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A MULTI-CRITERIA DECISION ANALYSIS OF WHEAT PRODUCTION SUSTAINABILITY IN THE SEMI-ARID ENVIRONMENT OF MASHHAD, NORTHEASTERN IRAN

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ABSTRACT

Globally, wheat is the most staple food for one-third of the population and provides more daily calories and protein than any other crop. However, its production still poses great social and environmental challenges for humanity. Hence, agricultural sustainability indices are commonly used to evaluate all economic, ecological, and social dimensions of crop production from theory into practice around the world. This assessed agricultural sustainability of irrigated (IWPS) and rainfed (RWPS) wheat production systems in the semi-arid environment of Mashhad (northeastern Iran). Data were obtained from irrigated and rainfed wheat farms in Mashhad for the growing seasons (Oct-May) during 2006-2010. The questionnaire was also designed to collect data from the farmers. A multi-criteria decision analysis (MCDA) was performed to identify the most significant economic, ecological, and social criteria influencing the agricultural sustainability index. The results determined that IWPS is more sustainable than RWPS in Mashhad as the economic viability for IWPS is relatively higher than that for RWPS. However, RWPS has also a high potential to achieve agricultural sustainability in environments without water stress. Finally, face-to-face interviews confirmed that farmers do not invest heavily in RWPS because of its high sensitivity to precipitation, temperature, and soil quality in Mashhad (northeastern Iran).

Contribution/Originality: This study is one of very few studies which have investigated the agricultural sustainability (in all economic, ecological, and social dimensions) of both irrigated and rainfed wheat production systems in semi-arid environments using a multi-criteria decision analysis.

1. INTRODUCTION

Wheat (*Triticum aestivum*) is one of the most important staple crops for human civilization, providing 20% of calories consumed by people around the world (Shiferaw et al., 2013). With one-sixth of the total arable lands on Earth, this crop (wheat) generally plays a key role in global food security (Portmann, Siebert, & Döll, 2010). In different parts of the world, wheat production can substantially guide many developing countries (e.g. Iran) to improve economic conditions (Ahmed, Hamrick, Guinn, Abdulsamad, & Gereffi, 2013) and thereby acting toward achieving the sustainable development goals (SDGs) adopted by the United Nations in 2015 (UN, 2015) particularly on the local scale. However, high dependencies of current wheat production systems on large amounts of resources (e.g. water, land, energy, and chemical and labor forces) principally pose different environmental and social challenges for humanity (Roy, Chan, & Rainis, 2013) mostly in the arid and semi-arid environments of developing countries.

In Iran, typically known as arid and semi-arid environment, the agriculture sector donates about 11% to the gross domestic product (GDP) (Karamidehkordi, 2010) providing livelihoods for about 25.8% of total population (Zahedi, 2004) as well as about 41.7% (25.3 million) of all rural people (~60.6 million) (Balali, 2009). In Iran's agriculture, wheat is considered as the most dominant cereal crop, accounting for about 70% of the aggregate cereal production. Accordingly, wheat is cultivated throughout almost 6.6 million hectares of land in Iran during each year. About 39% (2.6 million hectares) of such wheat cultivation area is irrigated, while the remaining 61% (4.0 million hectares) is rainfed or totally reliant on rainfall during its growth cycle (Eyshi & Bannayan, 2011). The sustianbility of both irrigated and rainfed wheat production systems in Iran is under critical threats due to wide-spread soil degradation (e.g. nutrient imbalances, decreases in water retaining capacity, loss of organic matter, etc.) as well as poor water resources availability (in response to climate change and human interventions) and practices (because of illiteracy, poverty, etc.) for different agricultural activities (Shabani, 2010). Hence, this country has significantly increased investment in different watershed programs (WPs) for both rural development and natural resources management (Golrag, Ghoddosi, & Mashayekhi, 2006). However, the impacts of such WPs on environment and society have received relatively less attention in national and international research communities (Ahmadvand & Karami, 2009; Emadodin, Narita, & Bork, 2012). Accordingly, only a few studies focused on the sustainability of wheat farming system in different parts of Iran (Ali-Beigi & Baboli, 2008; Ireavani & Darban-Astaneh, 2004; Shahi, Irvani, & Kalantari, 2009; Veisi, Rezaei, Khoshbakht, Kambuozia, & Liaghati, 2015). Given this background, the present study aimed at assessing the sustainability of wheat production systems (irrigated and rainfed) in the semi-arid environment of northeastern Iran, in terms of economic, ecological, and social dimensions.

2. AGRICULTURAL SUSTAINABILITY

Since the 1980s, the concept of agricultural sustainability has widely been developed around the world, with at least 70 different definitions in the literature (Zhen & Routray, 2003). These definitions generally adopted three basis features: (i) environmentally friendly, (2) stable biodiversity, and (3) social suitability. However, there exists a controversy among researchers about which components should receive more attention in assessing agricultural sustainability. According to the particular academic or professional backgrounds, some scholars prefer ecological aspects, including agro-environmental indicators (Makowski, Tichit, Guichard, Van Keulen, & Beaudoin, 2009) biodiversity and energy (Giampietro, Mayumi, & Munda, 2006) and landscape quality (Clemetsen & van Laar, 2000; Stobbelaar, Kuiper, van Mansvelt, & Kabourakis, 2000) while others emphasize on socio-economic dimensions of sustainability like equity, self-reliance, profitability, and benefit-cost ratio (e.g. López-Ridaura, Masera, and Astier (2002)). Although any conclusions regarding the agricultural sustainability drawn based on one or two indicators may only satisfy the concerns of some scholars, the sustainable agriculture principally needs to meet all economic, ecological, and social requirements. Hence, an approach was developed to integrate all indicators for producing a value that measures sustainability (Thompson, 2007) e.g. the agricultural sustainability index (ASI) (Rao & Rogers, 2006).

