     potato       onion
1368   531477.6      742342.6    1273523.8    1658971.6
1369   534508.6      746813.6    966791.5     1231062.2
1370   528074.5      737322.6    903840.0     1276900.0
1371   570912.1      800512.7    920041.5     1180506.0
1372   587659.6      825217.3    1089200.5    1471596.5
1373   606465.0      852957.2    1315119.8    1768971.0
1374   517163.4      721227.6    650672.8     1181893.8
1375   577232.9      809836.7    778075.4     1845649.4
1376   717633.9      1016943.6   2923398.7    2042334.1
1377   971793.8      1391857.2   -44411.4     -173322.6
1378   286303.8      380684.5    983642.0     1888771.0
1379   267088.4      352339.6    1320043.9    2245666.3
1380   116775.9      130612.3    538130.6     590988.2
1381   714105.9      1011739.3   1184981.1    1553531.5
1382   803109.0      1143028.6   1228154.0    1517075.2

parameter mean(c) "mean return to activities x(c)"
          covar(c,cc) "variance covariance matrix of return to activities";
mean(c)=sum (t,k(t,c)/card(t));
covar(c,cc)=sum(t,(k(t,c)-mean(c))*(k(t,c)-mean(c)))/card(t);
display mean , covar;
 scalar a "implies variation in absolute risk aversion coefficent" /1/
       rmin " minimum risk aversion coefficient" / 0.00000047/
       rmax " maximum risk aversion coefficient" / 0.0000210/
       rap risk aversion parameter/0.0/;
option nlp=minos;
variable x(c) "decision variables"
          u(t)   "utility"
          tou "total utility"
          w(t)
          z
positive variable  x,u ;
x.up('sugbeet15')=3.5;
x.up('barely6')=4.5;
Equation obj "objective function of uep"
         obj1 "objective function of e-v"
         utility(t) "expected utility"
         const(j) "constraints"
         const1(t) "state of nature";
const(j) .. sum (c , d(j,c)*x(c)) =l= b(j);
const1(t) .. sum (c ,k(t,c)*x(c)) =e= w(t);
utility(t) ..  u(t) =e= 1- exp(-((1-a)*rmin+a*rmax)*w(t));
```

```
obj ..    tou =e= sum(t, u(t)*(1/card(t)));
*obj ..  tou =e=(1-sum(t,(sum(tt, exp(-((1-a)*rmin+a*rmax)*w(tt))))/(1/card(t))));
obj1 .. z =e= sum(c,mean(c)*x(c))-rap*0.5*(sum(c,sum(cc,x(c)*covar(c,cc)*x(cc))));
model      utefprg /obj,const,const1,utility/
           evsmall / obj1,const/;
solve evsmall using nlp minimizing z;
solve utefprg maximizing tou using nlp;
scalar var "the quantity of variance";
set raps risk aversion coefficient /r1*r21,r0/;
parameter risk(raps) risk aversion coefficients
/r1         0.00002100
r2         1.99735E-05
r3         0.000018947
r4         1.79205E-05
r5         0.000016894
r6         1.58675E-05
r7         0.000014841
r8         1.38145E-05
r9         0.000012788
r10        1.17615E-05
