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# Investigating the Effect of Variations in Irrigation Water Price on Cropping Pattern and Gross Margin under Uncertainty (Case Study: Khorasan Razavi)

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**Abstract**

Water shortage crisis is an issue that has led to drastic changes in different agricultural policies, especially in arid and semi-arid areas. Uncertainty in the amount of resources, e.g. water, used for agricultural production entails risk for farmers' income and cropping pattern changes. In the present study, the robust optimization model was used for optimal allocation of arable lands of Khorasan Razavi Province under uncertainty. During the allocation, the effect of water input price variations on total gross margin and cropping pattern was considered. It was found that under certain data, both parameters of total gross margin and total acreage are more than uncertain data. Given that water price variations resulted in tangible changes in wheat acreage, it is recommended to adopt appropriate policies to reduce its production risk.

***Keywords:***
***Optimization, Uncertainty, Water price, Khorasan Razavi Province***

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## INTRODUCTION

Changing a farm's ongoing costs is a powerful tool for orienting the optimal cropping pattern with regional macroeconomic policies. The variations in prices can be caused by the changes in production costs of inputs including the very limited input of water. Uncertainty in the amount of resources, e.g. water, used for agricultural production entails risk for farmers' income and also cropping pattern changes. Using a flexible model to determine the cropping pattern under uncertainty reduces the probability of system failure, where failure is defined as not meeting a given demand or other system constraint. Hazell and Norton (1986) believe that the distinction between risk and uncertainty is not beneficial in the mathematical programming because the available information for income distribution is usually limited to relatively small time series samples and subjective expectations held by farmer (farmer's mental background) and only estimation of possible income outcomes and probabilities related to each of these cases can be achieved (Chizari *et al*., 2005).

Several studies have been conducted to optimize allocation of arable lands in different parts of the world (Sharma *et al*., 2006 and Soltani *et al*., 2008). Pfeiffer and Lin (2014) examined the effects of energy prices on groundwater extraction using an econometric model of a farmer's irrigation water pumping decision that accounts for both intensive and extensive margins. They found that energy prices had a significant effect on both the intensive and extensive margins and that the increase in energy prices would affect crop selection decisions, crop acreage allocation decisions, and farmers' demand for water. Various models have been used in research including goal programming (Sabouhi and Soltani, 2008; Sharma and Jana, 2009), fuzzy goal programming (Rastgaripoor and Sabouhi, 2009; Kohansal and Zare, 2008), multi-objective programming (Yeh and Labadie, 2003) and/or multi-objective fuzzy programming (Zeng *et al*., 2010). In Iran, many studies have been done on determining optimal cropping patterns of agricultural products (El-Shishiny, 1988). In some of these studies, fuzzy models (Bagheri and Moazzazi, 2010) have been used to determine the optimal pattern. In these studies, the researchers chose different ways to apply existing risks in agricultural productions and calculated the existing risks in this sector.

The studied area is Khorasan Razavi Province with an area of 116,349 km$^2$. Agricultural section of Khorasan Razavi Province, as one of the largest and most important suppliers of agricultural products having a vast capacity of more than 1,081,130 hectares of various crops, has a decisive position in the national and provincial economy and an important role in providing critical needs of the community, food security, supply of material requirements of industries, and job creation (Biswas and Pal, 2005). The model used in the present study is to determine the optimal cropping pattern through robust optimization. One of the obvious advantages of robust optimization model is the flexibility in the application of uncertainty with regard to the social, economic and political conditions. Imposition of a type of optimal cropping pattern is avoided in this model and appropriate cropping pattern of each region is provided according to its specific circumstances.

## MATERIALS AND METHODS

Table 1 lists the signs and indicators used in the present study.