Sustainable indicators are principally workable approaches and credible tools for assessing farm performances in economic, ecological, and social terms (Rigby, Woodhouse, Young, & Burton, 2001). The indicator is "a variable that describes the state of a system" and can be used to "evaluate the health of the system" (Pham & Smith, 2013; Walz, 2000). Several studies have introduced different indicators for sustainable agriculture assessment (e.g. (Bonny, Prasad, & Paulose, 2010; Dantsis, Douma, Giourga, Loumou, & Polychronaki, 2010; Hayati, Ranjbar, & Karami, 2010; Heink & Kowarik, 2010)). However, the division for sustainable development and the statistics division of the United Nations in 2007 released general indicators for sustainable development assessment (United Nations Publications, 2007). Accordingly, to facilitate the process of choosing different criteria, three general groups of indicators were categorized (United Nations Publications, 2007): economic, ecological, and social. The economic indicators normally encompass crop productivity, per capita food grain production, net farm income, and the benefit-cost ratio of crop production. The ecological indicators should explain the environmental quality of farms or environmental impacts of the production process in farms (Dantsis et al., 2010; Hayati et al., 2010; OECD Organization for Economic Co-operation and Development, 2011). The social indicators include food self-sufficiency, access to resources and training services, educational background of farmers, and equitability in food and income distribution among farmers. Due to such multi-dimensional concept of sustainability (Bonny et al., 2010; Tiwari, Loof, & Paudyal, 1999) as well as the lack of reliable quantitative data and complexity of agricultural decisions (Reed, Chan-Halbrendt, Tamang, & Chaudhary, 2014) especially in developing countries, hence, a large number of studies have recently focused on the applicability of multi-criteria decision analysis (MCDA) as an approach to analyzing agricultural sustainability (Ananda & Herath, 2009; Dantsis et al., 2010; Herath, Hardaker, & Anderson, 1982). Hence, this study also applied MCDA to measure agricultural sustainability index for wheat production in both irrigated and rainfed farms located in the semi-arid environments of Mashhad, northeastern Iran.

2.1. Study Area

Mashhad is the capital of Khorasan Razavi province located in the northeast of Iran. It lies between 36°19′ N and 59°37′ E, with an area of 9130.80 km^2 (Figure 1). In Mashhad, with the semi-arid environment (http://e.mashhad.ir), long-term (1980-2010) annual precipitation and evapotranspiration were typically about 256 and 1000 mm, respectively. In 2013, the Khorasan Razavi province with 1.63 million tons was the third most wheat producer in Iran (Khorasan Jehad-Agriculture Organization, 2013). During this year, in Mashhad, the total area under cultivation of irrigated (rainfed) wheat was about 17,400 (13,215) hectares yielding almost 55,883 (3,250) tons of wheat (Table 1). In addition, Mashhad generally ranks between first and third in the Khorasan Razavi province in barley, cucumber, tomato, melon, pear, quince, plum, cherry, damask rose and apple production. Mashhad has also other different agricultural activities, including agronomy, horticulture, greenhouse, poultry, honey been production, livestock, and silkworm rearing. Contributing 43% to the total population of the Khorasan Razavi province, about 3 million people (2.7 million urban and 0.3 million rural) are living in Mashhad (scattered in 3 towns and 591 villages), with an almost equal male to female ratio. In Mashhad, there are about 37,261 farmers, while only ~190 (0.5%) people have agriculture academic education (Figure 2).

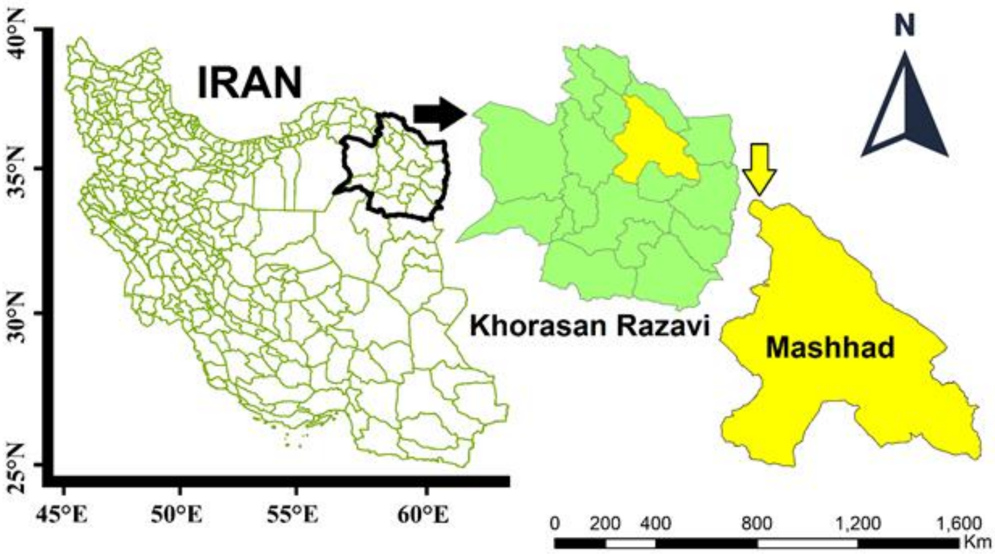

Figure-1. Location of the study area (Mashhad) in the Khorasan Razavi province, northeastern Iran.