r11        0.000010735
r12        9.7085E-06
r13        0.000008682
r14        7.6555E-06
r15        0.000006629
r16        5.6025E-06
r17        0.000004576
r18        3.5495E-06
r19        0.000002523
r20        1.4965E-06
r21        0.00000047
r0         0 /;

parameter output (*,raps) "results from model running whit varying rap"
loop (raps , rap=risk(raps);
solve evsmall maximizing z using nlp;
var= sum(c,sum(cc,x.l(c)*covar(c,cc)*x.l(cc)));
output("z" ,raps)=z.l;
output("rap" , raps)=rap;
output(c,raps)=x.l(c);
output("mean",raps)=sum(c, mean(c)*x.l(c));
output("var", raps)=var;
output("std", raps)=sqrt(var)
);
set rraps risk aversion parameter /rr1*rr21/;
parameter risk1(rraps) risk aversion parameter
/rr1        0.000021
rr2        1.99735E-05
rr3        0.000018947
rr4        1.79205E-05
rr5        0.000016894
rr6        1.58675E-05
rr7        0.000014841
rr8        1.38145E-05
rr9        0.000012788
rr10       1.17615E-05
rr11       0.000010735
rr12       9.7085E-06
rr13       0.000008682
rr14       7.6555E-06
rr15       0.000006629
rr16       5.6025E-06
rr17       0.000004576
```

```
rr18      3.5495E-06
rr19      0.000002523
rr20      1.4965E-06
rr21      0.00000047/;
parameter output1 (*,rraps) "results from model runs whit varying rmax"
loop (rraps , rmax=risk1(rraps);
solve utefprg maximizing tou using nlp;
var= sum(c,sum(cc,x.l(c)*covar(c,cc)*x.l(cc)));
output1("tou" ,rraps)=tou.l;
output1("rmax" , rraps)=rmax;
output1(c,rraps)=x.l(c);
output1("mean",rraps)=sum(c, mean(c)*x.l(c));
output1("var", rraps)=var;
output1("std", rraps)=sqrt(var)
);
display output , output1;
parameter z2, mean2;
z2=output("z","r0");
mean2=output("mean","r0")
display z2;
variable y;
equation const3 new constraint for MGA
        obj4 objective function for MGA;
const3 ..  mean2=g= 0.05*z2;
*const3 .. yy =e= 0.05*output("mean","r0")-rap*0.5*(sum(c,sum(cc,x(c)*covar(c,cc)*x(cc))));
obj4..  y=e=sum(se,x(se));
model mga /const, const3, obj4/;
solve mga minimizing y using nlp;
display x.l;
```

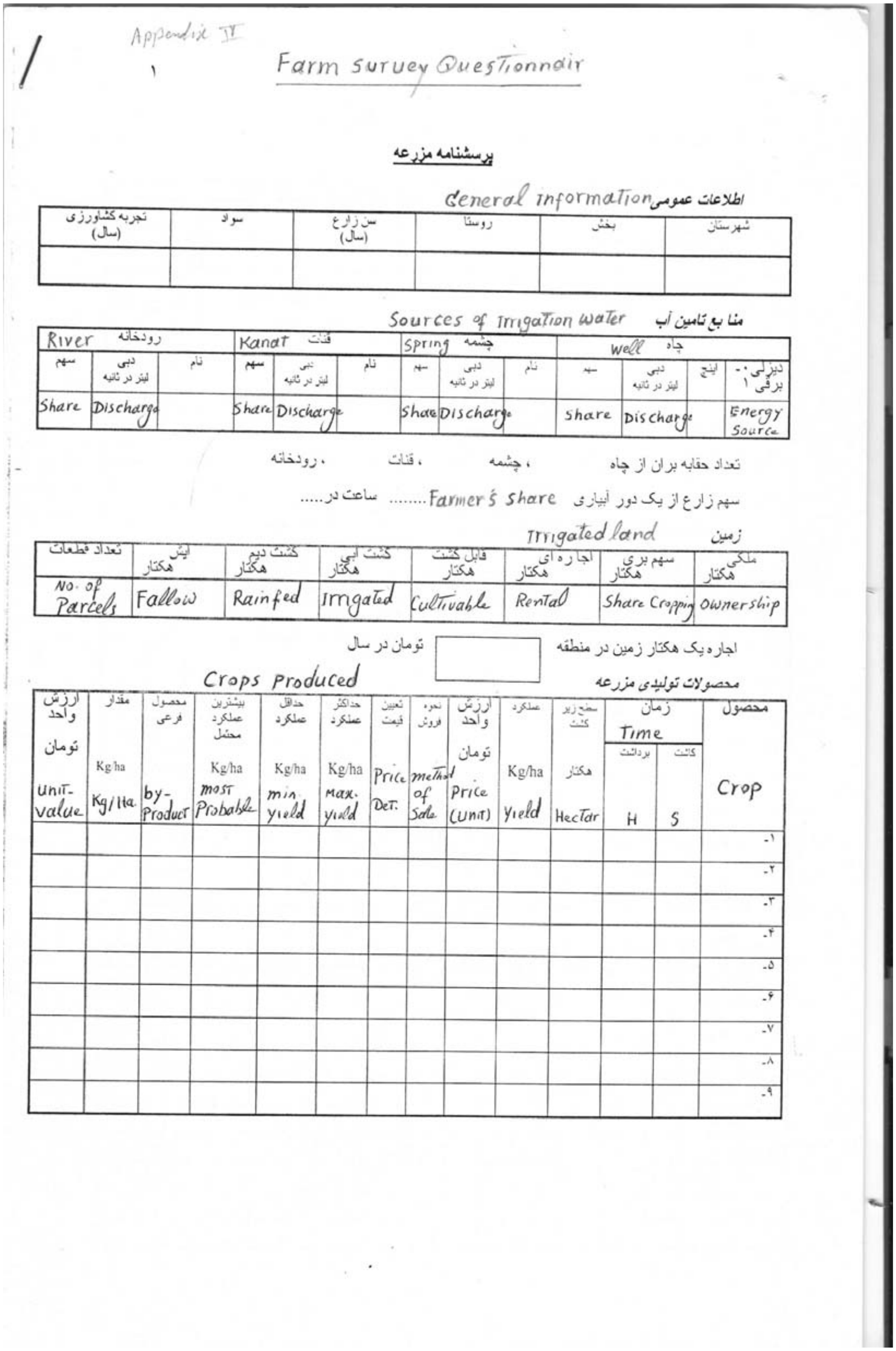
Appendix 3: Programs for Policy Scenarios

```
$include "planmnsm";
variable lx(i,g) acres planted
         linprof lp profit
parameter
      rr(i,g,j) leontif coefficients
      cl(i,g)   linear cost
      net(i,g)  net return;
rr(i,g,j)$(x(i,g,j)) =(x(i,g,j)/x(i,g,"land"));
     cl(I,g) = sum(j, (c(i,g,j)*rr(i,g,j)));
net(i,g) = yb(i,g)*v(i,g)-cl(i,g);
display rr, cl,net;
positive variable lx;
equation resource(j,g) constrained resources
         calib(i,g) upper caliberation constraints
         lprofit lp objective function;
resource(j,g).. sum(i,rr(i,g,j)*lx(i,g))=l= rhs(j,g);
