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A multi-attribute preference model for optimal irrigated crop planning under water scarcity conditions

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Abstract

Water resources sustainability has a key role in the existence and durability of irrigated farming systems and strongly depends on the crop planning. The decision process is complex due to a number of constraints and the desire to secure crop diversification and the involvement of affected various parameters. The objective of the present study was to develop a comprehensive multi-criteria model for selecting adequate cropping pattern in an irrigation district under water scarcity condition. Eleven and nine attribute decisions were considered in ranking the type of crop and determination of the percentage of crop cultivation area as an optimal irrigated crop planning system, respectively. The results indicate that the proposed multi-attribute preference approach can synthesize various sets of criteria in the preference elicitation of the crop type and cultivated area. The predictive validity analysis shows that the preferences acquired by the proposed model are evidently in reasonable accordance with those of the conjunctive water use model. Consequently, the model may be used to aggregate preferences in order to obtain a group decision, improve understanding of the choice problem, accommodate multiple objectives and increase transparency and credibility in decision making by actively involving relevant criteria in the crop planning.

Additional key words: analytical hierarchy process; cropping pattern; Koohdasht irrigation district; multi-criteria approach.

Resumen

Modelo de preferencia multiatributo para la planificación óptima de cultivos de regadío en condiciones de escasez de agua

La sostenibilidad de los recursos hídricos tiene un papel clave en la existencia y durabilidad de los sistemas agrícolas de riego y depende en gran medida de la planificación de los cultivos. El proceso de decisión es complejo, debido a una serie de restricciones y el deseo de asegurar la diversificación de los cultivos y la participación de diversos parámetros afectados. El objetivo del presente estudio fue desarrollar un modelo multicriterio completo para seleccionar una combinación adecuada de cultivo en un distrito de riego con escasez hídrica. La planificación de un sistema óptimo de cultivos en regadíos se realizó considerando once y nueve atributos de decisión para jerarquizar el tipo de cultivo y su porcentaje de superficie, respectivamente. Los resultados indican que el enfoque de preferencia de atributos múltiples puede sintetizar varios conjuntos de criterios en la selección del tipo de cultivo y la superficie cultivada. El análisis de validación muestra que las preferencias generadas por el modelo propuesto están razonablemente de acuerdo con las obtenidas en el modelo de uso del agua. En consecuencia, el modelo podría ser utilizado para agregar preferencias a fin de obtener una decisión de grupo, mejorar la comprensión del problema de elección, adaptarse a múltiples objetivos y aumentar la transparencia y la credibilidad en la toma de decisiones en las que la planificación de cultivos esté involucrada.

Palabras clave adicionales: enfoque multicriterio; distrito de riego Koohdasht; planificación de cultivos; proceso de jerarquía analítica.

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Introduction

Water resources sustainability has a key role in the existence and durability of the irrigated farming systems and strongly depends on the crop planning. The different agricultural, environmental and socio-economic criteria should be taken in to account to find an appropriate water management and consequently crop planning practices in farming systems. These criteria are generally conflicting and inconsistent. For example, maximizing the net return in a farming system requires more withdrawal of water resources, while the sustainability of the system entails reducing the water consumption. However, it is believed that with appropriate water management practices in crop planning, up to 50% of available water can be saved (Shangguan *et al.*, 2002).

Cropping pattern of an irrigation command area is the manifestation of the climate, the soil, the facilities available like irrigation, fertilizer, mechanization and the socioeconomic factors. Multiple criteria decision making (MCDM) methods have frequently been used to simultaneously optimize several objectives in crop planning (Tsakiris & Spiliotis, 2006; Sharma & Jana, 2009; Vivekanandan *et al.*, 2009), water resources management (Al-zahrani & Ahmad, 2004; Bravo & Gonzalez, 2009) and agriculture planning (Alphonce, 1997). A recent progress in this context was considered fractional programming (FP) procedure with multiple objectives (Amini Fasakhodi *et al.*, 2010). A land and water allocation model, as a multi objective plan using fuzzy technique, was formulated by Gore & Panda (2009). As a result of the study, farmers were advised to advocate the optimal cropping pattern obtained by multi-objective allocation model for better return. Montazar (2011) developed a conjunctive water management model for the Koohdasht Irrigation District of Iran. In his research, an integrated soil water balance algorithm was coupled to a non-linear optimization model in order to carry out water allocation planning in complex deficit agricultural water resources systems based on an economic efficiency criterion.

Over the past several decades, the environmental decision-making strategies have increasingly been evolved into more sophisticated, information-intensive, and complex approaches including expert judgment, cost-benefit analysis, toxicological risk assessment, comparative risk assessment as well as the methods of public and stakeholder values incorporation. Multi-criteria techniques are considered as promising frameworks for evaluation, in which the multi-dimensional, incommensurable and uncertain effects of decisions are explicitly taken into account (Munda, 2000; Omann, 2000; Ananda & Herath, 2008).