3. RESEARCH DESIGN

3.1. Economic, Ecological, and Social Indicators

This study selected the following economic indicators that provide information about the financial soundness of farm families and enterprises (Dantsis et al., 2010):

- Farm gate price (Rial per kilogram) – is the price of each kilogram of wheat, which was bought by the Khorasan Jehad- Agriculture Organization in Iran.
- Gross farm income (Rial per hectare) – is calculated as the ratio of farm gate price to yield (ton per hectare).
- Machinery use status (Rial per hectare) – includes total machinery operation (preparing of the farm, harvesting, etc.) for each hectare of farmland.
- Cost of cultivation (Rial per hectare) – is estimated by dividing machinery use status to yield.
- Benefit cost ratio – is recorded as a result of division of farm gate price to cost of cultivation.
- Irrigation intensity – is the percentage of irrigated wheat area.

Besides, the present work included straw yield and pesticides as well as Nitrogen (N), Phosphate (P_2O_5), and Potassium Oxide (K_2O) fertilizers (Kilogram per hectare) in the economic indicators studied following the research by Bonny et al. (2010).

Table-1. Total cultivation area (ha) and production (ton) of crops and wheat in Mashhad (northeastern Iran) for the growing season (Oct-May) during 2006-2010.

Production system	Cultivation area (ha)	Total production (tons)
Irrigated crops	48,310	517,122
Irrigated wheat	17,400	55,883
Rain-fed crops	14,613	3,531
Rain-fed wheat	13,215	3,250

Source: Khorasan Jehad-Agriculture Organization (2013).

In developing countries, water and soil are two essential resources to ensure sustainable agricultural production (Zhen & Routray, 2003). Hence, this study considered water quality and soil characteristics (organic matter and pH) as well as biodiversity as ecological indicators. In general, biodiversity indices are measures of species diversity expressed as ratios between numbers of species and "importance values" (numbers, biomass, productivity, etc.) of individuals (Glossary of Environment Statistics, 1997). Accordingly, this study selected the following biodiversity indices:

- Shannon-Wiener, Simpson, and Margalef diversity indices of weed.
- Shannon-Wiener diversity index of insects and plants.
- Species richness (the number of species present) of bacteria (per $5m^2$), plants, and insects.

The Shannon-Wiener diversity index (Equation 1) ranges from 0.0 to 5.0 (Shannon & Weaver, 1963). It is generally estimated between 1.5-3.5, while exceeds 4.5 very rarely. The Shannon diversity index above 3.0 indicates that the structure of habitat is stable and balanced, while under 1.0 indicates that there are pollution and degradation of habitat structure. The Simpson diversity index (Equation 2) varies between 0-1 (Simpson, 1949) while the Margalef diversity index (Equation 3) has no limit (Margalef, 1958) and shows a variation depending upon the number of species (Gamito, 2010; Türkmen & Kazanci, 2011).

$$Shannon - Wiener\ diversity\ index\ (H') = -\sum_{i=1}^{s} P_i\ LnP_i \quad (1)$$

$$Simpson\ diversity\ index(\Delta) = \frac{1}{\sum_{i=1}^{s} P_i^2} \quad (2)$$

$$Margalef\ diversity\ index\ (d) = \frac{s-1}{Log\ N} \quad (3)$$

where P is the proportion (n/N) of individuals of one particular species (n) divided by the total number of individuals (N); Ln is the natural logarithm; Σ is the sum of the calculations; and s is the number of species. In the Margalef diversity index, s is the total number of species, and N is the number of individuals (Gliessman, 1990).

Social dimensions of an agricultural system should embody the equity of family farmers (Sustainable Development Strategy Research Group of SAC, 2004).

Hence, this study considered all family size (the number of family members), the amount of participation of family members in farms, landholdings, and other sources of income for farmers as the social indicators for the study area (Mashhad) in northeastern Iran.