calib(i,g)$(x(i,g,"land")).. lx(i,g) =l= x(i,g,"land")*1.00001;
lprofit .. sum((i,g),((v(i,g)*yb(i,g))-cl(i,g))*lx(i,g))
                  =e= linprof;
model caliberate / resource,calib,lprofit/;
solve caliberate using lp maximizing linprof;
display lx.l,lx.m;
parameter
           la(i,g,j) pmp dual value on land
           op(j,g)      opportunity cost of land
           to(i,g) tota1 output
           cs(i,g,j) cost plus opp cost
           norm(i,g) normalization cost
           eta(i,g) function of substitution
           theta minus one over sub
           beta(i,g,j) share parameter
           cn(i,g)    scale parameter
           ni(j) resource counter
           sw(j) switch
           adj(g)     adjustment to marginal crops ;
ni(j) =ord(j);
scalar nj number of inputs;
        nj=smax(j,ni(j));
         sw(j)=0;
sw(j)$(ord(j) eq 1)=1 ;
sw(j)$(ord(j) eq nj)=2;
display resource.m;
adj(g) = resource.m("land",g)*0.25;
display adj;
la(i,g,"land")= calib.m(i,g)+adj(g);
op(j,g)= resource.m(j,g);
op("land",g) = resource.m("land",g)-adj(g);
to(i,g)$(x(i,g,"land"))=yb(i,g)*x(i,g,"land");
**************************************
* the place fr considering the effects of policies
**************************************
option decimals=4;
*c(i,"mas","water") =c(i,"mas","water")*1.5;
rhs("water", "mas")=rhs("water","mas")*0.90;
*c(i,g,"azote") = 179.15;
*c(i,g,"phosphate") =194.53;
*c(i,g,"potash") =195.33;
*v("sugmono",g)=27.075;
*v("sugbeet",g)=27.075;
************************************
cs(i,g,j)$(x(i,g,j))=c(i,g,j)+op(j,g)+la(i,g,j);
```

```
display cs;
eta(i,g)$(x(i,g,"land"))=(sub-1)/sub;
theta =-(1/sub);
display sw,nj,x;
parameter alph(i,g,j) cost intercept
        gam(i,g,j) cost slop;
alph(i,g,j)=c(i,g,j)-la(i,g,j);
gam(i,g,j)$((la(i,g,j) ne 0)and x(i,g,"land"))=(2*la(i,g,j))/x(i,g,j);
display alph ,gam;
beta(i,g,j)$((x(i,g,j)and cs(i,g,j)and sw(j) eq 1)) =
 1/( sum(p, (cs(i,g,p)/cs(i,g,j))*( x(i,g,j)/x(i,g,p))**theta ) + 1 ) ;
beta(i,g,j)$((x(i,g,j)and cs(i,g,j)and sw(j) eq 0)) =
sum(r,beta(i,g,r))*(cs(i,g,j)/SUM(r,cs(i,g,r)))*(SUM(r, x(i,g,r))/x(i,g,j))**theta ;
beta(i,g,j)$((x(i,g,j)and cs(i,g,j)and sw(j) eq 2)) =
1 - sum(l$(sw(l) ne 2), beta(i,g,l) ) ;
cn(i,g)$(x(i,g,"land")) = to(i,g) / (sum(j, beta(i,g,j)*
      ((x(i,g,j)+0.0001)**((sub-1)/sub )))** (sub/(sub-1))) ;
display  beta,cn,cs ;
*######################################################################
* CES   programming solution for base year r#######################################################################
option nlp=minos;
variables xn(I,g,j) resource allocation
          tprofit  total profit;