One of the most widely applied pair-wise comparison techniques is the Analytic Hierarchy Process (AHP; Saaty, 1987, 2005). The approach involves comparing criteria and alternatives in every unique pair giving $\frac{n\,(n-1)}{2}$ comparisons. The comparisons can be made to attain criteria weights and decision option performance scores. Various scaling systems can be used. Decision makers are asked to express preference for one criteria/option over another in each pair on a nine point scale. The criteria used for modeling agricultural systems and to identify the difficulties for practitioners in applying the multi-criteria analysis were classified and evaluated by Hayashi (2000). AHP is an effective way to deal with complicated problems that cannot be analyzed by quantitative method completely. The approach has been developed and applied to agricultural and water management numerous areas (Montazar & Behbahani, 2007; Okada *et al.*, 2008a,b; Srdjevic & Medeiros, 2008; Zahang, 2009; Montazar & Zadbagher, 2010).

It is directly related to productivity of irrigation systems and greatly contributes to improved soil and water utilization. Due to a number of constraints and the desire to secure crop diversification, operational research techniques have been employed for finding adequate cropping patterns. However due to the involvement of various factors in cropping pattern programming, typically a multi-objective problem, MCDM may be considered as a well-suited decision support tool. However, the present issue in this research is such

Abbreviations used: AHP (analytic hierarchy process); AW (available water); CDS (crops disease susceptibility); CGW (constraint on groundwater availability); CMA (consumption market accessibility); CME (cultivation-maintenance and harvesting costs of the crop); CMH (cultivation-maintenance and harvesting costs of the crop); CV (crop value); CWP (crop water productivity); EC (electrical conductivity); ET (amount of evapotranspiration); FAS (farmers' abilities and skills); FP (fractional programming); IM (irrigation method); KID (Koohdasht Irrigation District); LWC (Lorestan Water Company); MCDM (multiple criteria decision making); MCM (million cubic meters); NAP (national agricultural policies by government); RA (amount of rainfall); RDC (regional demand to the crop); SAR (sodium adsorption ratio); ST (soil texture); WP (water price); WQ (water quality).

a problem that it is proper to apply AHP to it. The main objective of the present study was to develop and evaluate a comprehensive model for selecting optimized cropping pattern based on different criteria and factors including water requirements, net returns, climatic conditions availability of resources, social needs, technological innovations and agronomic practices factors affecting cropping system efficiency. AHP is used in this study, thereby testing its capacity as a decision making tool for optimal irrigated crop planning under water scarcity conditions.

Material and methods

Study area

The present study was done on the Koohdasht Irrigation District (KID), a semi-arid region in the West of I. R. Iran. The KID lies between 33°25' N to 33°45' N latitude and 47°25' E to 47°50' E longitude. The average annual precipitation is 413.6 mm, which corresponds to semiarid conditions. The mean annual temperature is 13.8°C. The main crops of area are wheat, barley, maize (and corn), sugar beet, colza, tomato, bean, cucumber, summer crops (includes melon, water melon, gourd and cantaloupe), and rice. The evapotranspiration of the main crops of the area during growing season may be obtained in Table 1. It serves an estimated gross irrigated area of 40,000 ha, which the water requirement is supplied from Madian River, and 396 wells and 8 springs scattered along the irrigation district. The available surface water is about 39.270 million cubic meters (MCM), and it supplies 31.744 MCM during the period months of March to August, *i.e.,* 80% of annual water delivered. During August to December, the available surface water decreases to 7.526 MCM, and during January, there is no available surface water. The groundwater level varies from 10 to 85 m below the surface. The recharge to the aquifer comes from rainfall (10% as percolation of precipitation), canal seepage and the deep percolation from the root zone of the crops grown, which is estimated at 30% of the total allocated water in KID (Montazar, 2010). Surface water supplies are inadequate to meet irrigation needs of crops. Consequently, groundwater is heavily exploited through the uncontrolled heavy pumping of groundwater in the irrigation area. Around 95,000 ha of KID are managed as rain-fed agricultural system, which is not considered in this study.

Large parts of the region have only limited freshwater resources, and in other areas, potential resources are insufficiently well-known to permit reliable planning. Gravity irrigation accounts around 95% of the total irrigated area, and 5% is irrigated with pressurized irrigation systems. This aggravates erosion; especially in sloping plots. Irrigation systems consist of an open canal network, generally unlined, with rudimentary water intakes and distribution systems supplying small plots devoted mostly to subsistence agriculture. Less than 5% of irrigated land is equipped with improved on-farm irrigation systems. However, traditional irrigation schemes need modernization to achieve higher yields and better resource utilization. The majority of the rainfall occurs between November and May, and the rest of the year irrigation depends on low-tech systems. Several institutional frameworks have been created by the local farmers, which are organized under Lorestan Water Company (LWC).

The simulation results of 18 crop planning scenarios (ten proposed and eight existing cropping patterns) of KID were reported by Montazar (2011). Here, only the scenarios E_5 and P_2 are considered. Table 2 indicates the percentage of cultivated area for each scenario (Montazar, 2011). The E_5 scenario was the existing cropping pattern of KID in growing seasons of 2005. As it can be seen in Table 2, wheat has the maximum cultivated area of scenarios. The percentage of wheat cultivated area was 44.9% (17,960 ha) in case E_5 and 57.1% (22,840 ha) in case P_2. It has minimum value for colza, which was 0.09% for E_5 and 0% for both colza and sugar beet in case P_2.