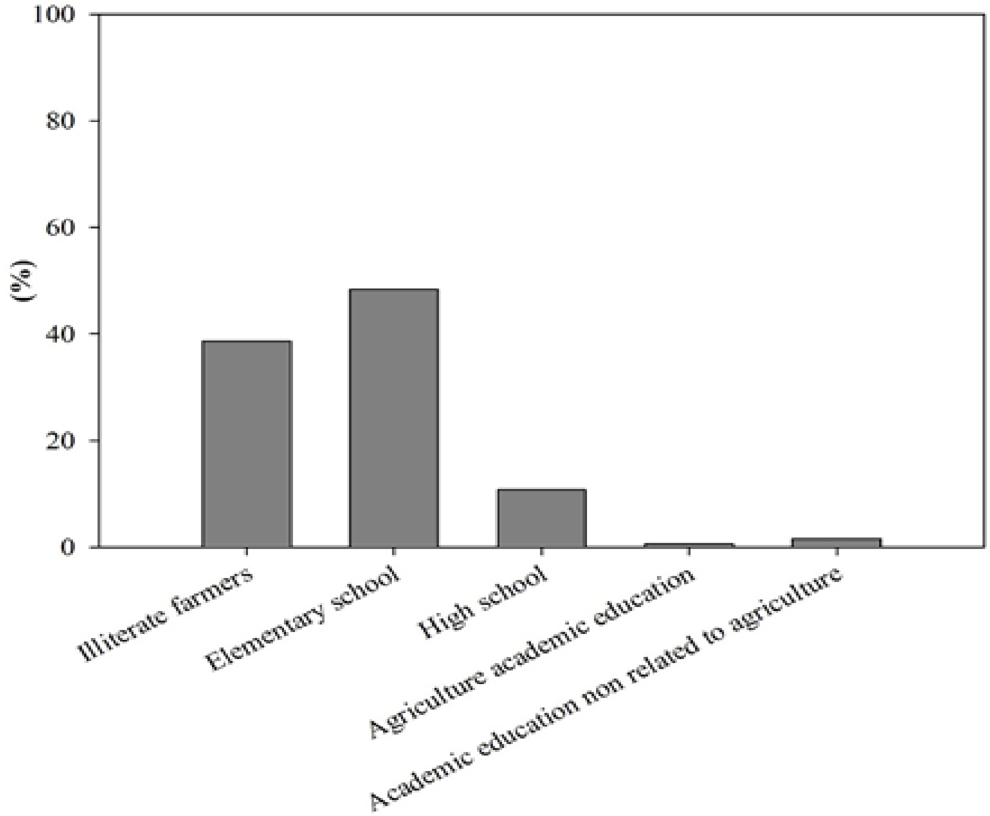

Figure-2. Distribution (%) of education level for farmers living in the study area (Mashhad), northeastern Iran.
Source: Khorasan Jehad-Agriculture Organization (2013).

3.2. Data Collection

Data were collected from both irrigated and rainfed wheat farms in Mashhad (northeastern Iran) for the growing seasons (Oct-May) during 2006-2010. Socio-economic data were obtained from the Khorasan Jehad-Agriculture Organization (http://www.koaj.ir) in Iran. Soil physical and chemical properties, weed diversity, and crop yields in northeastern Iran were collected from the study by Jahani, Koocheki, Nassiri, and Rezvani (2011). Both species richness and abundance of soil bacteria for the study area (Mashhad) were calculated based on Khodashenas (2008).

Social and economic data were partially extracted from the study by Mahdavi, Koocheki, Rezvani, and Nassiri (2005). Eventually, some questionnaires were designed for filling the gap in data related to the social and economic characteristics of both irrigated and rain-fed wheat production systems. The questionnaire and data were finally completed through the face to face interview with farmers. In total, 50 questionaries were completed in the study area (Mashhad). Accordingly, 36 economic, ecological, and social indicators were finally designed and their mean values were calculated from the questionnaires and other databases (Table 2).

Table-2. The mean values of economic, ecological, and social indicators estimated for both irrigated and rainfed wheat production systems in Mashhad, northeastern Iran.

No.	Dimension	Indicators	Wheat production systems	
			Irrigated	Rainfed
1		Wheat yield (ton ha^{-1})	3.3	0.5
2		Straw yield (ton ha^{-1})	6.3	1
3		N (kg ha^{-1})	228.4	12.5
4		P_2O_5 (kg ha^{-1})	171.8	13
5		K_2O (kg ha^{-1})	20.8	0.4
6		Irrigation intensity	2	2.4
7	Economic	Input use status (kg ha^{-1})	518.5	26.4
8		*Machinery use status (Rial ha^{-1})	4,954,688	787,240
9		*Cost of cultivation (Rial kg^{-1})	1610	1688
10		*Farm gate price (Rial kg^{-1})	2094	2094
11		Benefit Cost Ratio	1.4	1.3
12		*Gross farm income (Rial ha^{-1})	7,056,623	1,031,440
13		Soil organic matter (%)	0.7	0.5
14		Water quality (T.D.S mg l^{-1})	571.4	189.6
15		Soil pH	7.4	8
16		Species richness of bacteria (per 5m^2)	5.3	4.3
17		Species richness of Insects	4	5
18	Ecological	Species richness of plant	5.4	4.2
19		Shannon-Wiener diversity index	0.3	0.4
20		Shannon-Wiener diversity index	2.4	2.6
21		Shannon-Wiener diversity index	0.6	0.9
22		Simpson diversity index (weed)	2.2	2.4
23		Margalof diversity index (weed)	0.9	1.4
24		Total landholding (ha)	52,206.6	33,774.4
25		Land area under wheat (ha)	1000	1640
26		Private land (land owner) (%)	90.7	92
27		Renting land (%)	9.3	7.9
28		Academic education	3.2	2.3
29		Family member numbers (2-5) (%)	43.6	43.7
30	Social	Family member numbers (6-8) (%)	43.2	45.7
31		Family member numbers (>8) (%)	44	8.8
32		Carpet- weaving (%)	22.6	11.6
33		Handicraft (%)	0.2	1.6
34		Family participation	56	59
35		Absence family participation	43.6	41
36		Other income sources	63	61.2

Note: * 10350 Rials = 1 USD (on 31 December 2010 as the study period refers to the growing seasons (Oct-May) during 2006-2010).

3.3. Multi-Criteria Decision Analysis (MCDA)

A multi-criteria decision analysis (MCDA) was used to assess the sustainability of irrigated and rainfed wheat production systems in Mashhad, northeastern Iran. MCDA is an approach as well as a group of techniques to prioritize an overall ordering (from the most to the least preferred) of options for policy-makers and stakeholders (Ananda & Herath, 2009; Chen, Kilgour, & Hipel, 2012).

The complete process of MCDA generally consists of four basic components: (i) criterion set, (ii) favorite structure, (iii) alternative set, and (iv) performance values (Fülöp, 2005). Although the decision is finally made according to the performance of alternatives, an explicit criterion arranging the constituents' preferred structure is a crucial factor that must be prepared in advance. Accordingly, the options are examined based on each criterion, and weights for all criteria are assessed with respect to the importance of those criteria. Finally, one can indicate the overall value of each option or alternative that reveals its preference (Mustajoki & Marttunen, 2013).