### Robust optimization model

One of the mathematical programming assumptions under certainty is that all parameters (input data) are fully known and determined. In practice, this assumption is unrealistic since most predicted or measured parameters are associated with uncertainty. To limit the uncertainty, a reliable system that can be designed. Soyster (1999) offered the following linear programming model to find answer for all uncertain data belonging to a convex set:

$$\begin{aligned} &\text{Maximize} \quad cx \\ &\text{subject to} \quad \sum_{j=1}^{n} \tilde{A}_{\cdot j} x_j \le b, \qquad \forall \tilde{A}_{\cdot j} \in K_j \\ &\quad j = 1,\dots,n, \qquad X \ge 0, \quad \forall j. \end{aligned} \tag{1}$$

$\tilde{A}_{\cdot j}$ determines the $j^{th}$ column of the constraints

Table 1: The list of signs and indicators used in the present study

| **Sets** | |
|---|---|
| *j*: the set related to product *j*, | $j \in \{1,2,...,J\}$ |
| *s*: the set related to season *s*, | $s \in \{1,2,...,S\}$ |
| *i*: the set related to month *i*, | $i \in \{1,2,...,S\}$ |
| *t*: the set related to the type of fertilizer *t* | $t \in \{1,2,...,T\}$ |
| *e:* the set related to basic products *e* | $e \in \{1,2,...,E\}$ |
| **Parameters** | |
| $p_{si}$ : price of water in month *i* of season *s* | |
| $A_e$ : Minimum acreage requirement for basic products of *e* | |
| $C_{sj(e)}$ : The amount of gross margin (without deducting the cost of water) per hectare of crop *i* or *e* in season *s* | |
| $W_{sij(e)}$: The amount of water requirement to produce one hectare of crop *i* or *e* in season *s* ($m^3$/hectare) | |
| $f_{tj(e)}$: The amount of fertilizer type *t* requirement to produce crop *i* or *e* | |
| **Random Data** | |
| $\tilde{W}_{si}$: The average amount of water available in month *i* of season *s* | |
| $\tilde{A}$: Available acreage for all crops under study | |
| $\tilde{L}$ : The number of available workforce | |
| $\tilde{F}_t$ : The total amount of available fertilizer of *t* type | |
| **Decision variable** | |
| $x_{sj(e)}$: acreage of crop *i* in season *s* | |
| **Model Variables** | |
| $\Gamma_i$ : degree of conservation control parameter (uncertainty): | |
| $\tilde{\eta}_i$ : Random variable for constraint *i* | |
| $b_i$ : Right side values of constraint *i* | |
| $\varepsilon$ :Level of specific uncertainty | |
| $\bar{a}_i$: Nominal value of uncertain data in constraint *i* | |
| $\hat{a}$ : nominal value of uncertain data multiplied by the level of specific uncertainty | |
| $\tilde{a}_i$ : random value of uncertain data in constraint *i* | |
| $\Omega_i$ : degree of uncertainty control parameter (for quadratic programming) | |
| *P* : probability of each constraint violation from its boun | |

matrix and it is assumed that the uncertainty column belongs to the known and convex set of *K*. This model defines hard constraints (i.e. all such constraints must be provided) for all subsets of $K_j$. Thus, the optimal solution in this situation is likely to lose its optimality compared to the problem in certain circumstances because of the conservation model against uncertainty. The growth of conservation to ensure system reliability in uncertainty increases the operating and maintaining costs of the systems. On the contrary, flexibility in economic models leads to various options to choose from as compared to the rigid models such as Soyster's model (Soyster, 1973). To solve this problem, a different method is introduced to incorporate uncertainty in the problem. Uncertain variables are expressed as random perturbations for uncorrelated variables (Bertsimas and Sim, 2004):

$$\tilde{a}_{ij} = \bar{a}_{ij} + \tilde{\eta}_{ij}\varepsilon\bar{a}_{ij} = \bar{a}_{ij} + \tilde{\eta}_{ij}\hat{a}_{ij} \quad (2)$$

where, $\bar{a}_{ij}$ determines the nominal value of the uncertain parameter, $\varepsilon > 0$ specifies the determined uncertainty level, $\tilde{\eta}_{ij}$ is random variables distributed symmetrically in [-1, 1], $\hat{a}_{ij}$ is obtained by multiplying the nominal value of the variable $\bar{a}_{ij}$ e and the specified level of confidence, $\varepsilon$ . Thus, the variable $\tilde{a}_{ij}$ has symmetric and bounded distribution in the constraint of $[\bar{a}_{ij} - \hat{a}_{ij}, \bar{a}_{ij} + \hat{a}_{ij}]$ . Model (1) was modified after adding two additional variables of y and z as follows (9):