Surface supplies are inadequate to meet irrigation needs of crops. Consequently, groundwater is being heavily exploited through the wells. The programmable surface water and groundwater in the agricultural sector are considered 39.270 and 93.823 MCM, respec-

Table 1. Seasonal evapotranspiration of the main crops of the area

	Wheat	Bean	Colza	Maize	Summer crops	Rice	Tomato	Cucumber	Barley	Sugar beet
ET (mm)	409.5	671.9	366.7	713.6	510.0	872.2	761.5	607.6	419.9	814.8

Table 2. Percentage of cultivated area in the different cropping pattern scenarios (Montazar, 2011)

	Barley	Bean	Colza	Maize	Summer crops	Rice	Tomato	Wheat	Cucumber	Sugar beet
E_5	2.09	0.20	0.09	29.68	9.50	0.58	0.34	44.90	5.44	0.45
P_2	1.68	0.05	0.00	24.31	7.21	0.12	0.28	57.30	4.82	0.00

tively (with a mining allowance of groundwater resource factor of 0.83). The mining allowance of groundwater resource factor (=1 when no mining is allowed) can be considered as the ratio of the groundwater allocation to the irrigation area to the annual recharge of groundwater resources. This definition has been already used by Khare *et al.* (2006), Montazar & Zadbagher (2010), and Montazar (2011).

The irrigation water, from Madian River and 396 wells, has a good quality (pH = 7.2-7.7; electrical conductivity–EC = 0.5-3.1 dS m^{-1}; sodium adsorption ratio– SAR = 1.2-1.9). The soil texture in the study area changes from coarse-grain at the beginning of KID alluvial fan to loam at the middle and downstream zones of plain.

Analytic hierarchy process model

We use the method of AHP combined with survey to analyze the reasonable allocation of optimal cropping pattern in the KID. In this approach, separate performance indicators are aggregated into an integrated one (Bouma *et al.*, 2000). By applying AHP, a hierarchical decision scheme was constructed, decomposing the decision problem into its elements. Here, the attributes were compared in pair-wise manners for their preferences and the quantitative values were driven by using numerical techniques. In the comparisons, the more important one out of two attributes as well as its priority value was clarified. Where two criteria are of equal importance, the value 1 is given in the comparison; the value 9 shows absolute importance of one criterion overall. The preference values of pair-wise comparisons proposed by Saaty (1980) were used.

The use of AHP involves developing a hierarchical decision model comprising decision attributes (criteria), sub-attributes and options. The procedure for using the AHP can be summarized as: 1) model the problem as a hierarchy containing the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives (Fig. 1); 2) establish priorities among the elements of the hierarchy by making a series of judgments based on pairwise comparisons of the elements; 3) synthesize these judgments to yield a set of overall priorities for the hierarchy; 4) check the consistency of the judgments; and 5) come to a final decision based on the results of this process.

The model, developed in this study, is of two submodels. In the first sub-model, three levels are considered in the hierarchical analysis for ranking the type of crops in the cropping system (Fig. 1a), which are: objective level (level one), selecting the best type of crop (level two); the criteria level (level three) which are the parameters involved in the selection of crop type (11 criteria); finally, alternative or option level, regional main crops of the study area.

In order to determine the type of crops in the cropping pattern, the effective factors are considered in three groups: socio-economic, water and soil resources, and climatic criteria. The first group, socio-economic, includes water price (*WP*), cultivation-maintenance and harvesting costs of the crop (*CMH*), crop value (*CV*), crop water productivity (*CWP*) and regional demand to the crop (*RDC*). The second one, water and soil resources, includes available water (*AW*), water quality (*WQ*), irrigation method (*IM*), and soil texture (*ST*). The last group, climatic criteria, which is the climatic factor including the amounts of evapotranspiration (*ET*) and rainfall (*RA*). Water availability and evapotranspiration are two evaluation factors for selecting the type of crop that require separate consideration. Evapotranspiration determines the water demand by the crop, and hence, it is considered an important factor in the crop planning process. It should be noted that all effective factors in determining of the type of crops (1st sub-model) and the percentage of cultivated area for each of the ranked crops (2nd sub-model) are recognized as the major effective factors in the determination process of crop planning for an irrigation command area.

After ranking the crops using sub-model one, the percentage of cultivated area for each of the ranked crops is obtained from sub-model two. In this submodel, three levels are also considered in the structure of hierarchical analysis for determining the relative crop area (Fig. 1b). The objective level (level one)