Accordingly, a broad range of different MCDA approaches have been developed (see, e.g., Belton and Stewart (2002)) and used in different studies focusing on many sustainability issues (e.g. (Hipel, Fang, & Heng, 2010; Khalili & Duecker, 2013; Rozman et al., 2009; Wolfslehner & Seidl, 2010)). In the last decade, MCDA has received considerable attention for evaluating agricultural sustainability in different parts of the world (e.g. (Amini, Nouri, & Aslani, 2015; Bartzas & Komnitsas, 2020; Poursaeed, Mirdamadi, Malekmohammadi, & Hosseini, 2010; Talukder, Hipel, & vanLoon, 2018; Talukder., 2016; Vogdrup-Schmidt et al., 2019)).

One of the key subfile of MCDA is Multi-Attribute Utility Theory (MAUT) (Munda, 2008) which is also known as the Multi-Attribute Value Theory (MAVT). In general, this theory establishes a simple procedure for understanding MCDA and is applied for multi-criteria evaluation (Antunes, Santos, Videira, & Colaço, 2012). Assigning appropriate weights (in terms of trade-offs) to different criteria, MAVT helps decision-makers to simply evaluate alternatives in a more reliable way through a common framework. MAVT first identifies a hierarchy of criteria, also known as a value tree, and then applies numerical values for quantitatively evaluating those criteria (Keeney & Raiffa, 1993).

Main three steps of MAVT are: (i) arranging the problem through the value tree, criteria, and alternatives; (ii) generating the preference model by specifying value functions and providing weights to different criteria; and (iii) analyzing the findings, including sensitivity assessment (Marttunen & Hämäläinen, 2008). The details of most important MAVT processing steps are comprehensively expressed in De Montis, De Toro, Droste-Franke, Omann, and Stagl (2004) and Keeney and Raiffa (1993).

Similar to Dantsis et al. (2010) this study applied MAVT for combining different economic, ecological, and social indicators in order to express a unique index for assessing the sustainability of wheat production systems (irrigated and rainfed) in Mashhad, northeastern Iran.

Such MAVT was performed utilizing Web-HIPRE (HIerarchial PREference analysis in the World Wide Web) software (Bertsch et al., 2007) that is freely available online (http://hipre.aalto.fi). Accordingly, the first step was to create the value tree to summarize economic, ecological, and social indicators based on the overall goal: sustainability (Figure 3).

To prioritize the importance of different criteria, then the weighting of these indicators was performed using: (i) direct weighting in which the weights can be written into the corresponding sub-criteria or alternative; (ii) SMARTER-technique in which the attributes can be ranked in the order of the worst to the best importance levels; and (iii) value function in which the ratings of different alternatives are directly mapped to their values. This study identified such rankings based on the questionnaires, literature review, and regional and local priorities (Tables 3-5); for instance, (i) irrigation status is the most important economic indicator in semi-arid and arid regions after yield; (ii) land indicator is the most significant social indicator on account of some family heritage rules of land in the study area (Dantsis et al., 2010). Ultimately, the "Agricultural Sustainability Index" was developed for irrigated and rain-fed wheat production systems in the semi-arid environment of Mashhad in northeastern Iran.

