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Land Suitability Evaluation for Alfalfa and Barley Based on FAO and Fuzzy Multi-Criteria Approaches in Iranian Arid Region

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Abstract

The present research aims to apply several approaches for suitability evaluation of lands under cultivation of alfalfa and barley in Chaharmil mechanized farming center, Ardestan town, Isfahan province, Iran. Climatic and soil maps of the climate and soil data were provided in raster format. Land evaluation carried out using maximum limitation, parametric and multi-criteria (Analytical Hierarchy Process (AHP) and fuzzy AHP) approaches. Land indices, calculated by these methods were correlated with the observed yields. The best relationships were given by fuzzy AHP for alfalfa and barley, which illustrates the accuracy of this approach for land evaluation. The results of fuzzy AHP showed that the majority of the study area is potentially more suitable for alfalfa than for barley. The membership functions revealed that soil texture is the main constraint for alfalfa and barley production.

***Keywords*:** Land suitability; Multi-criteria; Fuzzy set; AHP; Alfalfa; Barley; Ardestan

1. Introduction

Land suitability evaluation is defined as the classification of lands in terms of their suitability for a given use. De La Rosa and van Diepen (2002) believe that the main object of the land suitability evaluation is the prediction of potential capacity of the land unit for a given use without deterioration. Land Evaluation (LE) is also defined as "the process of assessment of land performance when used for specific purposes…". The FAO LE framework has been the primary procedure employed worldwide to address local, regional, and national land use planning (Manna et al., 2009). Land evaluation can be carried out on the basis of biophysical parameters and/or socioeconomic conditions of an area (FAO, 1976). Biophysical factors tend to remain stable, unlike socioeconomic factors that are affected by social, economic, and political settings (Dent and Young, 1981; Triantafilis et al., 2001). Thus physical land suitability evaluation is a prerequisite for land-use planning, because it guides decisions on optimal utilization of land resources (Van Ranst et al., 1996).

In multi-criteria decision making, which is used for determination of the optimum land utilization type for an area, unequal importance of different land criteria is taken into account. This approach could be perceived as a collection of concepts, models and methods that aim an evaluation (expressed by weights, values or intensities of preference) according to several criteria. The investigation of a number of alternatives, taking into account multiple criteria 78 conflicting objectives is the main goal of multi-criteria evaluation (MCE) techniques. In these techniques it is necessary to select alternatives and rank them according to their degree of importance. (Ceballos-Silva and López-Blanco, 2003).

Fuzzy set theory has been widely used in soil science for land evaluation, soil classification

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and soil quality indices (Zhu et al., 2010). According to it, observations are grouped into continuous classes, instead of classifying them into hard classes (Burrough et al., 1992; McBratney et al., 1992). In addition, modeling of vague concepts is feasible by application of the fuzzy sets (Zadeh, 1965).

Several crop specific land suitability evaluation approaches exist: “maximum limitation” and “parametric” methods are two of them. The maximum limitation method considers that crop production is affected by the most limiting factor. The parametric method consists in a numerical rating of the different limitation levels of the land characteristics (Sys et al., 1991). In order to enhance the qualitative interpretation of land resource surveys, land evaluation procedures tend to use quantitative approaches. In order to estimate the land suitability it is crucial the matching of land characteristics with the requirements of the envisaged land utilization types. Most of these procedures are highly subjective. For instance, additive or multiplicative land indices involve classification of land characteristics into severity levels based on arbitrary cut off points (Rossiter, 1996). With this approach GIS can play a major role in spatial decision making. Considerable effort is involved in the information collection for the suitability analysis for crop production. This information should present both opportunities and constraints for the decision maker (Ghafari et al., 2000). Consequently, the integration of MCE within the GIS context could help users to improve decision making processes, beside its evident usefulness for land suitability assessments (Joerin et al., 2001). Fuzzy modeling of spatial data based on theoretical knowledge has been demonstrated to be useful in various GIS-based studies of land suitability classification (Liu and Samal, 2002; Malczewski, 2004; Malczewski, 2006; Nisar Ahamed et al., 2000; Rashmidevi et al., 2009; Triantafilis et al., 2001; Zhu et al., 2010).

The objective of this study was to evaluate land suitability for alfalfa and barley in the Chaharmil mechanized farming center, Isfahan province, Iran, using FAO crop specific land suitability classification and multi-criteria evaluation methods, in a GIS context. Also an attempt is made to apply the multi-criteria evaluation approach with the fuzzy set theory, because several land characteristics with different relative importance and continuous lateral variability were used in the evaluation.

2. Materials and Methods

2.1. Study area

The study area is located in the Chaharmil mechanized farming center, Ardestan town, Isfahan province, Iran, between latitudes 33º 25′ 20″ and 33º 30′ 25″ N and longitudes 52º 21′ 14″ and 52º 22′ 02″ E (Fig. 1). Its surface area is 312 ha. The mean annual rainfall in the area is 120 mm and its mean annual temperature is 20.9 °C. The area has an Arid climate and Aridisols and Entisols are the major soils of the area which are developed on alluvial and aeolian deposits. The landscape is very gently sloping. Two of the most important crops cultivated in the area are alfalfa and barley. These crops cover 40 and 22% of the study area, respectively.

2.2. Data sources

47 soil profiles with an interval distance of 250 m, along two parallel north-south oriented transects were described (Fig. 1). Soil samples were collected from different horizons of the profiles and the required physical and chemical analyses were carried out on the samples.