$$\begin{aligned} &\text{Maximize} \quad cx \\ &\text{subject to} \quad \sum_j \bar{a}_{ij}x_j + \sum_{j\in J_i}\hat{a}_{ij}y_{ij} + \Omega_i\sqrt{\sum_{j\in J_i}\hat{a}_{ij}^2 z_{ij}^2} \le b_i, \quad \forall i \\ &-y_{ij} \le x_j - z_{ij} \le y_{ij}, \quad \forall i, j \in J_j \\ &l \le X \le u, \\ &y \ge 0 \end{aligned} \quad (3)$$

where, $J_i$ is a subset of the uncertain data indicator in constraint $i$, and $\Omega_i$ is a conservation control parameter for constraint $i$. Although this method caused conservation control, quadratic programming problems which had computational complexity had to be used. To overcome this problem, a new method was developed where model (1) remained linear and the degree of conservation was also controlled (Oliveira *et al.,* 2003). Consider the following optimization problem:

$$\begin{aligned} &\text{Maximize} \quad cx \\ &\text{subject to} \quad \sum_{j=1}^{n} \tilde{a}_{\cdot j}x_j \le b, \quad \forall i, j \in J_j \\ &l \le X \le u. \end{aligned} \quad (4)$$

Uncertainty in this model is the same as that in model (3). $J_i$ is a subset of indicators related to the uncertain parameter of $\tilde{a}_{ij}$, which is determined for every constraint of $i$. It is assumed that all $\tilde{a}_{ij}$ are independent, symmetric, and bounded in the range of [-1, 1]. To control the degree of conservation, a parameter ($\Gamma_i$) is defined that a real number in the range of $[0, J_i]$ and can be attributed to it. Here, model (4) is rephrased in an optimization form by parameters which control the degree of conservation that improves the reliability of systems under uncertainty (Oliveira *et al.,* 2003):

$$\begin{aligned} &\text{Maximize} \quad cx \\ &\text{subject to} \quad \sum_i \bar{a}_{ij}x_j + \max_{\{S_i\cup\{t_i\}|S_i\subseteq J_i,|S_i|=[\Gamma_i],t_i\in J_i\setminus S_i\}} \\ &\left\{\sum_{j\in S_i}\hat{a}_{ij}y_j + (\Gamma_i - [\Gamma_i])\hat{a}_{it_i}y_t\right\} \le b_i, \quad \forall i \\ &-y_j \le x_j \le y_j, \quad \forall j \in J_j \\ &l \le X \le u, \\ &y \ge 0 \end{aligned} \quad (5)$$

where for each $j$, we have $y_i = |x_j^*|$. In model (5), $\sum \bar{a}_{ij}x_j \le b_i$ represents the *ith* constraint under certainty. In robust optimization model, there is an additional maximizing term (second term) as compared to the previous condition. This maximizing term ensures reliability of the model against uncertainty by the degree of conservation control parameter of ($\Gamma_i$). Certainty level of the model against uncertainty depends on the value of $\Gamma_i$ parameters. Whenever $\Gamma_i$=0, maximizing term is deleted from the model and the constraint under uncertainty is converted to constraint under certainty. Whenever $\Gamma_i = |j_i|$, the model protection against uncertainty reaches its peak and is completely done. In this method, an evaluation is performed between system conservation against uncertainty ($\Gamma_i$) and system capacity ($x_i$). In other words, the more the system conservation is increased against uncertainty, the less the capacity of the system becomes.