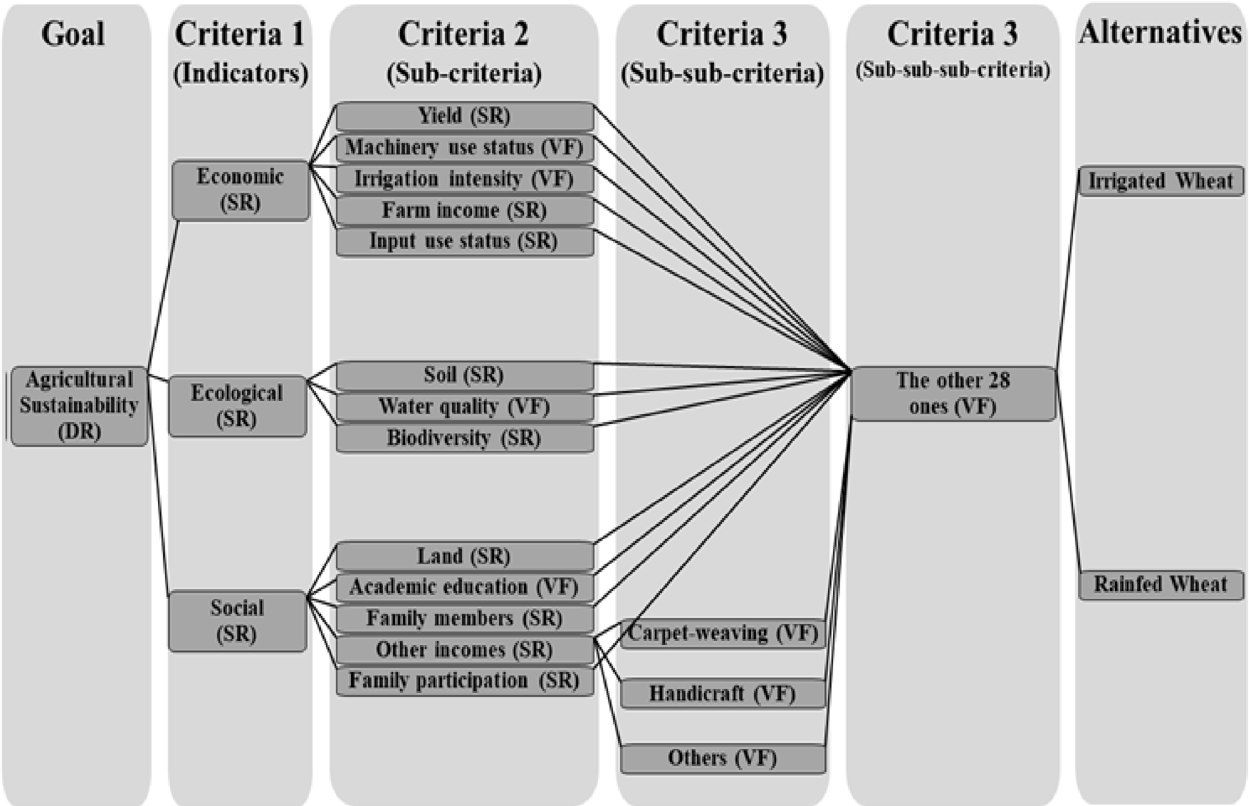

Figure-3. Hierarchical structure and sustainability level generated through Web-HIPRE software by this study. The selected weighting methods (WM) are denoted by DR (direct), SR (SMARTER-technique), and VF (value functions).

Table-3. Ranking and weighting of different economic indicators considered in this study.

Criterion	Rank	Weight	Sub-criterion	Rank	Weight
Yield	1	0.457	Grain yield	1	0.750
			Straw yield	2	0.250
Irrigation intensity	2	0.257			
Input use status	3	0.157	Nitrogen	1	0.611
			Phosphate	2	0.275
			Potassium Oxide	3	0.111
Machinery use status	4	0.090			
Farm income	5	0.040	Farm gate price	1	0.521
			Benefit cost ratio	2	0.271
			Cost of cultivation	3	0.146
			Gross farm income	4	0.063

Table-4. Ranking and weighting of different ecological indicators considered in this study.

Criterion	Rank	Weight	Sub-criterion	Rank	Weight
Soil	1	0.611	Soil organic matter	1	0.750
			pH	2	0.250
Biodiversity	2	0.278	Shannon-Wiener diversity index (plants)	1	0.340
			Species richness of plants	2	0.215
			Shannon-Wiener diversity index (insects)	3	0.152
			Species richness of insects	4	0.111
			Species richness of bacteria (per 5m2)	5	0.079
			Shannon-Wiener diversity index (weed)	6	0.054
			Simpson diversity index (weed)	7	0.033
			Margalef diversity index (weed)	8	0.016
Water quality	3	0.111			

Table-5. Ranking and weighting of different social indicators considered in this study.

Criterion	Rank	Weight	Sub-criterion	Rank	Weight
Land	1	0.457	Private land	1	0.521
			Renting land	2	0.271
			Land area under wheat	3	0.146
			Total landholding	4	0.063
Other incomes	2	0.257	Carpet-weaving	1	0.911
			Handicraft	2	0.278
			Others	3	0.111
Academic education	3	0.157			
Family participation	4	0.090	Presence of family participation	1	0.750
			Absence of family participation	2	0.250
Family member	5	0.040	Family member numbers (2-5)	1	0.611
			Family member numbers (6-8)	2	0.275
			Family member numbers (>8)	3	0.111

4. RESULTS

The economic dimension of agricultural sustainability determined that the mean crop yield was 3.3 (tons ha^{-1}) for irrigated wheat production system (hereafter, IWPS), while about and 0.5 (tons ha^{-1}) for the rainfed wheat production system (hereafter, RWPS) (Table 2). Accordingly, the mean value of yield, fertilizer, input use status, and gross farm income for IWPS was significantly higher than those for RWPS (Table 2). Compared to the RWPS, undoubtedly, IWPS applies much more fertilizer and mechanization. Thus, both yield and farm gross income are at higher levels for IWPS than for RWPS. The mean farm gross incomes were 7,056,000 and 1,031,000 (Rials ha^{-1}) were for irrigated and rain-fed wheat, respectively (10350 Rials = 1 USD on 31 December 2010 as the study period refers to the growing seasons (Oct-May) during 2006-2010). Farm gross income is one of the primary indicators of agricultural sustainability because it reflects not only whether the farm enterprise stays in business, but also whether it is surplus income to devote resource conservation or development (Wei, Davidson, Chen, & White, 2009). However, IWPS and RWPS showed no clear differences in irrigation intensity, cost of cultivation, farm gate price, and benefit-cost ratio in Mashhad, northeastern Iran.

Analysis of ecological indicators identified a considerable difference between the water quality of IWPS (571 T.D.S mg l^{-1}) and RWPS (189 T.D.S mg l^{-1}), measured by the T.D.S (total dissolved solids) in groundwater near the irrigated and rainfed wheat farms (Table 2). Such water quality usually measured by the T.D.S (total dissolved solids). Obviously, the level of T.D.S in IWPS is higher than in RWPS due to the application of fertilizer and many more pesticides and insecticides. In Mashhad, however, the T.D.S. of IWPS (571 T.D.S mg l^{-1}) was even higher than its standard level (450-500 T.D.S mg l^{-1}) adopted by the World Health Organization (WHO World Health Organization, 1993). The soil pH for IWPS and RWPS were 7.4 and 8.0, respectively (Table 2). The soil organic matter (%) was about 0.7 for IWPS, while 0.5 for RWPS (Table 2). In this study, biodiversity indices did not reveal any significant differences between IWPS and RWPS (Table 2). However, except for species richness of bacteria and plants, all other biodiversity indices were lower in IWPS than those in RWPS (Table 2) mainly due to the intensive application of fertilizers and pesticides in IWPS.