positive variable xn;
equations           input(j,g)    fixed inputs
          profit      profit definition ;
input(j,g)..   sum(i, xn(i,g,j) )  =l= rhs(j,g);
profit.. tprofit =e= sum((i,g), v(i,g) * (cn(i,g)* (sum(j, beta(i,g,j)*
        ((xn(i,g,j)+0.00001)**((sub-1)/sub )))** (sub/(sub-1)))))
  -sum((i,g,j), alph(i,g,j)*xn(i,g,j) + 0.5* gam(i,g,j) * sqr(xn(I,g,j)));
 xn.l(i,g,j) $(x(i,g,j)) = x(i,g,j) ;
model production /input,profit/;
solve production using nlp maximizing tprofit;
parameter    perdif(i,g,j)  % difference in input allocation ;
            perdif(i,g,j)$(x(i,g,j)) = ((xn.l(i,g,j) - x(i,g,j)) * 100) / x(i,g,j) ;
display      cn, beta, alph, gam, input.m , resource.m, xn.l, x, perdif ;
scalar difrence/0/;
difrence=(linprof.l-tprofit.l)/sum ((i,g,r),x(i,g,r));
display difrence;
*##############################################################3
***************
parameter tscost (i,g)"current total social cost (TSC)of each activity"
        tsp(i,g)"current total social benefit (TSB) of  each activity";
tscost(i,g)$(x(i,g,"land"))=SUM(J, (Cc(I,G,J)*x(I,G,J)))+tocost(i,g);
tsp(i,g)=yb(i,g)*vs(i,g)*x(i,g,"land")-tscost(i,g);
parameter tscost1(i,g)" change in 'TSC' result of change policy"
          tsp1(i,g) " change in 'TSB' result of change policy" ;
tscost1(i,g)$(x(i,g,"land"))=sum(j,xn.l(i,g,j)*cc(i,g,j))+tocost(i,g);
tsp1(i,g)=yb(i,g)*vs(i,g)*xn.l(i,g,"land")-tscost1(i,g);
parameter difs(i,g) " net change in 'TSB' result of change policy" ;
difs(i,g)=tsp1(i,g)-tsp(i,g);
display tscost1,tscost,tsp,tsp1,difs ;
*******************************************
*##############################################
*&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
scalar ww/0/
      wws/0/  ;
 ww=sum((k,g),tsp(k,g));
 wws=sum((k,g),tsp1(k,g));
 scalar efpo "total net change in social profit result of change policy"/0/;
efpo=(wws-ww);
display ww,wws, efpo;
scalar ggg "currected total change in social profit"  /0/;
```

```
ggg=(efpo+1461.658)/2298.89;
display efpo,ggg;
*************************
```

Appendix 4: Questionnaire



Appendix IV

۱

Farm survey Questionnair

پرسشنامه مزرعه

اطلاعات عمومی General information

شهرستان	بخش	روستا	سن زارع (سال)	سواد	تجربه کشاورزی (سال)

منا بع تامین آب Sources of Irrigation water

چاه well				چشمه Spring			قنات Kanat			رودخانه River		
دیزلی ۰ - برقی ۱	اینچ	دبی لیتر در ثانیه	سهم	نام	دبی لیتر در ثانیه	سهم	نام	دبی لیتر در ثانیه	سهم	نام	دبی لیتر در ثانیه	سهم
Energy Source		Discharge	Share		Discharge	Shae		Discharge	Share		Discharge	Share

تعداد حقابه بران از چاه ، چشمه ، قنات ، رودخانه

سهم زارع از یک دور آبیاری Farmer's share .... ساعت در.....