Model (5) can be solved by linear programming without computational complexity. Also, the maximizing term can be calculated out of this model. $\Gamma_i$ is a suitable tool for investigating system power against uncertain parameters or its inability against these parameters. There are different values for $\Gamma_i$ depending on the probability of *ith* constraint violation from its bound and also the number of uncertain parameters in that constraint. Inserting in equation (5) as the optimal solution, the probability of *ith* constraint violation from its bound is defined as follows:

$$pr\left(\sum_j \tilde{a}_{ij}x^*_j > b_i\right) \le B(n, \Gamma_i) \quad (6)$$

such that:

$$B(n,\Gamma_i) \le (1-\mu)C(n,[\nu]) + \sum_{l=[\nu]+1} C(n,l)$$

where, $n = |K_i|,\ \nu = (\Gamma_i + n)/2,\ \mu = \nu - [\nu]$ (7)

and also,

$$C(n,l) = \begin{cases} \frac{1}{2^n}, & \text{if } l = 0 \text{ or } l = n \\ \frac{1}{\sqrt{2\pi}}\sqrt{\frac{n}{(n-1)n}}\exp\left(n\log\left(\frac{n}{2(n-l)}\right) + l\log\left(\frac{n-l}{l}\right)\right), & \text{otherwise} \end{cases} \quad (8)$$

To calculate $\Gamma_i$, a desirable level of probability of *ith* constraint violation from its bound is considered. Regarding the number of uncertain parameters in that constraint, equation (8) is used for its computation. Assuming that equation (7) is tight, equation (8) can be directly used to calculate $\Gamma_i$.

## Objective

The objective of the present study was to maximize gross margin by cropping pattern optimization. To investigate the effect of water price variations on optimal cropping pattern, water-related costs are individually included in the objective function. The objective function is as follows:

$$Max: \quad Z = \sum_{s=1}^{S}\sum_{j=1}^{J}(c_{sj(e)} - p_{si}w_{sij(e)})x_{sj(e)} \qquad \forall i \quad (9)$$

where, $z$ is the total gross margin, $C_{sj(e)}$ is gross margin (without deducting the cost of irrigation) from one hectare of product $j$ or $e$ in season $s$, $P_{si}$ is the price of water in month $i$ of season $s$, $W_{sij(e)}$ is the amount of water required to produce one hectare of crop $j$ or $e$ in month of season $s$ and $x_{sj(e)}$ is the acreage of product $j$ $e$ or in season $s$.

## Uncertain Data

In a cropping pattern model, uncertainty takes place due to the fluctuations of some parameters in the model to optimize it. Uncertain data here are: average amount of available water ($\tilde{W}_{si}$), total acreage of crops ($\tilde{A}$), number of available workforce ($\tilde{L}$) and the total amount of fertilizer type $t$ ($\tilde{F}_t$). According to equations (2) and (6), random form of each uncertain parameter can be written as follows:

$$\tilde{W}_{si} = \overline{W}_{si} + \tilde{\eta}_{si}\hat{W}_{si}, \qquad \forall s, \quad \forall i \quad (10)$$

$$\tilde{A} = \overline{A} + \tilde{\eta}_3\hat{A} \quad (11)$$

$$\tilde{L} = \overline{L} + \tilde{\eta}_4\hat{L} \quad (12)$$

$$F_t = \overline{F}_t + \tilde{\eta}_{t+4}\hat{F}_t, \qquad \forall t \quad (13)$$

Equation (10) corresponds to uncertain parameters of an average amount of available water where $\tilde{W}_{si}$ is the total amount of available water in month $i$ of season $s$, $\overline{W}_{si}$ is the nominal value, and is equal to 10% of the amount of $\overline{W}_{si}$ ($\varepsilon = 0.1$). Equation (11) corresponds to uncertain parameters of the total acreage in which $\tilde{A}$ is the total acreage of crops, $\overline{A}$ is the nominal total acreage and $\tilde{A}$ is equal to 10% of $\overline{A}$. Similarly, equations (12) and (13) can be similarly interpreted. $\tilde{\eta}_{si}$, $\tilde{\eta}$, $\tilde{\eta}_4$ and $\tilde{\eta}_{t+4}$ are random variables in [-1, 1].