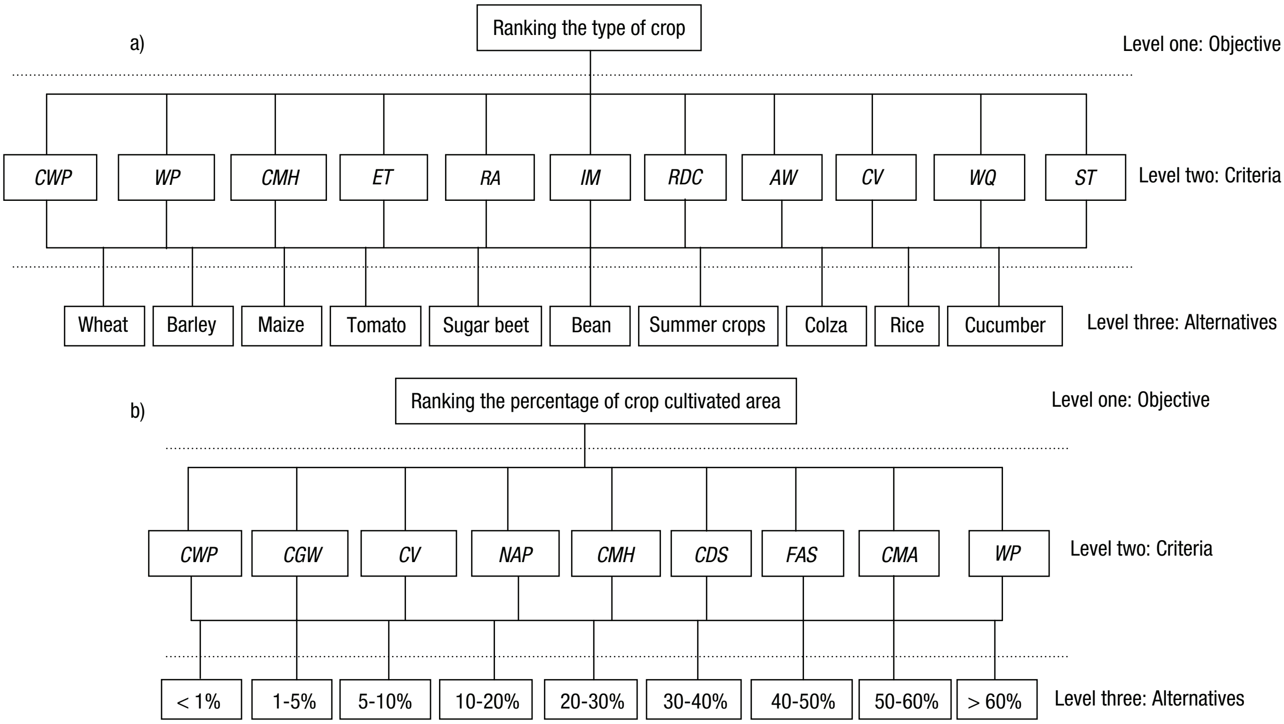

Figure 1. Hierarchy of ranking (a) type of crop, and (b) percentage of crop cultivated area.

determines the relative crops areas. The criteria level (level two) evaluates the factors effective in the determination of cultivation area of cropping pattern crops (nine factors). The alternatives level (level three) identifies relative crops areas using nine classes (< 1%, 1-5%, 5-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60% and > 60% of the irrigation district).

The nine effective factors for selecting percentage of cultivated area of cropping system are: national agricultural policies by government (*NAP*), available water (*AW*), water price (*WP*), cultivation-maintenance and harvesting costs of the crop (*CME*), constraint on groundwater availability (*CGW*), crop value (*CV*), crops disease susceptibility (*CDS*), farmers' abilities and skills (*FAS*)), and consumption market accessibility (*CMA*).

The outputs of the sub-models are integrated to have the global priority scores of type of crop (1st sub-model) and percentage of the cultivated area for each crop (2nd sub-model). The rank of the crops type is obtained from the first sub-model. For each of these crops, the rank of crop cultivated area is determined in the second sub-model. In other word, the results of each sub-model are considered separately. Cropping pattern, however, includes determination of crop type and percentage of cultivated area. Hence, the results of sub-models can be integrated and used for crop planning.

Weighting process of the criteria and alternatives

Weighting the criteria and alternatives was done using the pair comparison method. The elements of each level were compared to their correspondents in the upper level in pair form and their relative weights were calculated. The final weights of options were detected by combining the relative weights. The special vector method (Saaty, 1980), the most effective one in finding the levels, was used for calculating the weights in a level in relative to their correspondents in the upper level.

In order to weight the criteria and options as well as the aforementioned effective items, some questionnaires were provided for water industry experts. The ideologists of water industry, *i.e.,* are professors and government agency officers/researchers, which teach and do research on the operational irrigation network management, have ample knowledge on the agricultural water management and agronomy science and are familiar with the conditions of Iranian irrigation districts, so that, they can give a proper judgment or assessment of each item. The questionnaires were designed in such a way that the respondents could select their priorities in the criteria and options. Thirty five qualified experts were invited to attend the survey. The experts were of ample knowledge on the agricultural water management and agronomy science and were very familiar with the irrigated crop planning in the agricultural areas. Therefore, they could give a proper judgment or assessment on each item. Their work provided reliable information for the research.

Once the hierarchy was constructed, the experts analyzed it through a series of pairwise comparisons that derive numerical scales of measurement for the nodes. The criteria were pairwise compared against the goal to determine importance. The alternatives were pairwise compared against each of the criteria for preference. The comparisons were processed mathematically, and priorities are derived for each node. Priorities were numbers associated with the nodes of an AHP hierarchy. They represent the relative weights of the nodes in any group. Priorities are absolute numbers between zero and one, without units or dimensions. A node with priority 0.20 has twice the weight in reaching the goal as one with priority 0.10, ten times the weight of one with priority 0.02, and so forth. Depending on the problem at hand, "weight" can refer to importance, or preference, or likelihood, or whatever factor is being considered by the decision makers. Priorities are distributed over a hierarchy according to its architecture, and their values depend on the information entered by users of the process. Priorities of the goal, the criteria, and the alternatives are intimately related, but need separate consideration.