Regarding the social indicators, this study found that the percentage of farmers who have academic education was only about 3.2% and 2.3% in IWPS and RWPS, respectively (Table 2). It means the agricultural knowledge of farmers is too poor in Mashhad, where only 0.5% of all 37,261 farmers have agriculture academic education and even only 1.6% have an academic education not related to agriculture. The total landholding for farmers who have IWPS (52,206 ha) was at a higher level compared to those who run RWPS (33,774 ha) (Table 2). However, the mean value of land area under RWPS (1.640 ha) was greater than that under IWPS (1,000 ha) (Table 2).

Surprisingly, the percent of families with family member numbers more than 8 people was 44% for IWPS, while about 9% for RWPS (Table 2). Generally speaking, there was not any significant difference between the social indicators of IWPS and RWPS.

In Mashhad, all economic, ecological, and social dimensions of agricultural sustainability showed higher levels in IWPS than those in RWPS (Figure 4). The maximum difference (0.562) was primarily found between the sustainability of ecological indicators in IWPS (0.781) and RWPS (0.219) (Figure 4). The ecological sustainability index for IWPS (0.633) was also greater than that for RWPS (0.367) (Figure 4). However, the social sustainability of IWPS (0.532) and RWPS (0.468) were practically equal in Mashhad, northeastern Iran. Finally, the agricultural sustainability index showed a substantially higher level in IWPS (0.667) than that in RWPS (0.333) (Figure 5). Generally, speaking this study indicated that IWPS is more sustainable agriculture than RWPS in the semi-arid environment of Mashhad in northeastern Iran.

5. DISCUSSION AND CONCLUSIONS

This study assessed and compared the sustainability of both IWPS and RWPS in Mashhad (northeastern Iran) through a multi-criteria decision analysis (MCDA) approach. The results determined that the IWPS was generally more sustainable than the RWPS in the semi-arid environment of Mashhad due to the considerably high sustainability of economic indicators in IWPS. However, the ecological and social indicators were practically showed similar contributions to the agricultural sustainability index of both IWPS and RWPS in Mashhad. It indicates that the RWPS has also high potential to achieve agricultural sustainability in the environments with no water resources stress, which negatively influences crop production (Bannayan, Sanjani, Alizadeh, Lotfabadi, & Mohamadian, 2010). For instance, severe droughts during the 2000s put extra pressure on agricultural sustainability in Iran and neighbor countries (Afghanistan, Pakistan, Tajikistan, and Uzbekistan) located in arid and semi-arid environments, with already water availability shortage (Lioubimtseva & Henebry, 2009). Such effects of droughts on the rainfed agricultural sustainability were reflected by the relatively higher and lower annual yields of IWPS and RWPS, respectively, in Mashhad during the 2000s (Figure 6). According to the higher yield of IWPS, the economic indicators also showed higher farm gross income for IWPS than that for RWPS.

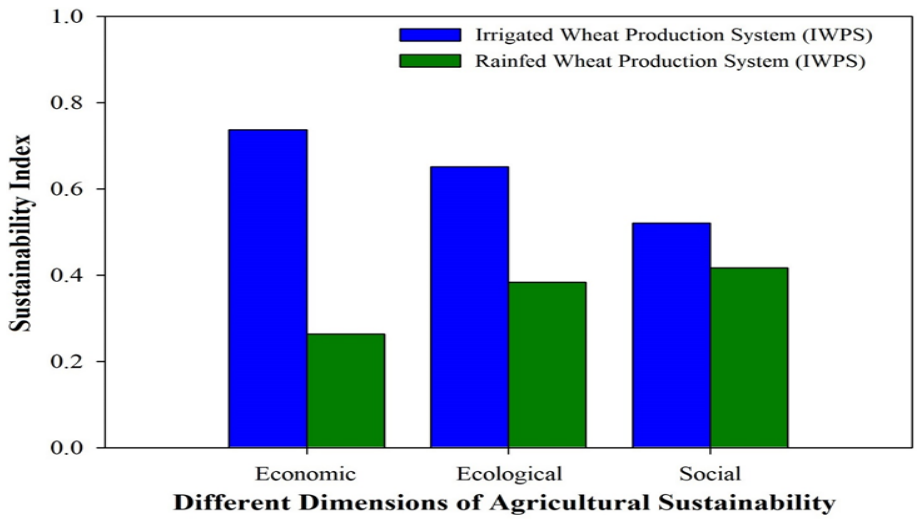

Figure-4. The sustainability index for all economic, ecological, and social dimensions of both irrigated (IWPS) and rainfed (RWPS) wheat production systems.

In agreement with this study, face-to-face interviews with farmers confirmed that they do not invest heavily in RWPS due to its high sensitivity to soil quality, temperature, and precipitation. Hence, farmers allocate unused/neglected lands to RWPS, with very low-level land preparing cultivation methods. Even with the practically similar ecological and social dimensions of agricultural sustainability in RWPS and IWPS, farmers prefer to invest in the latter one (IWPS) because of its stability and economic viability. Likewise, ecological and social stresses can equally reduce the sustainability of RWPS and IWPS, but still, the later one (IWPS) provides farmers with higher economic sustainability.