Landscape characteristics such as slope, drainage and flooding were not considered in the land evaluation, because these characteristics did not show any limitation for the crop production.

According to Sys et al. (1991) each profile was subdivided into equal sections and to each section, a weighting factor was attributed (Table 1). The weight factors decrease from the uppermost section towards the lowermost one. Soil criteria were averaged over the rooting system depth with the exception of pH, for which only the upper 25 cm was considered. To obtain the average for each variable, weighting factors for the different profile sections were used. The rooting system depth for alfalfa and barley was considered to be 150 and 100 cm, respectively (Sys et al., 1991).

Climatic data was obtained from a nearby meteorological station. Climatic and soil requirements of alfalfa and barley are given in Table 2 (Givi, 1997).

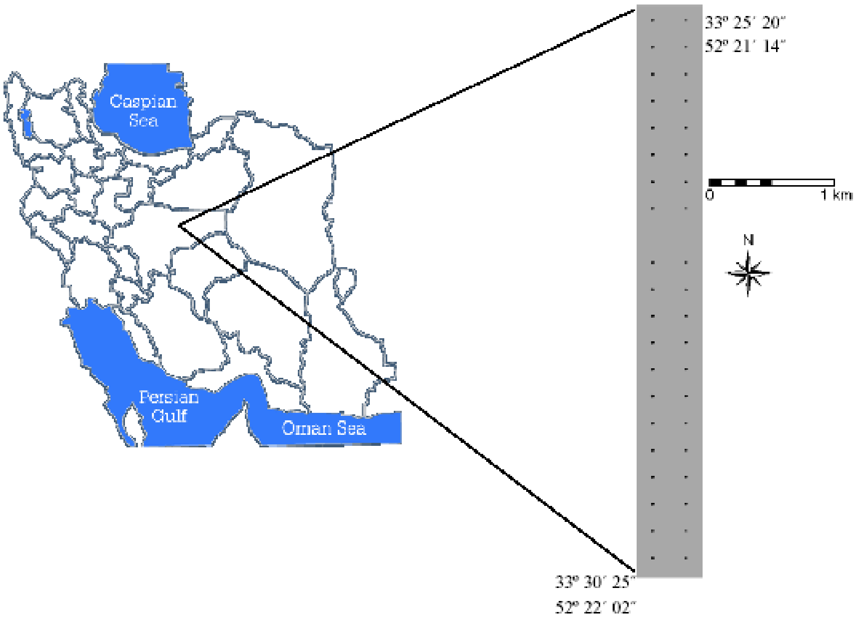

Fig. 1. Study area and location of the soil profiles

Table 1. Number of sections and weighting factor for each section (Sys et al., 1991)

Depth (cm)	Number of equal sections	Weighting factors
125-150	6	2.00-1.50-1.00-0.75-0.50-0.25
100-125	5	1.75-1.50-1.00-0.50-0.25
75-100	4	1.75-1.25-0.75-0.25

Yield data of alfalfa and barley were measured in landscapes of some of the soil profiles.

Criteria maps were also developed for each of the parameters in raster format with a spatial resolution of 10.3 m, using ILWIS 3.3. Spatial interpolation of these maps was carried out using the inverse distance technique.

2.3. FAO crop specific land suitability evaluation approach

2.3.1. Maximum limitation method

In this method, climatic and landscape requirements for the crops under consideration are grouped into different suitability classes (Table 2): highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N). Depending on matching of the collected data for each land characteristic with the numerical range allocated to each of the above mentioned classes in Table 2, a suitability class is attributed to that land characteristic. By this way, different suitability classes are determined for different land characteristics. The suitability class of the land units is considered to be the lowest one among these classes.

For development of a final suitability map, the criteria maps were reclassified based on the suitability classes (Table 2). These maps were crossed according to the lowest suitability class.

2.3.2. Parametric method

In this method, a numerical rating with a scale of 0 to 1 is allocated for different suitability classes (Table 2). If a land characteristic has no limitation for crop growth or crop production, ratings between 1 and 0.95 are attributed. Ratings between 0.95 and 0.85, 0.85 and 0.60, 0.60 and 0.40 and 0.40 and 0.00 are used respectively for slight, moderate, severe and very severe limitations.

Depending on the matching of the collected data for each land characteristic, with the numerical range allocated to each of the above mentioned ranges of ratings in Table 2, a suitability rating is attributed for that land characteristic. In this way, different suitability ratings are determined for different land characteristics and for given crops.

Table 2. Climatic and soil requirements for irrigated (a) alfalfa, (b) barley (Givi, 1997).