## Constraints

The total consumed water for all products in season $s$ should not be more than the total available water in month $i$ of season $s$.

$$\sum_{s=1}^{S}\sum_{j=1}^{J} w_{si}x_{sj(e)} \le \sum_{i=1}^{I}\tilde{W}_{si} \quad (14)$$

Available water in month $i$ of season $s$ is considered as uncertain parameters. In other words, the available water in each month is considered as an uncertain parameter. So, there are six uncertain parameters in one season. So, the random constraint for the first season (from October to the end of March) is as follows:

$$\sum_{j=1}^{J} w_{1i}x_{1j(e)} \le \sum_{i=1}^{6}(\overline{W}_{1i} + \tilde{\eta}_{1i}\hat{W}_{1i}) \quad (15)$$

In addition, this equation for the second season (from April to late September) is written as follows:

$$\sum_{j=1}^{J} w_{2i}x_{21j(e)} \le \sum_{i=7}^{12}(\overline{W}_{2i} + \tilde{\eta}_{2i}\hat{W}_{2i}) \quad (16)$$

Table 2: Descriptions of Data

| | Wheat | Barely | Corn | Sugar beet | Cotton | Tomatoes |
|---|---|---|---|---|---|---|
| Gross margin (IRR*/ ha) | 3593541 | 2937292 | 14162471 | 9177122 | 6105133 | 22263984 |
| Water requirement (m³/ha) | 4983 | 4183 | 11283 | 15200 | 12550 | 13517 |
| Phosphate (Kg /ha) | 179 | 148 | 210 | 255 | 231 | 323 |
| Nitrogen (Kg/ha) | 246 | 204 | 197 | 371 | 323 | 408 |
| Potash (Kg/ha) | 19 | 12 | 44 | 80 | 31 | 18 |
| Workforce (Man-day/Ha) | 26.87 | 20.12 | 53.46 | 116.46 | 69.2 | 209.36 |

*Note: US $ 1≈ 32000 IRR
Source: Organization of Agriculture Jihad (2011)

Random constraints of (15) and (16) can be rewritten using the definition of the degree of conservation control parameters of $\Gamma_1 \geq 1$ and $\Gamma_2 \geq 1$, respectively and according to the model (5) as follows:

$$\sum_{j=1}^{J} w_{1i} x_{1j(e)} - \sum_{i=1}^{6} \overline{W}_{1i} + (\Gamma_1 - 1)\sum_{i=1}^{6}\left|-\hat{W}_{1i}\right| \leq 0 \qquad (17)$$

$$\sum_{j=1}^{J} w_{2i} x_{2j(e)} - \sum_{i=7}^{12} \overline{W}_{2i} + (\Gamma_2 - 1)\sum_{i=7}^{12}\left|-\hat{W}_{2i}\right| \leq 0 \qquad (18)$$

and it can be rewritten to the following form for $\Gamma_1 < 1$ and $\Gamma_2 < 1$:

$$\sum_{j=1}^{J} w_{1i} x_{1j(e)} - \sum_{i=1}^{6} \overline{W}_{1i} + \Gamma_1\sum_{i=1}^{6}\left|-\hat{W}_{1i}\right| \leq 0 \qquad (19)$$

$$\sum_{j=1}^{J} w_{2i} x_{2j(e)} - \sum_{i=7}^{12} \overline{W}_{2i} + \Gamma_2\sum_{i=7}^{12}\left|-\hat{W}_{2i}\right| \leq 0 \qquad (20)$$

Other constraints used in this study are also converted to the degree of conservation control parameters. The final forms of these constraints are as follows:

$$\sum_{j=1}^{J} x_{sj(e)} - \overline{A} + \Gamma_3\left|-\hat{A}\right|, \quad \forall S$$
$$\Gamma_3 \in [0,1] \qquad (21)$$

$$\sum_{j=1}^{J} l_j x_{sj(e)} - \overline{L} + \Gamma_4\left|-\hat{L}\right| \leq 0, \quad \forall s$$
$$\Gamma_4 \in [0,1] \qquad (22)$$

$$\sum_{t=1}^{T}\sum_{j=1}^{J} f_{tj} x_{sj} - \overline{F}_t + \Gamma_{t+4}\left|-\hat{F}_{tj}\right| \leq 0, \quad \forall t$$
$$\Gamma_5, \Gamma_6, \Gamma_7 \in [0,1] \qquad (23)$$