The matrices of pair-wise comparisons criteria regarding their contributing importance in the general objectives for the sub-models are presented (Tables 3 and 4). For example, the evapotranspiration (*ET*) with priority of 5.0 has five times the weight of irrigation method and soil texture with priority of 1.0. Its importance is triple the water quality (*WQ*) and regional demand to the crop criteria, *RDC*, (importance ratio 3:1) and a third in comparison to available water, *AW*, (importance ratio 1:3). Also, cultivation-maintenance and harvesting costs of crop (*CMH*) and crop value (*CV*) are one fourth as important as evapotranspiration.

The relative weights are aggregated to obtain the final weight of each option. One advantage of AHP is its capacity for controlling decision consistency that is always amenable to computation and evaluation. For each matrix, the quotient of consistency index to inconsistency index of a stochastic matrix of the same vector is used as the criterion to judge the decision inconsistency; defined as the consistency ratio. In cases where this value is less than 0.1, the system has an acceptable consistency. Otherwise, judgments are repeated. In the present study, evaluation of decision consistency was performed for each of the matrices developed.

Results and discussion

We used the method of AHP combined with survey to analyze cropping pattern of KID. The analysis was carried out at two levels: individual preferences and aggregated preferences. The data were further analyzed using equal weights and self-assessed (participants) weights. Data for pair-wise comparisons were analyzed

Table 3. Pair-wise comparisons of the criteria ratio to the objective (sub-model 1)

Criterion	*CWP*	*ET*	*RA*	*ST*	*IM*	*WQ*	*CV*	*CMH*	*WP*	*AW*	*RDC*
CWP	1	5	3	6	4	2	5	4	4	3	2
ET		1	1	5	5	3	4	4	5	1/3	3
RA			1	4	4	4	2	3	4	1/2	2
ST				1	2	1/5	2	1/5	2	1/6	1/4
IM					1	1/4	1/2	1/4	1/2	1/5	1/5
WQ						1	4	4	6	1/4	2
CV							1	1/4	2	1/7	1/4
CMH								1	5	1/6	3
WP									1	1/7	1/4
AV										1	6
RDC											1
Consistency ratio = 0.09 < 0.1											

CWP crop water productivity, *ET* and *RA* amounts of evapotranspiration and rainfall, *ST* soil texture, *IM* irrigation method, *WQ* water quality, *CV* crop value, *CMH* cultivation-maintenance and harvesting costs of the crop, *WP* water price, *AW* available water, and *RDC* regional demand to the crop.

Table 4. Pair-wise comparisons of the criteria ratio to the objective (sub-model 2)

Criterion	*CGW*	*CWP*	*CV*	*CMH*	*WP*	*AW*	*FAS*	*CDS*	*CMA*	*NAP*
CGW	1	1	3	4	6	2	8	5	8	4
CWP		1	4	3	7	2	5	3	4	1/3
CV			1	4	3	1/2	3	1/2	2	1/4
CMH				1	4	1/3	3	1/3	1	1/5
WP					1	1/2	2	1	2	1/5
AW						1	2	2	3	1/3
FAS							1	1/3	1/2	1/8
CDS								1	2	1/4
CMA									1	1/7
NAP										1
Consistency ratio = 0.07 < 0.1										

CGW: constraint on groundwater availability; *FAS:* farmers' abilities and skills; *CDS:* crops disease susceptibility; *CMA:* consumption market accessibility; and *NAP:* national agricultural policies by government.

using Expert Choice Professional Version Software (Expert Choice, 2000). The pair-wise comparisons made by the respondents were consistent. The overall mean consistency ratio of the comparisons was 0.08% (standard deviation 5.83%), which is acceptable for general public surveys. The results of the individual and aggregate level analyses of the pair-wise comparison data are presented in the following sections.

Weights of decision attributes

The pair-wise comparisons of the criteria ratio to the objectives of crop type and percentage range of cultivated area in crop planning were used to obtain Tables 5 and 6, respectively. Table 5 shows the priority weights computed for the eleven attributes using the pair-wise comparison data for the total sample and for individual crop type of cropping system. In other words, Table 5 shows how the importance of each decision attribute in the first sub-model is varied over the alternatives. The results indicate that available water criterion with a weight of 0.02 was the most important attribute.

The available water criterion has the highest weight in detecting crop type because of water availability restriction. Surface water supplies are inadequate to meet irrigation needs of crops, so groundwater is being heavily exploited through the integrated wells. Hence, the uncontrolled heavy pumping of groundwater has caused over-exploitation in the KID. The second priority in the criteria corresponds to the crop water productivity with a weight of 16%. Salinity level is medium in the KID; so it imposes little limitation on cultivation. However, it should be considered for crops sensitive to salinity. The irrigation method and water price criteria with 3% weight were the lowest priorities. Modern irrigation methods are rare in the region, so irrigation method shows no significant effect on the determination of cropping pattern.

The criteria weights for selection of the crop cultivated area are shown in Table 6. The most and the least important criteria were national agricultural policies by government with a weight of 0.24 and the least important criterion was farmers' abilities and skills with a weight of 0.03, respectively. According to the results obtained in this study, the criterion of national agricultural policies with a weight of 24% is in the first rank in the determination of the cultivated area. The farmers' ability and skills, with a weight of 3%, is the last criterion in the region. The farmer's ability has also lower effect on the determination of under-cultivation area according to higher agricultural mechanization.