Characteristics	Suitability classes and ratings				
	S1		S2	S3	N
	1.0	0.95	0.85	0.60	0.40 0
(a) Alfalfa					
Mean temperature of the growing cycle (ºC)	24-26	20-24 26-28	15-20 28-32	10-15 32-40	<10 >40
Relative humidity of the growing cycle (%)	30-50	24-30 50-75	20-24 75-90	<20 >90	-
Texture/structure[a]	SiCL, CL, L, SC, SCL, SL	C<60c, SiCs	C<60v, LS, C>60s, LfS	C>60v, fS, S, LcS	Cm, SiCm
Surface stoniness (rock fragments > 25 cm in diameter)(m apart)	>30	10-30	1.5-10	0.8-1.5	<0.8
Coarse fragments (2mm-25cm in diameter)(% Vol.)	0-3	3-15	15-35	35-55	>55
Soil depth (m)	>100	75-100	50-75	20-50	<20
pH	7.0-7.8	7.8-8.0	8.0-8.2	8.2-8.5	>8.5
EC (dS/m)	0-3	3-5	5-9	9-12	>12
ESP	0-8	8-20	20-35	35-50	>50
$CaCO_3$ (%)	3-20	20-35	35-50	50-60	>60
Gypsum (%)	0-25	25-40	>40	>>40	>>>40
(b) Barley					
Mean temperature of vegetative stage (ºC)	8-12	6-8 12-18	4-6 18-24	2-4 24-28	<2 >28
Mean temperature of flowering stage (ºC)	14-22	12-14 22-24	10-12 24-32	8-10 32-36	<8 >36
Mean temperature of ripening stage (ºC)	16-24	14-16 24-30	12-14 30-36	10-12 36-42	<10 >42
Mean daily minimum temperature of coldest month (ºC) and Mean daily maximum temperature of coldest month (ºC)	<8 and <8	---- ----	>8 and <21	8-13 and >21	>13 and >21
Texture/structure[a]	SiCL, SiCs, SiL, C<60s, SC, CL	SCL, L	SL	LS, Cm, SiCm	S
Surface stoniness (rock fragments > 25 cm in diameter)(m apart)	>30	10-30	1.5-10	0.8-1.5	<0.8
Coarse fragments (2mm-25cm in diameter)(% Vol.)	0-3	3-15	15-35	35-55	>55
Soil depth (m)	>90	60-90	30-60	10-30	<10
pH	7.0-7.8	7.8-8.2	8.2-8.5	>8.5	-
EC (dS/m)	0-8	8-12	12-16	16-20	>25
ESP	0-15	15-25	25-35	35-45	>45
$CaCO_3$ (%)	3-20	20-35	35-50	50-60	>60
Gypsum (%)	0-25	25-40	>40	>>40	>>>40

[a] S: sand, Si: silt, C: clay, < 60: < 60% clay, > 60: > 60% clay, L: loam, m: massive, s: blocky structure, v: prismatic and columnar structure, f: fine, c: coarse

The final suitability map was obtained by constructing the rated criteria maps based on suitability ratings (Table 2). In order to classify each raster cell within the map into suitability classes, the rated criteria maps were multiplied, using Equation 1 (Khiddir 1986):

$$LI = \left(R_{\min}\sqrt{\Pi_{j=1}^{n} R_i}\right) \quad (1)$$

where LI is the land index, Rmin is the minimum rating value, Rj is the rating value of the j[th] criterion map, n is the number of criteria maps.

2.4. Multi-criteria evaluation approach

2.4.1. Analytical Hierarchy Process (AHP)

The analytic hierarchy process was introduced by Saaty (1994) and is an effective means of dealing in the context of decision making process. Malcewiski (1999) states that the relationship between the objectives and attributes has a hierarchical structure. At the highest level, the objectives can be distinguished, and at lower levels the attributes can be decomposed. Figure 2 shows the hierarchical structure used in this study. To make pairwise comparisons at each level of the hierarchy, decision makers can develop relative weights, called priorities to differentiate the importance of each land characteristic. The scale recommended by Saaty (1994) is from 1/9 to 9. The 9 and 1/9 indicate that one criterion is significantly the most and the least important, compared with the others, respectively. Thus, if two criteria are of equal importance, they would receive the same rating. The essence of AHP calculation is solution of an eigenvalue problem involving a reciprocal matrix of comparison. In the current study, the weight for each land characteristic was determined by pairwise comparisons in the context of a decision making process known as the analytical hierarchy process (Saaty, 1990).