زمین Irrigated land

ملکی هکتار	سهم بری هکتار	اجاره ای هکتار	قابل کشت هکتار	کشت ابی هکتار	کشت دیم هکتار	ایش هکتار	تعداد قطعات
Ownership	Share Croppin	Rental	Cultivable	Irrigated	Rainfed	Fallow	No. of Parcels

اجاره یک هکتار زمین در منطقه ☐ تومان در سال

محصولات تولیدی مزرعه Crops Produced

محصول Crop	زمان Time		سطح زیر کشت	عملکرد	ارزش واحد	نحوه فروش	تعیین قیمت	حداکثر عملکرد	حداقل عملکرد	بیشترین عملکرد محتمل	محصول فرعی	مقدار	ارزش واحد
	کاشت S	برداشت H	هکتار HecTar	Kg/ha Yield	تومان Price (Unit)	method of Sale	Price Det.	Kg/ha max. yield	Kg/ha min yield	Kg/ha most Probable	by-Product	Kg/ha Kg/Ha.	تومان Unit-value
۱-													
۲-													
۳-													
۴-													
۵-													
۶-													
۷-													
۸-													
۹-													

مقدار نهاده های مورد استفاده Quantity of Inputs used

بذر Seed

محصول Crop	نوع Kind	Inputs Per Ha. مقدار مصرف در هکتار (کیلو گرم)			
		ازاد	ارزش واحد (تومان)	دولتی	ارزش واحد (تومان)
۱-					
۲-					
۳-					
۴-					
۵-					
۶-					
۷-					
۸-					
۹-					

کود شیمیایی Chemical Fertilizer (تومان)

محصول Crop	نوع	مقدار مصرف در هکتار (کیسه)				نوع	مقدار مصرف در هکتار (کیسه)				نوع	مقدار مصرف در هکتار (کیسه)			
		ازاد	ارزش	دولتی	ارزش		ازاد	ارزش	دولتی	ارزش		ازاد	ارزش	دولتی	ارزش
۱-															
۲-															
۳-															
۴-															
۵-															
۶-															
۷-															
۸-															
۹-															

سموم Poison (تومان)

محصول Crop	نوع	مقدار مصرف در هکتار (لیتر)				نوع	مقدار مصرف در هکتار (لیتر)				نوع	مقدار مصرف در هکتار (لیتر)			
		ازاد	ارزش	دولتی	ارزش		ازاد	ارزش	دولتی	ارزش		ازاد	ارزش	دولتی	ارزش
۱-															
۲-															
۳-															
۴-															
۵-															
۶-															
۷-															
۸-															
۹-															

Hours and Timing of Irrigation ساعات آبیاری محصولات مختلف مزرعه

months	Crop محصول	۱	۲	۳	۴	۵	۶	۷	۸	۹
فروردین	تعداد دفعات آبیاری									
	ساعت آبیاری در هر دفعه									
اردیبهشت	تعداد دفعات آبیاری									
	ساعت آبیاری در هر دفعه									
خرداد	تعداد دفعات آبیاری									