Table 5. Criteria weights in the ranking model (sub-model 1)

Criterion	*CWP*	*CV*	*WP*	*CMH*	*RDC*	*AW*	*WQ*	*ST*	*IM*	*ET*	*RA*
Weight in the ranking model	0.16	0.07	0.03	0.09	0.07	0.20	0.12	0.04	0.03	0.11	0.08
Standard deviation (%)	0.21	0.16	0.12	0.19	0.13	0.21	0.21	0.13	0.11	0.22	0.18

Table 6. Criteria weights in the ranking model (sub-model 2)

Criterion	*CWP*	*NAP*	*AW*	*WP*	*CMH*	*CV*	*CDS*	*FAS*	*CMA*	*CGW*
Weight in the ranking model	0.19	0.24	0.16	0.04	0.05	0.07	0.06	0.03	0.04	0.12
Standard deviation (%)	0.18	0.24	0.21	0.12	0.15	0.18	0.17	0.10	0.14	0.16

Aggregate ranking crop planning options

In this paper, aggregation using equal weights for the different criterion approach was used in synthesizing aggregate level or criterion preferences. In the approach, the geometric means of the pair-wise comparisons of each criterion were used to yield the attribute weights. Options were ranked by combining the attributes using equal weights for the criteria. The ranking of options (Fig. 2) shows that crop system was prioritized as: wheat, maize, summer crops, cucumber, barley, tomato, colza, sugar beet, rice, and bean.

The rankings of the nine different cultivated areas options were also aggregated using geometric means of pair-wise comparisons and equal weights scenario. For example, the importance of each option (percentages of cultivated area), for wheat and maize, are graphically shown in Figure 3 where the *x*-axis is priority score. The highest global priority score was obtained for the option of 40-50% implying that cultivating 40-50% of the area to wheat is best. For maize, the results indicate that cultivating 10-20% of the area is best.

Sensitivity analyses on the effects of changes in the criteria priorities provide useful insights into the options preferences. Table 7 shows the relative importance of each decision attribute in the sub-models is varied over the alternatives. It indicates how the options are prioritized over others with respect to each objective as well as the overall objective. For example, variability in importance of the crop water productivity across crop type of cropping system is as: maize > wheat > summer crops > cucumber > tomato > bean > barley > colza > sugar beet > rice. The criterion of available water is as: colza > wheat = barley > maize > summer crops > cucumber > tomato > bean > sugar beet > rice.

Figure 3 shows how a crop was prioritized relative to other crops with respect to each criterion as well as the overall objective. Wheat and maize have the greatest priority over other crops in regards to the criteria importance. The choice of crop type, however, is somewhat sensitive to the weights assigned to the available water (0.20) and crop water productivity (0.16) attributes (Table 4). These preferences indicate that the crop type is insensitive to the assigned weights of irrigation method and water price attributes (0.03). In the study area, agricultural water price is inexpensive, but price of the groundwater (0.010 USD m^{-3}) is more as than surface water (0.006 USD m^{-3}), which may be a concern for the farmers. Results show that wheat had higher scores in cultivation-maintenance and production costs, regional demand, irrigation method, soil structure, water price, and evapotranspiration attributes

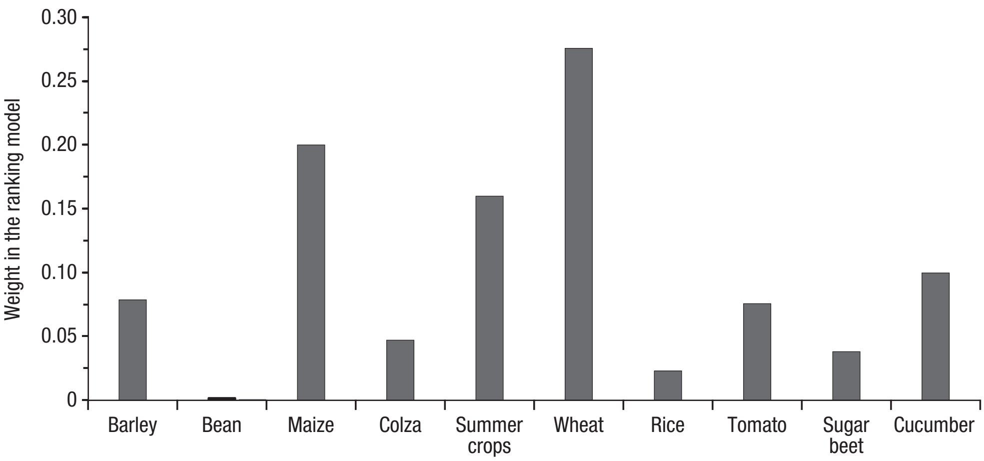

Figure 2. Options weight in the ranking model.