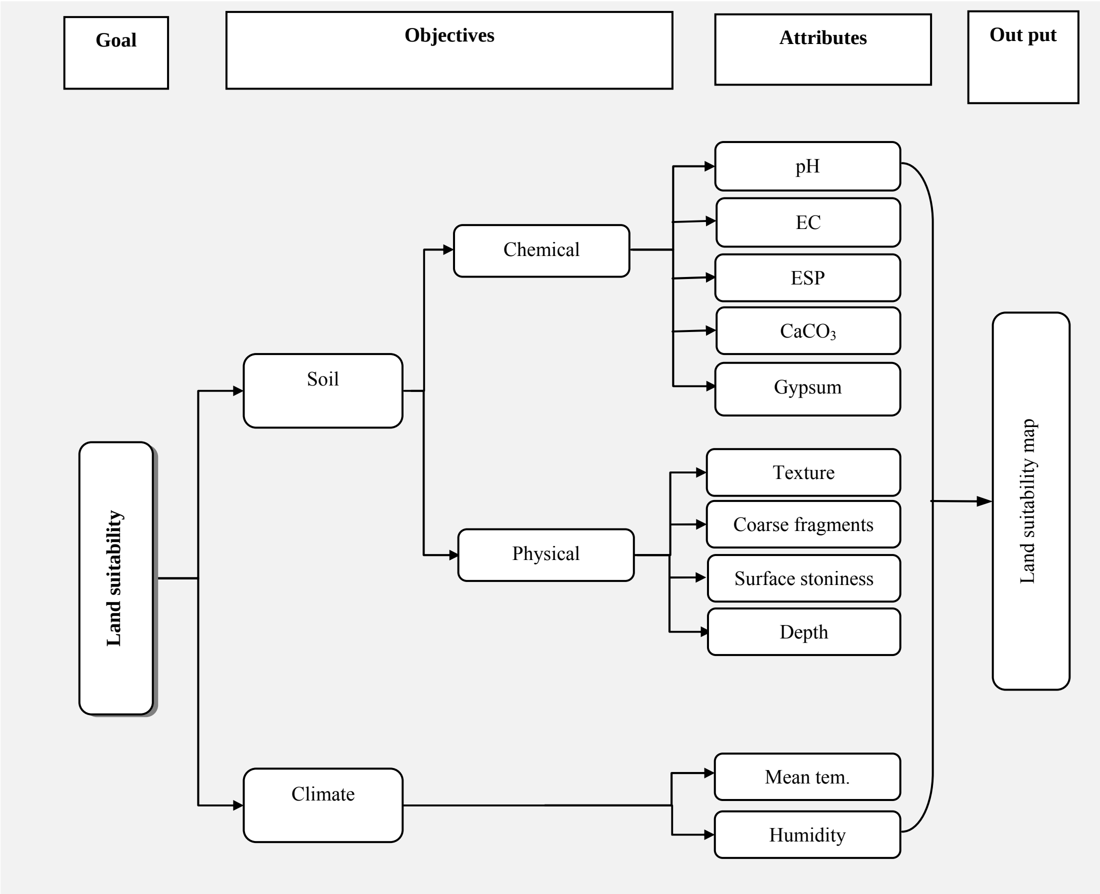

Fig. 2. Hierarchical organization of the land criteria for alfalfa production

The pairwise matrices were made over hierarchy levels for alfalfa and barley (Tables 3 and 4). In the weight calculation step, the principal eigenvector of the pairwise comparison matrix was computed to produce a best fit of the weight set. In a MCE, it is necessary to use a weighted linear combination, where the sum of the weights should always be 1. The consistency ratio of the matrix should be calculated as well. This value indicates the probability of randomly assignment of the ratings. A consistency ratio of 0.1 or less is considered acceptable (Saaty, 1990).

After mapping of the criteria, the rated criteria maps were constructed based on suitability ratings (0-1) for alfalfa and barley (Table 2). Each of these maps was multiplied by its weight and then the results were summed up to develop a suitability rating map at hierarchy level. The suitability ratings and weights were aggregated over hierarchy levels (Fig. 2). Eventually, final suitability rating map was multiplied by average of indices of the different suitability classes and then was reclassified into suitability classes.

2.4.2. Fuzzy Analytical Hierarchy process (fuzzy AHP)

Fuzzy logic is preferred to Boolean logic for land evaluation, because fuzzy techniques lead to estimates for land use suitability on a continuous scale and can therefore, be more informative than the Boolean (crisp) technique. Land evaluation based on fuzzy sets also helps to deal with vagueness or imprecision characterizing natural resources data (Burrough, 1989). If X represents a finite set of objects or properties, a fuzzy subset, A of X, is defined by a function, μ_A, in ordered pairs (Burrough and McDonnell, 2000; McBratney and Odeh, 1997):

$$A = \{X, \mu_A(X)\} \quad \text{for each } x \in X \qquad (2)$$

where $\mu_A(X)$ is the membership function of any $x \in X$ in A. It indicates the degree of membership of x in A by taking values within the interval [0,1]. 0 representing non membership and 1 representing full membership of the subset. Intermediate values ($0<\mu_A(X)<1$) means that x belongs to A in some degree, implying that partial membership is possible.

Table 3. Pairwise comparison matrix for assessing the relative importance of different land characteristics for alfalfa production

Chemical soil properties requirements	pH	EC	ESP	$CaCO_3$	Gypsum	Weights
pH	1	1/7	1/6	1/2	1	0.0583
EC		1	1	5	6	0.4096
ESP			1	4	5	0.3660
$CaCO_3$				1	2	0.1034
Gypsum					1	0.0627
Consistency ratio						0.01
Physical soil properties requirements	Texture	Surface stoniness	Coarse fragments	Depth		
Texture	1	1/4	1/3	1/5		0.0737
Surface stoniness		1	2	1/2		0.2842
Coarse fragments			1	1/3		0.1712
Depth				1		0.4710
Consistency ratio						0.02
Soil requirements	Physical soil properties	Chemical soil properties				
Physical soil properties	1	3				0.7500
Chemical soil properties		1				0.2500
Climatic requirements	Mean Temperature	Relative Humidity				
Mean Temperature[a]	1	2				0.6670
Relative Humidity[b]		1				0.3330
Crop growth requirements	Soil requirements	Climatic requirements				
Soil requirements	1	3				0.7500
Climatic requirements		1				0.2500

[a] Mean Temperature of the growing cycle, [b] Relative Humidity of the growing cycle

Table 4. Pairwise comparison matrix for assessing the relative importance of different land characteristics for barley production.