	ساعت آبیاری در هر دفعه									
تیر	تعداد دفعات آبیاری									
	ساعت آبیاری در هر دفعه									
مرداد	تعداد دفعات آبیاری									
	ساعت آبیاری در هر دفعه									
شهریور	تعداد دفعات آبیاری									
	ساعت آبیاری در هر دفعه									
مهر	تعداد دفعات آبیاری									
	ساعت آبیاری در هر دفعه									
آبان	تعداد دفعات آبیاری									
	ساعت آبیاری در هر دفعه									
آذر	تعداد دفعات آبیاری									
	ساعت آبیاری در هر دفعه									
دی	تعداد دفعات آبیاری									
	ساعت آبیاری در هر دفعه									
بهمن	تعداد دفعات آبیاری									
	ساعت آبیاری در هر دفعه									
اسفند	تعداد دفعات آبیاری									
	ساعت آبیاری در هر دفعه									

هزینه عملیات زراعی مشترک (کاشت) Labor & machinery Cost Per Ha. (تومان در هکتار)

عملیات زراعی Operation	نیروی مورد استفاده													
	Machinery ماشین						labor کارگر							
	ملکی			اجاره ای			روزمزد				خانوادگی			
	نام وسیله	تعداد	هزینه	نام وسیله	تعداد	هزینه	مرد		زن		مرد		زن	
							تعداد	دستمزد	تعداد	دستمزد	تعداد	دستمزد	تعداد	دستمزد
شخم														
دیسک														
لولر														
کش زنی (ردیفکار)														
نهرکشی و لایروبی														
سایر هزینه ها														

محصول Crop	تعداد دفعات عملیات زراعی Number of farm operations					
	شخم	دیسک	لولر	کش زنی	نهرکشی و لایروبی	ملاحظات
۱-						
۲-						
۳-						
۴-						
۵-						
۶-						
۷-						
۸-						
۹-						

هزینه عملیات زراعی غیرمشترک در هکتار (داشت)

Irrigation schedule and Cost (Per hectare)

آبیاری و سهم منابع مورد استفاده

محصول Crop	آب اول تاریخ	آب آخر تاریخ	کل دفعات آبیاری	دفعات آبیاری قبل از کاشت	مدت زمان مورد نیاز برای آبیاری یک هکتار	هزینه پرداختی بابت آب در سال (تومان)				سهم استفاده از		
						موتوربان	تعمیر و نگه داری	سوخت، روغن،...	برق	قنات	رودخانه	چشمه
۱-												
۲-												
۳-												
۴-												
۵-												
۶-												
۷-												
۸-												
۹-												

محصول Crop	وجین و تنک کردن (تومان در هکتار) Weeding and Pruning													
	ماشین Machine						کارگر Labor							
	ملکی			اجاره ای			روزمزد				خانوادگی			
	نام وسیله	تعداد	هزینه تومان	نام وسیله	تعداد	هزینه تومان	مرد		زن		مرد		زن	