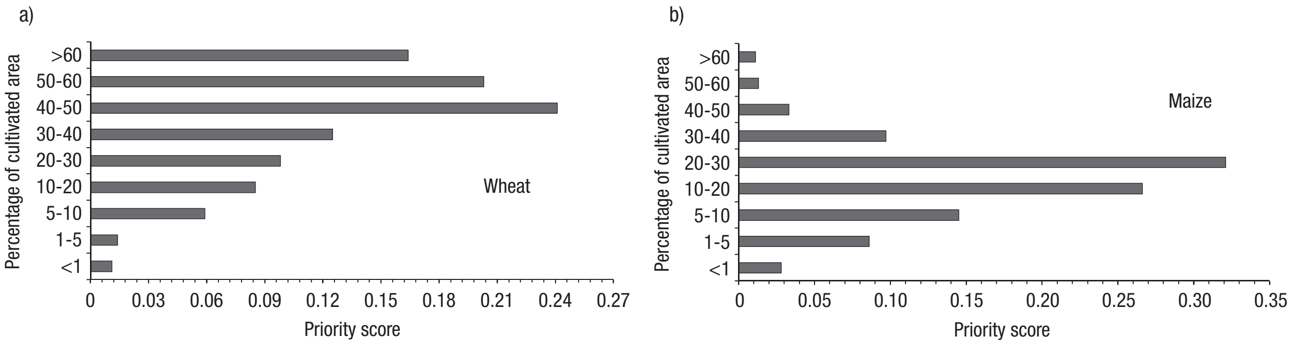

Figure 3. Priority scores of percentage of the cultivated area for wheat (a) and maize (b).

and overall one (Table 4). Moreover, no significant difference is observed between wheat and barley in the soil texture, irrigation method, water price, and evapotranspiration attributes. Also, the percentage of cultivated area had a greater sensitive to the national agricultural policies by government (0.24) crop water productivity (0.19), and available water (0.16) attributes (Table 4). It depicts that the cultivated area of crops is insensitive to the assigned weights of farmers' abilities and skills (0.03), consumption market accessibility (0.04), and water price (0.04) criteria.

The sensitivity analysis is carried out on the effects of local priorities, changing the weights of decision criteria. Assuming the ratios of other weights are constant, if the weight assigned to the available water is less than 0.20, then wheat is the best alternative. If the weight assigned to available water was more than 0.47, then the final outcome would change from wheat to maize. Similarly, by changing the weights of any decision criteria, one can determine how robust the choice of crop type is. Also, if the weight assigned to the crop water productivity changes to greater than 0.19, then the final outcome would change from the percentage of 40-50% as relative cultivated area to the percentage of 50-60%. Assuming the ratios of other weights are constant, if the weight given to this criterion, is less than 0.11, then the percentage of 30-40% as relative cultivated area is the best alternative for wheat.

Validity of multi-attribute preference model

The predictive validity of multi-attribute preference model (AHP model) was examined using nonparametric tests. The crops rank of predicted AHP model were compared with those of a conjunctive model presented by Montazar (2011), case E_5 and P_2, (Table 8). In the scenario E_5, a net benefit of 58.478 million USD was obtained from the 17,852 ha area using 37.456 and 68.889 MCM utilization of surface and

Table 7. Variability in criterion importance across crop type of cropping system

Criterion	Option (Type of crop)[1]
CWP	Maize > Wheat > Summer crops > Cucumber > Tomato > Bean > Barley > Colza > Sugar beet > Rice
CV	Maize > Cucumber > Summer crops > Tomato > Bean > Rice > Wheat > Barley > Colza > Sugar beet
WP	Wheat = Barley > Bean = Colza > Maize > Cucumber > Tomato > Summer crops > Rice > Sugar beet
CMH	Wheat > Barley > Bean = Colza > Maize > Cucumber > Tomato > Summer crops > Rice > Sugar beet
RDC	Wheat > Maize > Summer crops > Cucumber > Tomato > Barley > Bean > Rice > Sugar beet > Colza
AW	Colza > Wheat = Barley > Maize > Summer crops > Cucumber > Tomato > Bean > Sugar beet > Rice
WQ	Barley > Wheat = Colza > Maize > Summer crops = Cucumber = Tomato > Rice > Bean > Sugar beet
ST	Wheat = Barley = Colza > Bean > Maize > Summer crops > Cucumber = Tomato > Sugar beet > Rice
IM	Wheat = Barley = Bean = Colza > Maize > Cucumber = Tomato = Summer crops > Sugar beet > Rice
ET	Wheat = Barley = Colza > Maize > Summer crops > Cucumber > Tomato > Bean > Rice > Sugar beet
RA	Maize = Cucumber = Tomato > Rice > Summer crops > Sugar beet > Bean > Wheat = Barley = Colza
Overall	Wheat > Maize > Summer crops > Cucumber > Barley > Tomato > Colza > Been > Rice > Sugar beet

[1] The notations > and = symbolise the option preceding the sign is 'preferable to' and 'equal to' the one after the sign, respectively.