Chemical soil properties requirements	pH	EC	ESP	$CaCO_3$	Gypsum	Weights
pH	1	1/5	1/4	1/2	1	0.0767
EC		1	1	3	4	0.3614
ESP			1	3	4	0.3451
$CaCO_3$				1	2	0.1367
Gypsum					1	0.0801
Consistency ratio						0.01
Physical soil properties requirements	Texture.	Surface stoniness	Coarse fragment	Depth		
Texture	1	1/2	1/3	3		0.1718
Surface stoniness		1	1/3	4		0.2582
Coarse fragments			1	4		0.4902
Depth				1		0.0798
Consistency ratio						0.06
Soil requirements	Physical soil properties	Chemical soil properties				
Physical soil properties	1	2				0.6670
Chemical soil properties		1				0.3330
Climatic requirements	MTVS	MTFS	MTR[3]	MMinMaxTC		
MTVS[a]	1	1/3	1/3	2		0.1506
MTFS[b]		1	1	3		0.3685
MTRS[c]			1	3		0.3685
MminMaxTC[d]				1		0.1095
Crop growth requirements	Soil requirements	Climatic requirements				
Soil requirements	1	3				0.7500
Climatic requirements		1				0.2500

[a] Mean temperature of vegetative stage, [b] Mean temperature of flowering stage, [c] Mean temperature of ripening stage, [d] Mean daily minimum and maximum temperature of coldest month.

In this study, Semantic Import (SI) model was used to generate membership values for land characteristics, mentioned in section 2.2. The basic symmetric SI model (Fig. 3) (Burrough, 1992; McBratney and Odeh, 1997) is expressed as:

$$\mu_A(x) = \frac{1}{1+a(x-c)^2} \quad \text{for } 0 \le x \le \alpha \qquad (3)$$

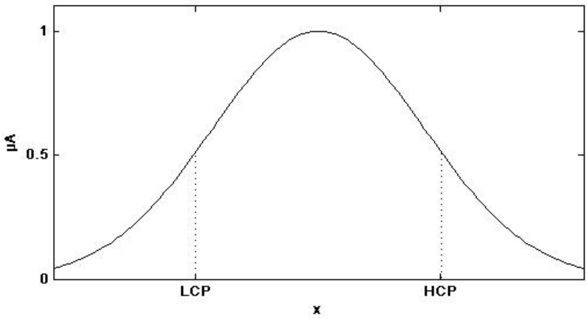

Fig. 3. Fuzzy membership function with cross over points

where A is land characteristic, c (ideal point) is the value of attribute x, representing the centroid of the subset, α is the maximum value of x. The parameter a, determines the shape of the function. The cross over points are the x values at which membership is 0.5. Both high and low cross over points (HCP and LCP, respectively) make suitability of the land characteristics for a specific land use, marginal. These parameters are chosen based on data, experience or conventionally imposed criteria. Asymmetric variants of SI model are used, if only lower or higher limits of a class have realistic relation to the envisaged land utilization type. Equations (4) and (5) are used for a land characteristic for which the higher and lower limits, respectively, contribute positively to crop yield:

$$\mu_A(x) = \frac{1}{1+(\frac{x-c_1-d_1}{d_1})^2} \quad \text{for } x<c_1+d_1 \qquad (4)$$

$$\mu_A(x) = \frac{1}{1+(\frac{x-c_2+d_2}{d_2})^2} \quad \text{for } x>c_2-d_2 \qquad (5)$$

where d_1 and d_2 are the width of the transition zone.

The membership function parameters for the soil characteristics used in this study are presented in Table 5. Similar membership functions were established for climatic characteristics that are considered in the study. It is necessary to mention that the classic set theory was used for assessing texture membership function. For each criteria map (each raster cell within each map), the membership values were computed, using the pre-determined membership functions. The membership value indicates the suitability rating for each land characteristic in a given site. For example, a membership value of 0.7 for soil texture expresses that land suitability rating is 70% of the optimum soil texture. Also it denotes that the limitation degree of the soil texture is 30%. The membership values of the different land characteristics (soil and climate) for each raster cell were subsequently arranged in a characteristic matrix (R). The weight values (over hierarchy levels) of the characteristics were presented as a weight matrix (W). Then the weight matrix was combined with the characteristic matrix to obtain an evaluation matrix (E), using a fuzzy set operator (Van Ranst et al., 1996) (Equation 6):

$$E = W^{o}R \qquad (6)$$

where "o" is the fuzzy set operator. The evaluation matrix (E) was calculated by Equation (7):

$$E = \min(a_1 + \ldots + a_n, 1) \text{ with } a_i = \max(0, w_i + r_i - 1) \qquad (7)$$

where W_i is the weight value for the i^{th} characteristic and r_i denotes an element of the matrix R for the i^{th} characteristic. The element of matrix E expresses the degree of membership of the considered raster cell to ideal suitability. A final map in this stage is output of the map calculation in GIS environment. The resulting map was classified into suitability classes, similar to what was done in the AHP method.

2.5. Validation

For validation, linear regressions were used to show correlation between the land indices obtained by different methods and the observed yields.

Table 5. Membership function parameters for land characteristics for (a) alfalfa, (b) barley

	Membership function parameters*				
Soil characteristics	LCP	C	HCP	d1	d2
(a) Alfalfa					
Surface stoniness	0.8	10		9.2	
Coarse fragments		15	55		40
Depth	20	75		55	
pH		8	8.5		0.5
EC		5	12		7
ESP		20	50		30
$CaCO_3$		35	60		25
Gypsum		40	70		30
(b) Barley					
Surface stoniness	0.8	10		9.2	
Coarse fragments		15	55		40
Depth	10	60		50	
pH		8.2	8.7		0.5
EC		12	20		8
ESP		25	45		20
$CaCO_3$		35	60		25
Gypsum		40	70		30

*LCP: low cross over point, C: ideal point, HCP: high cross over point, d_1 and d_2: width of the transition zone

3. Results and Discussion

3.1. Land suitability classification for alfalfa

According to Fig. 4, the dominant suitability classes are as follows: S3 for maximum limitation, S3 for parametric (square root), S1 for AHP and S2 for fuzzy AHP approaches. These classes occupy 56%, 54%, 95%, and 96% of the surface area, respectively.