The constraints (21), (22) and (23) are related to arable land, workforce and chemical fertilizer, respectively. The constraint (23) with parameters $\Gamma_5$, $\Gamma_6$, and $\Gamma_7$ is for the three types of potash, nitrogen and phosphate fertilizers, respectively. Another constraint is related to the land acreage of the crops which are regarded as essential to meet the domestic needs. This constraint is defined as follows:

$$\sum_{e=1}^{E} x_{sj(e)} \geq A_e, \quad \forall S \qquad (24)$$

where, $A_e$ represents the minimum acreage required for essential products of $e$. Monte Carlo simulation method is used to evaluate the model for which 1000 random numbers (with a predetermined probability distribution), for each of generated uncertain data and optimal cropping

Table 3: Current and optimal cropping pattern with different water prices under certainty (p=1)

| | | | | Water Price (IRR/m³) | | | |
|---|---|---|---|---|---|---|---|
| | Product | Variable | Current | 120.5 | 250 | 640.2 | 1000 |
| **Acreage (ha)** | Wheat | $x_{11}$ | 284573 | 332509 | 33250 | - | - |
| | Barely | $x_{12}$ | 142946 | 29384 | 29384 | 364869 | - |
| | Corn | $x_{23}$ | 23315 | 85846 | 85846 | 67838 | 7322 |
| | Sugar beet | $x_{24}$ | 24443 | - | - | - | - |
| | Cotton | $x_{25}$ | 45280 | 5200 | 5200 | 5200 | 5200 |
| | Tomato | $x_{26}$ | 14491 | 30498 | 30498 | 45531 | 94048 |
| | Total | $A$ | 535048 | 483437 | 184178 | 483438 | 106570 |

Table 4: Optimal cropping pattern with different water prices under uncertainty with the probability of p=0.1

| | | | Water Price (IRR/m³) | | | |
|---|---|---|---|---|---|---|
| | Product | Variable | 120.5 | 250 | 640.2 | 1000 |
| Acreage (ha) | Wheat | $x_{11}$ | 288232 | 288232 | - | - |
| | Barely | $x_{12}$ | 29840 | 29840 | 320651 | - |
| | Corn | $x_{23}$ | 85580 | 85580 | 69970 | 16787 |
| | Sugar beet | $x_{24}$ | - | - | - | - |
| | Cotton | $x_{25}$ | 5200 | 5200 | 5200 | 5200 |
| | Tomato | $x_{26}$ | 26241 | 26241 | 39272 | 83668 |
| | Total | $A$ | 435093 | 435093 | 435093 | 105655 |

pattern model, are resolved for different levels of the probability of each constraint violation from its bound (p). The final value obtained from these numbers for the constraints in which there is uncertain parameter, is compared to the final value of original data. For each series of random numbers generated on each constraint, if the intended constraint is provided, "one" and otherwise "zero" is attributed to them. Finally, the percentage obtained from total number of "one" in this process is determinant of the functionality and flexibility of the proposed model in providing optimal solutions.

The data used in this study were obtained from Organization of Agriculture Jihad of Khorasan Razavi Province in 2011 (Jehad-Agriculture Organization, 2011).

## RESULTS AND DISCUSSION

In this study, the optimization issue consists of decision variables to determine the acreage of six crops: wheat, barley, corn, sugar beet, cotton and tomato. Cotton is one of the crops for which an acreage of at least $A_e$=200 hectares is considered (to meet the needs of some spinning firms). The issue was optimized under uncertainty and with each constraint violation from its bound at the level of 10% (p=0.1), and also under certainty (p=1), for different water prices of (120.5, 250, 640.2, and 1000 IRR[1] /m³). According to equation (8), for p=0.1, to are {4.34, 4.34, 1, 1, 1, 1, 1}, respectively. Required data are summarized in Table 2.