Table 8. Comparing AHP- predicted and conjunctive model ranking of crops

Ranking model	Barley	Bean	Maize	Colza	Summer crops	Wheat	Rice	Tomato	Sugar beet	Cucumber
Conjunctive model (Case E_5)	5	8	2	9	3	1	6	7	10	4
Conjunctive model (Case P_2)	5	8	2	10	3	1	7	6	9	4
AHP model	5	8	2	7	3	1	9	6	10	4
Rank difference of AHP model & Case E_5	0	0	0	–2	0	0	+3	–1	0	0
Rank difference of AHP model & Case P_2	0	0	0	–3	0	0	+2	0	+1	0

ground water, respectively (Montazar, 2011). The global water productivity (*GWP*) and mining allowance of groundwater resource factor (μ) values for case this case are estimated 0.531 USD m^{-3} and 0.612, respectively (Montazar, 2011). For case P_2, the *GWP* and μ were 0.514 USD m^{-3} and 0.724, respectively. Also, a net benefit of 61.269 million USD has been obtained from the 20,745 ha area using 37.456 and 81.695 MCM utilization of surface and ground water, respectively (Montazar, 2011).

The preferences acquired by the proposed model are in reasonable accordance with those of the conjunctive model for the main crops of the KID. The AHP model has assessed the ranking priorities of wheat and barley, taking > 50% of under cultivation areas in the KID and including the fall's cultivation of the area, in accordance with the conjunctive model. The summer crops, maize and cucumber also show the same ranks in both methods. Wheat, maize, summer crops, cucumber, and barley have the first to fifth ranks in the AHP model and the conjunctive model scenarios.

In the AHP model, the stated priorities for the second crops group with a total percentage cultivated area of less than 5% are determined as: tomato (6), colza (7), bean (8), sugar beet (9), and rice (10). The stated preferences for cropping systems are captured in ordinal ranking, and the predicted ranking is obtained by synthesizing AHP pair-wise comparisons in the individual analysis. The rank difference of AHP model and case E_5 for rice, colza, and tomato is: +3, –2, and –1, respectively. The indicator value for case P_2 is computed –3, +2 and +1 for colza, rice, and sugar beet. The predictive validity describes the agreement between the cases and predicted preferences. Therefore, it can be concluded that AHP has proper capability for ranking cropping pattern.

The percentage cultivated areas of each crop obtained by AHP model are compared with those of case E_5 and P_2 (Fig. 4). The percentage cultivated area of

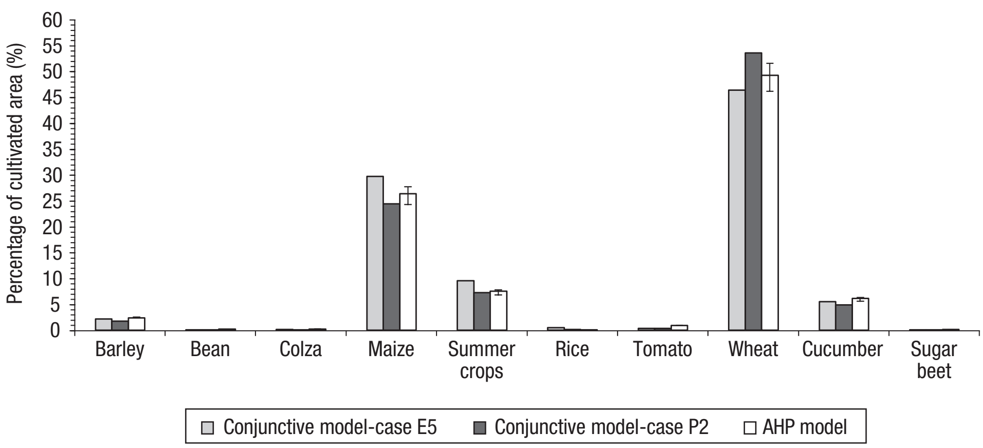

Figure 4. Comparison of the priority scores, percentage of the cultivated area for each crop at the AHP model and conjunctive model.

each crop for the case E_5 and P_2 is between the low and high margin of the percentage cultivated area by AHP model (standard deviation of 5%). As an example, the AHP under-cultivation area of wheat is 49%, while the low and high areas of this crop, error amount of 5%, are 48% and 52%, respectively. The percentage cultivated area for E_5 and P_2 is 46 and 54%, respectively.

The findings demonstrate that the model developed in the study help to determine the cropping pattern with an appropriate accuracy. AHP provides information on the relative importance of the different attributes and the tradeoffs involved, which could improve the decision making on crop planning. Consequently, the proposed model may be considered as a comprehensive tool and an effective way to improve participatory decision making in regional crop planning.

As conclusions, comprehensive crop pattern planning takes in to account the high level of interrelation of the environmental, economic and social aspects of farming systems. The hierarchical analysis model for selecting adequate cropping pattern is assessed based on different criteria and parameters include: water requirements, net returns, climatic status, resources availability, social needs, technological innovations and agronomic practices factors affecting cropping system efficiency. The paper examined selection of type and percentage of crop cultivated area objectives, attributes of cropping planning options, the relative importance of weights, and the ranking of cropping planning options in a multi-attribute context using AHP for the Koohdasht Irrigation District in Iran. The results indicate that the proposed model can determine the cropping pattern with an appropriate accuracy. Consequently, AHP can be used to aggregate preferences in order to obtain a group decision, improve understanding of the choice problem, accommodate multiple objectives and increase transparency in decision making by actively involving relevant criteria in the crop planning. The model may be used by irrigation district authorities as an applicable tool in evaluating the quantitative and qualitative factors effective in the crop planning for crop type cultivation area. Further research to extend the methodology could use other multi-objective methods and fuzzy set theory.

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