The land indices obtained by the different methods and observed alfalfa yields for some points which have the least distance to studied profiles are given in Table 6. Correlations between land indices obtained by the different methods and observed alfalfa yields are shown in Fig. 5. The highest (R^2=0.79) and the lowest (R^2=0.62) correlations were obtained respectively for fuzzy AHP and AHP. The correlation is also higher for the parametric (square root) (R^2=0.75) compared with the maximum limitation (R^2=0.71) method. Consequently, the fuzzy AHP is the best method for land suitability evaluation for alfalfa in the study area.

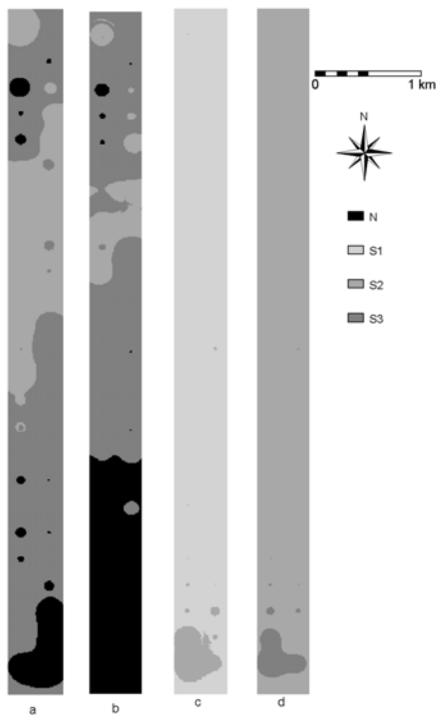

Fig. 4. Maps of land suitability classes for alfalfa: (a) maximum limitation method, (b) parametric method, (c) AHP method, (d) fuzzy AHP method

Table 6. Observed alfalfa yields and land indices obtained by the different methods for some certain places

Coordination of measurement place	Observed yield (kg/ha)	Land indices			
		Maximum limitation	Parametric	AHP	Fuzzy AHP
33° 26 ′ 49.42″ 52° ′21 31.72″	7550	20	8.423	52.36	25.53
33° 27 ′ 5.75″ 52° ′21 31.65″	9619	40	18.66	74.59	25.91
33° 26 ′ 49.15″ 52° ′21 4.44″	9835	20	9.26	74.65	26.29
33° 26 ′ 49.45″ 52° ′21 34.38″	9432	20	8.9	74.43	28.16
33° 26 ′ 58.35″ 52° ′21 41.55″	10376	20	9.39	75.11	51.31
33° 28 ′ 35.15″ 52° ′21 30.31″	10703	60	36.1	78.92	53.6
33° 27 ′ 45.89″ 52° ′21 41.71″	11000	40	10.35	77.74	52.56
33° 28 ′ 2.27″ 52° ′21 32.47″	11521	60	34.94	77.18	52.56
33° 28 ′ 42.17″ 52° ′21 32.83″	11816	60	37.51	79.18	56.72
33° 28 ′ 43.79″ 52° ′21 44.36″	12163	60	37.85	72.27	56.72
33° 28 ′ 48.11″ 52° ′21 46.31″	12534	60	42.24	80.05	59.95
33° 28 ′ 50.86″ 52° ′21 43.76″	12355	60	43.505	80.51	60.757
33° 28 ′ 59.25″ 52° ′21 33.42″	12878	70	49.25	80.13	56.39
33° 29 ′ 04.00″ 52° ′21 43.78″	12895	60	50.65	80.3	59.95
33° 28 ′ 55.07″ 52° ′21 39.43″	13240	60	42.27	80.16	61.02

Cumulative distributions of membership values for some land characteristics are shown in Fig. 6. Shapes and positions of the cumulative distributions curves are different for these land characteristics. According to the Fig. 6, 60% of the study area has µtexture < 0.73, µpH <0.87, < µcoarse fragments < 0.98, µEC, µsurface stoniness, µESP and µdepth <1. In other words, limitation of texture, pH and coarse fragments for alfalfa production, in 60% of the study area is at least 27%, 13% and 2%, respectively and EC, surface stoniness, ESP and soil depth have almost no limitation for this specific land use. The membership values for $CaCO_3$ and gypsum content in all parts of the study area are equal to 1.0, indicating that these characteristics have no limitation for alfalfa production. This is the reason why these two land characteristics are not shown in Fig. 6.

3.2. Land suitability classification for barley

The obtained dominant suitability classes, using maximum limitation method, parametric method, AHP and fuzzy AHP approaches are respectively: S2 (33.76%), S3 (35.22%), S3 (99.68%) and S2 (57.20%) (Fig. 7).