Table 3 shows the existing cropping plan and the results of the optimization model under certainty (p=1) to determine the optimal cropping pattern.

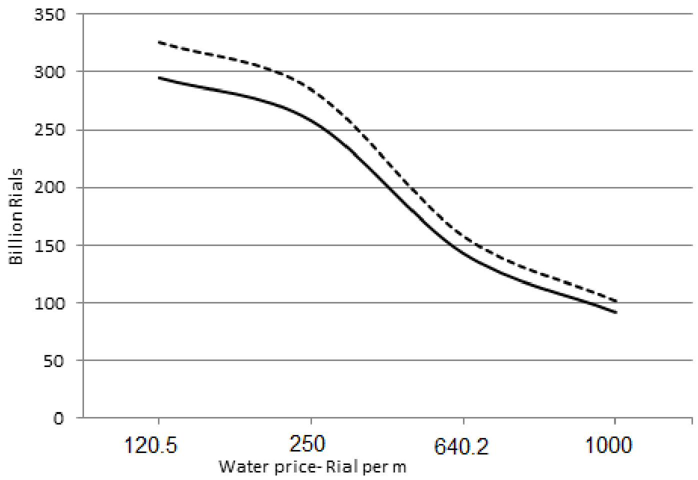
The total cultivated area in the current model shows 11% decrease in average water price (120.5 million) as compared to the optimal cropping pattern in the studied area. The optimal cropping pattern is reported at three different irrigation water prices in Table 3. Average water price in this area is 120.5 IRR and other prices are presented by an expert in Organization of Agriculture Jihad of Khorasan Razavi for the management of water resources of the province from supply management to demand management.

As seen, tangible changes are not observed in cropping pattern in spite of the rising of water price from 120.5 to 250 IRR/m³. Crop acreages, such as tomato which has more gross margin than other products, were greatly increased as water price was increased from 250 to 640.2

Table 5: Total gross margin related to the model at different conditions (unit - billion IRR)

| Description | Water Price (IRR/m³) | | | |
|---|---|---|---|---|
| | 120.5 | 250 | 640.2 | 1000 |
| Total gross margin under certainty | 326 | 285 | 158 | 102 |
| Total gross margin under uncertainty | 295 | 258 | 143 | 92 |

[1] 32000 Iranian Rials (IRR)≈US $ 1




**Gross profit under uncertainty ------- Gross profit under certainty**

Figure 1: Total gross margin at different prices and conditions

IRR/m³ (to compensate higher water costs). The increase in water price from 640.2 to 1000 IRR/m³ resulted in sharp reduction of the acreage of all products. This reduction is lower in products with lower gross margin. In addition, this price increase caused the reduction of the total acreage of 483,437 to 106,570 hectares.

In addition, it can be seen that sugar beet is placed in the model in the current cropping pattern; however, it is recommended in none of the optimal patterns of cultivation. The main reason can be seen in Table 2. As it can be seen in Table 3, technical coefficients of the sources needed to produce this crop are high (especially water requirement) and their benefits are low. Also, according to experts, given that the bulk of the production in South Khorasan Province is to meet the needs of the province, there is no need to restrict the minimum planting area.

Results in Table 3 are related to the conditions in which all data are known and determined. In contrast, the results under uncertainty are different. Table 4 shows the results of robust optimization model with possibility level of . It is considered that in addition to the previous optimal cropping pattern (issue under certainty), acreage of crops with higher gross margin increases with the increase in water price under uncertainty. The increase in water price from 640.2 to 1000 IRR/m³ causes sharp reduction of the total acreage from 435,093 to 105,655 ha.