							تعداد	دستمزد	تعداد	دستمزد	تعداد	دستمزد	تعداد	دستمزد
۱-														
۲-														
۳-														
۴-														
۵-														
۶-														
۷-														
۸-														
۹-														

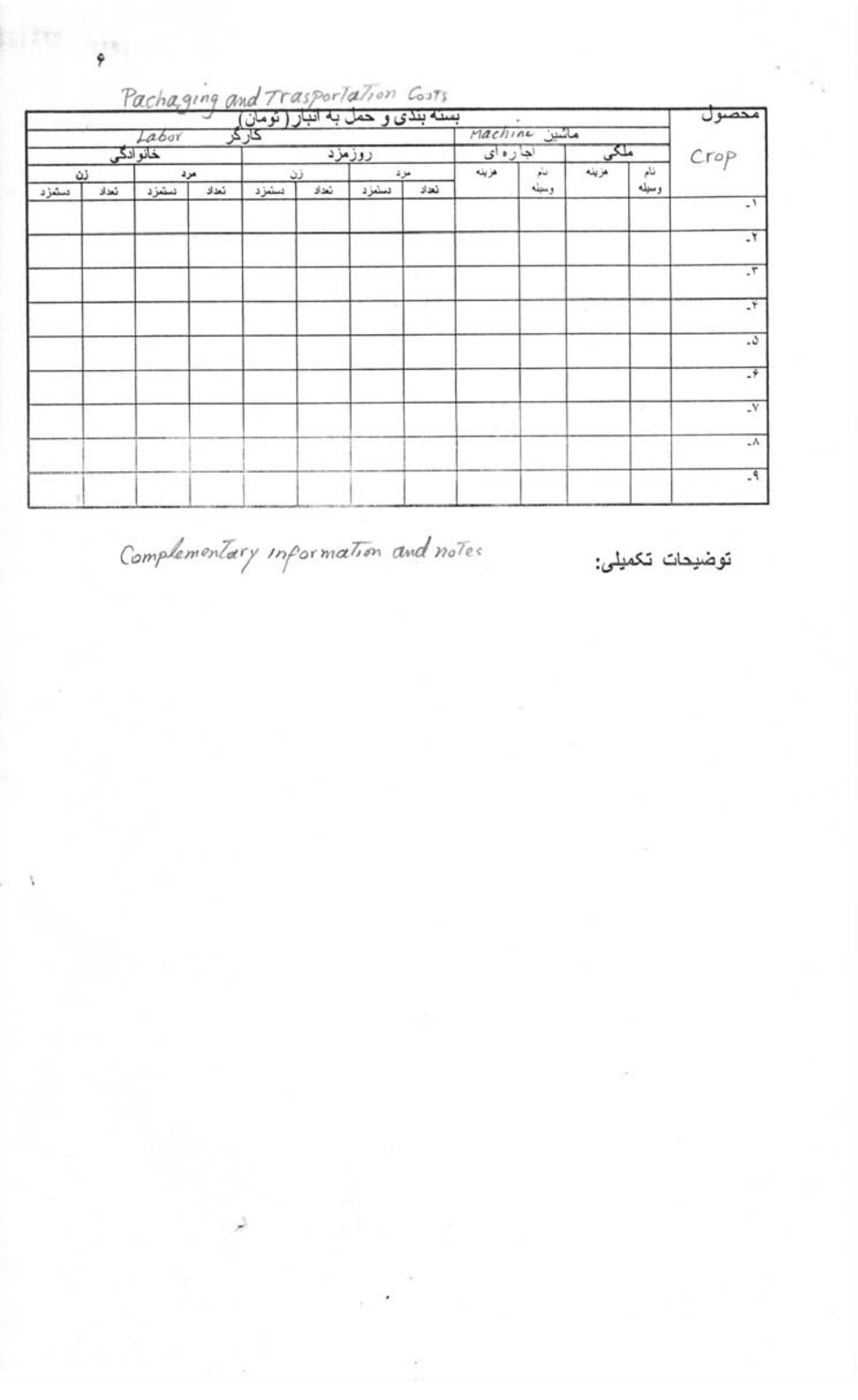
محصول Crop	سم پاشی (تومان در هکتار) Spraying Costs											
	machine ماشین				labor کارگر							
	ملکی		اجاره ای		روزمزد				خانوادگی			
	نام وسیله	هزینه	نام وسیله	هزینه	مرد		زن		مرد		زن	
					نفر	دستمزد	نفر	دستمزد	نفر	دستمزد	نفر	دستمزد
۱-												
۲-												
۳-												
۴-												
۵-												
۶-												
۷-												
۸-												
۹-												

محصول Crop	کود پاشی (تومان در هکتار) Fertilizing Cost													
	machine ماشین						Labor کارگر							
	ملکی			اجاره ای			روزمزد				خانوادگی			
	نام وسیله	تعداد	هزینه تومان	نام وسیله	تعداد	هزینه تومان	مرد		زن		مرد		زن	
							تعداد	دستمزد	تعداد	دستمزد	تعداد	دستمزد	تعداد	دستمزد
۱-														
۲-														
۳-														
۴-														
۵-														
۶-														
۷-														
۸-														
۹-														

هزینه عملیات برداشت

Harvesting Costs

محصول Crop	برداشت (تومان در هکتار)													
	machine ماشین						labor کارگر							
	ملکی			اجاره ای			روزمزد				خانوادگی			
	نام وسیله	تعداد	هزینه	نام وسیله	تعداد	هزینه	مرد		زن		مرد		زن	
							نفر	دستمزد	نفر	دستمزد	نفر	دستمزد	نفر	دستمزد
۱-														
۲-														
۳-														
۴-														
۵-														
۶-														
۷-														
۸-														
۹-														



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Pachaging and Trasportation Costs

محصول Crop	بسته بندی و حمل به انبار (تومان)											
	ماشین Machine				کارگر Labor							
	ملکی		اجاره ای		روزمزد				خانوادگی			
	نام وسیله	هزینه	نام وسیله	هزینه	مرد		زن		مرد		زن	
					تعداد	دستمزد	تعداد	دستمزد	تعداد	دستمزد	تعداد	دستمزد
۱-												
۲-												
۳-												
۴-												
۵-												
۶-												
۷-												
۸-												
۹-												

توضیحات تکمیلی:

Complementary information and notes