The land indices obtained by the different methods and observed barleya yields for some points which have the least distance to studied profiles are given in Table 7. Correlations between land indices obtained by the different methods and observed barley yields are shown in Fig. 8. The results obtained by the fuzzy AHP method are in the best confirmation (R^2=0.89) with the observed yield as compared with those obtained, using other methods: parametric (square root) (R^2=0.84), maximum limitation (R^2=0.81) and AHP (R^2=0.20).

Cumulative distributions of membership values for some land characteristics are shown in Fig. 9. Sixty percent of the study area has µtexture < 0.5, µcoarse fragments < 0.98, µpH, µsurface stoniness, µESP, µEC and µdepth <1. This means that the limitation of texture and coarse fragments for barley production in 60% of the study area is at least 50% and 2%, respectively and pH, surface stoniness, ESP , EC and soil depth have almost no limitation for this specific crop. The membership values for $CaCO_3$ and gypsum content in all parts of the study area are equal to 1.0, implying that these characteristics do not have any limitation for barely production.

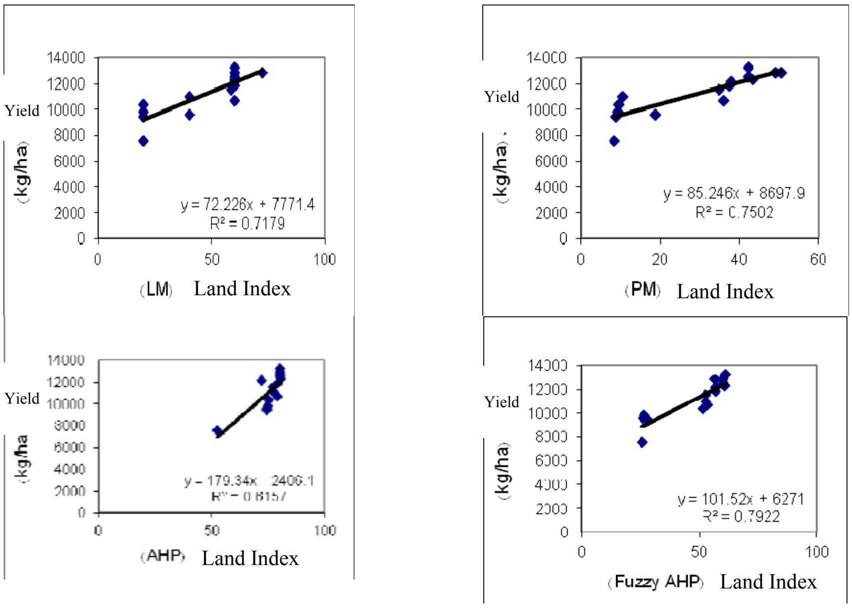

Fig. 5. Relationships between alfafa observed yields and land suitability indices obtained by the four methods (maximum limitation, parametric, AHP and fuzzy AHP)

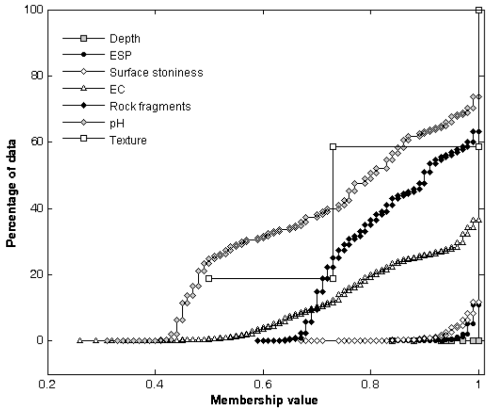

Fig. 6. Cumulative distribution functions of land characteristics for alfalfa

Table 7. Observed barley yields and land indices obtained by the different methods for some certain places

Coordination of measurement place	Observed yield (kg/ha)	Land indices			
		Maximum limitation	Parametric	AHP	Fuzzy AHP
33° 26 ′ 57.25″ 52° ′21 30.48″	2940	20	5.31	39.02	20.43
33° 26 ′ 53.01″ 52° ′21 31.58″	3312	20	9.74	39.42	21.14
33° 26 ′ 45.43″ 52° ′21 41.35″	4199	20	10.69	38.78	26.58
33° 27 ′ 21.71″ 52° ′21 41.72″	4333	20	10.70	40.07	24.86
33° 27 ′ 30.16″ 52° ′21 41.73″	4412	20	11.40	40.76	26.58
33° 27 ′ 54.35″ 52° ′21 42.23″	4467	45	26.56	41.88	27.30
33° 28 ′ 02.28″ 52° ′21 42.29″	5417	50	26.88	40.66	50.55
33° 28 ′ 17.79″ 52° ′21 45.96″	5223	50	30.61	40.59	51.75
33° 28 ′ 34.01″ 52° ′21 29.73″	5297	50	34.46	40.54	50.65
33° ۲۹ ′ 11.05″ 52° ′21 45.05″	5845	70	53.22	39.34	58.00
33° 29 ′ 15.35″ 52° ′21 43.50″	6098	70	52.67	40.34	59.34
33° 28 ′ 18.38″ 52° ′21 46.97″	6140	70	54.32	41.15	59.97