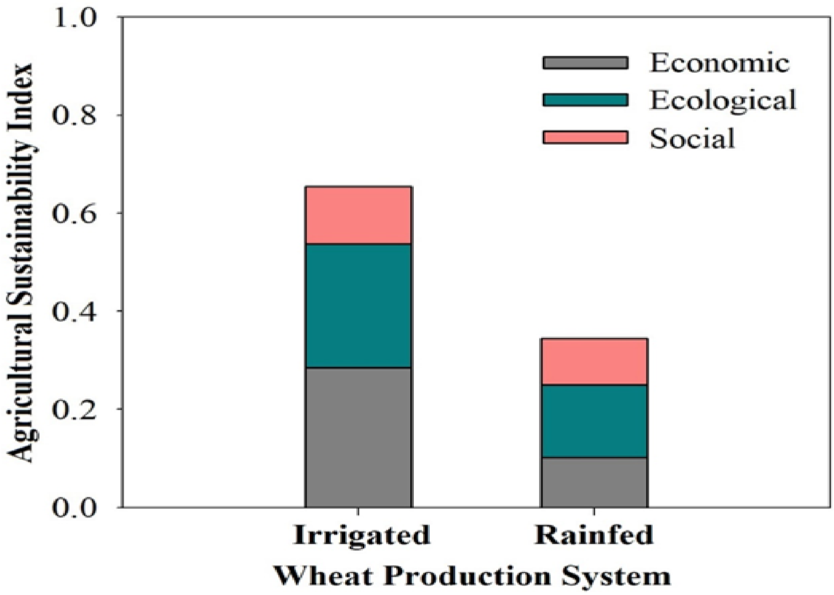

Figure-5. The agricultural sustainability index for both irrigated (IWPS) and rainfed (RWPS) wheat production systems in Mashhad, northeastern Iran.

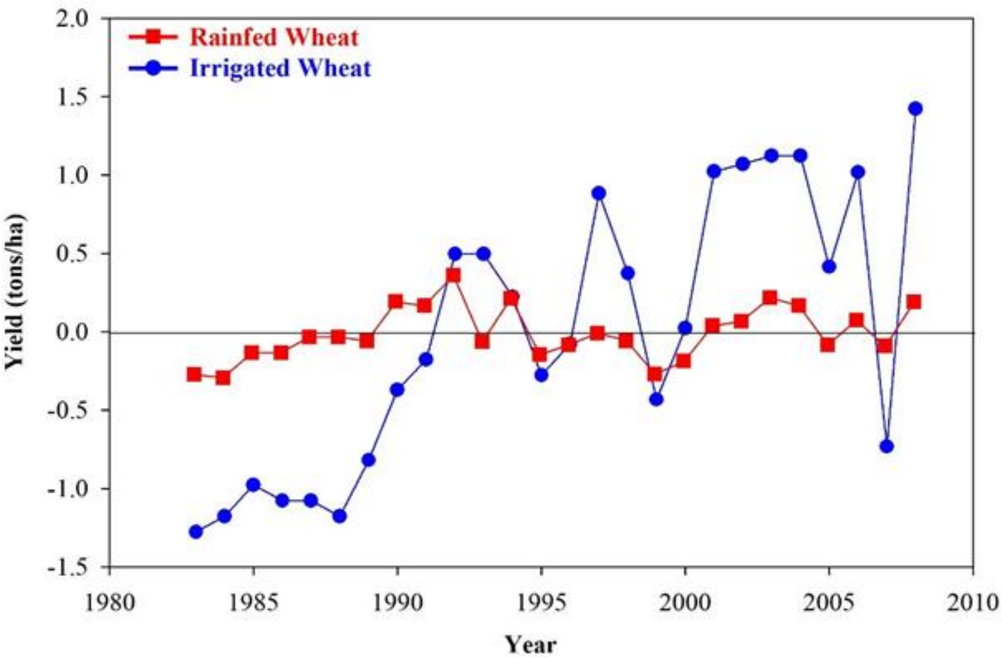

Figure-6. Annual yield anomalies (tons ha^{-1}) of both irrigated (IWPS) and rainfed (RWPS) wheat production systems in Mashhad, northeastern Iran, during 1983-2008.

In conclusion, the agricultural sustainability of RWPS is more likely to face challenges in arid and semi-arid environments (like Mashhad in northeastern Iran), where IWPS is more sustainable (in all economic, ecological, and social dimensions) because of less dependency on precipitation. However, integrated agricultural production is a complicated system that meets all biophysical and socio-economic requirements of sustainable yield (Szeląg-Sikora, Cupiał, & Niemiec, 2015). Thus, agricultural sustainability is a multidisciplinary concept based on many decisions for considering the trade-offs between different environmental and socio-economic objectives at different spatial (farm, national and international levels) and temporal dimensions (Kropff, Bouma, & Jones, 2001). Although sustainable land and water resources management generally receives high political priority, addressing the questions about equity, quality of life, and the perceived human well-being in the context of agricultural sustainability are often uncertain and needs more and deeper social studies (Ahmadvand & Karami, 2009; Emadodin et al., 2012) with a focus particularly on rural communities; e.g. equal access to resources such as extension and training services, food markets, access to healthy food (minimum toxic residues), labor wages, etc. (Brodt, Six, Feenstra, Ingels, & Campbell, 2011; Zhen & Routray, 2003). For Mashhad in northeastern Iran, hence, identifying the role of social challenges posed by the lack of job opportunity and security as well as low wages for farm labors who migrate from poorer nations (particularly Afghanistan) for agricultural sustainability is well-motivated to be considered as a potential future study.

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