The main difference between these two issues

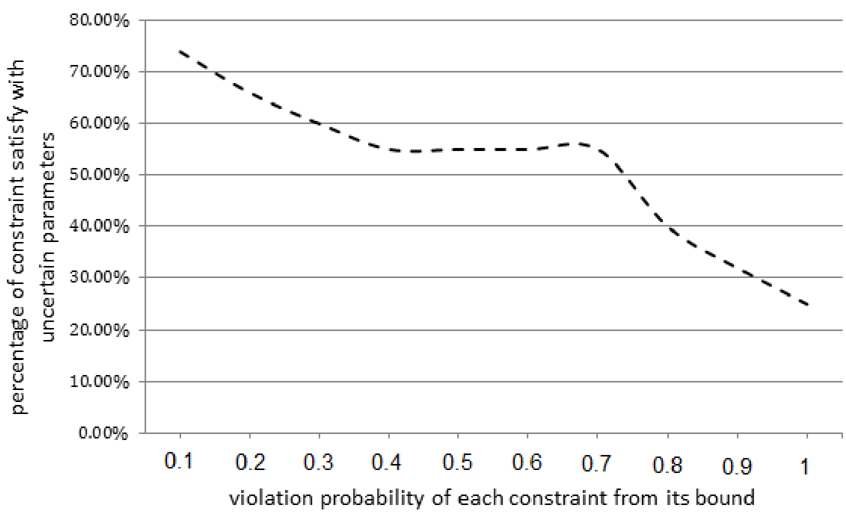



Figure 2: Determination of constraints supply percentage with uncertain parameter using Monte Carlo simulation (random numbers with a normal distribution)

(under certainty and uncertainty) is that the total acreage of crops under uncertain data with the probability level of at fixed prices is less than certain data Also, two crops, tomato and wheat, have less acreage under uncertainty than under certainty at different water prices due to higher gross margin and therefore, higher risk. For example, tomato acreage at a fixed price of 120.5 IRR/$m^3$ water is 30,498 ha under certainty and 26,241 ha under uncertainty (P=0.1). Also, it is seen that wheat price variation from 120.5 to 640.2 is neglected in cropping pattern under both certainty and uncertainty. However, barley acreage was increased sharply by price variations. The most stable acreage under different conditions and prices is related to corn.

Table 5 is related to the total gross margin of optimal cropping production at different water prices (under certainty and uncertainty with the probability of ).

It is seen that the total gross margin is higher under certainty than under uncertainty at the probability level of , at fixed prices and for each cubic meter of water. For example, at a fixed price of 250 IRR total gross margin is equal to 285 billion IRR under certainty and 258 billion IRR under uncertainty. Also, gross margin decreases by the increase in water price at the constant condition (Figure 1). With respect to the subjects covered in this section, it can be observed that the issue of uncertainty in optimal cropping pattern is very important. Therefore, using models like the robust optimization triggers various options under different economic, social and political conditions for agricultural decision- and policy-makers.

Figure 2 shows the results of Monte Carlo simulations for optimal cropping pattern model. Generating 1000 random numbers for each level of constraint violation probability from its bound (P) (normal distribution with a convergence of 99.99 %). It is seen that the percentage of constraint provisions having uncertain parameters increases due to the increase in system protection in optimal cropping pattern against uncertain data (reduction of the degree of constraint violation probability from its bound (P). In the probability of 0.1 (maximum system protection), over 70% of random numbers satisfied the constraints. This amount of constraint provision in 1000 random numbers (in normal distribution with the convergence of 99.99%) is very justifiable and appropriate for each uncertain parameter. Also, it is noted that with the elimination of the system protection against uncertain data, less than 30% of random numbers is satisfied in uncertain constraints. This figure shows the ability of optimization through conservative control parameters.

## CONCLUSION

In this study, robust optimization model was used to assess the uncertainty issue in the allocation of arable lands. Moreover, the effect of the variations of water price on gross margin irrigation and acreage of crops was studied. It was found that the total gross margin is higher under certainty than under uncertainty (at constant prices). With the increase in water price at constant conditions, the amount of gross margin reduces. Considering that the change in water price causes tangible changes in wheat acreage and giving that this product is strategic in domestic production, it is proposed to adopt appropriate policies to reduce risk and to prevent the acreage loss of the crop.

A desirable level of income for farmers and also a controllable use of water can be obtained using water price control policies at different conditions.

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