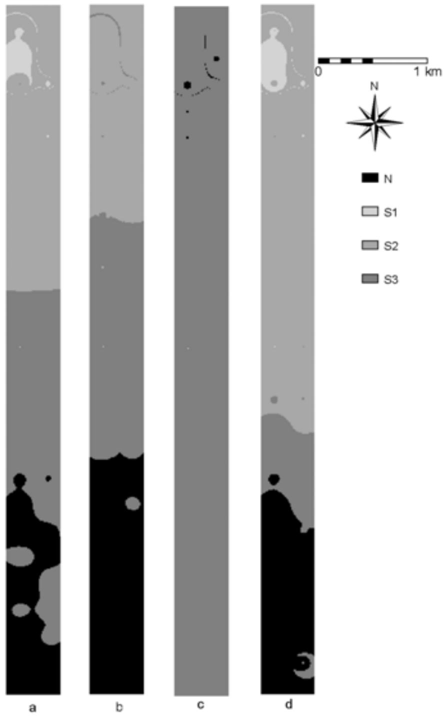

Fig. 7. Maps of land suitability classes for barley, (a) maximum limitation method, (b) parametric method, (c) AHP method, (d) fuzzy AHP method

According to Fig. 7d, the marginally and not suitable (S3 and N, respectively) areas for barley are located in the southern half of the study area. In this part, based on Soil Taxonomy (Soil Survey Staff 2010), the dominant soils are "Typic Torriorthents" and "Typic Haplogypsids", both with sandy skeletal particle size class at family level.

A 60.6% of the study area is highly and moderately suitable (S_1 and S_2, respectively) for barley production (Fig. 7d). At the present time, 22% out of this 60.6% is under barley cultivation.

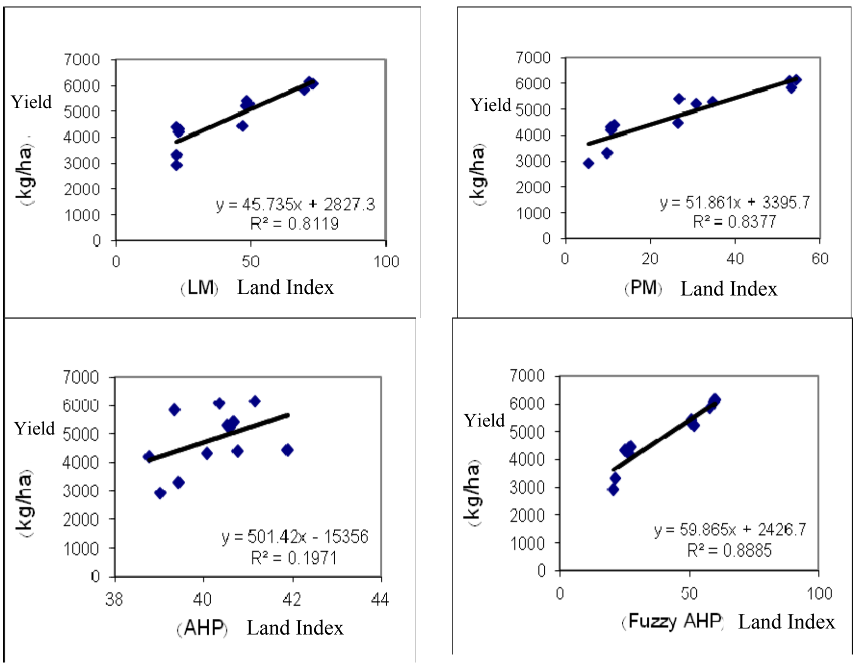

Fig. 8. Relationship between barley yield and land suitability indices obtained with the four methods

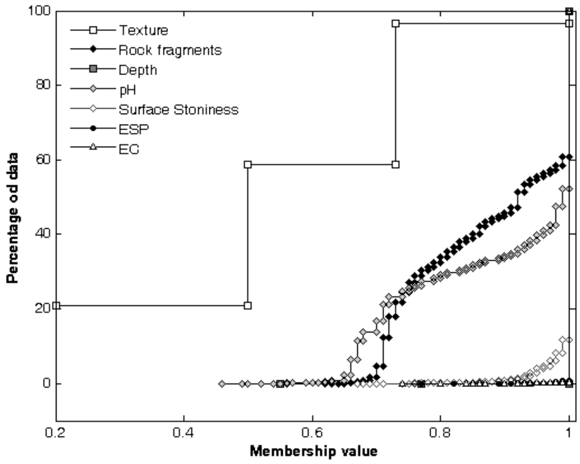

Fig. 9. Cumulative distribution functions of land characteristics for barley

4. Conclusion

The aim of using fuzzy logic is to reflect the continuous variability concept of soil properties in space. In reality, the overlap of the suitability classes happens usually in the attribute space (Braimoh and Vlek, 2004) and the use of fuzzy membership functions can express this partial overlap of the classes.

The fuzzy multi-criteria approach differs from the conventional land evaluation methods in its use of calculated weights and its organization of criteria in the hierarchy levels, to fit the suitability problems into the framework of decision-making. Moreover, in fuzzy multi-criteria methodology, the use of fuzzy membership value provides valuable information for indentifying the major restraints to crop performance and policies for overcoming them. In the study area, it was found that the major constraint for alfalfa and barley production is soil texture that can be improved by manure application. Other finding was that the majority of the study area is potentially more suitable for alfalfa cultivation as compared with barley.

This research also confirmed that the fuzzy AHP method as a credible and accurate approach could be applied for the integration of data from various domains and sources and to delineate an area in diverse suitability classes for specific crops through the MCE technique in a GIS context. This is in agreement with a study carried out by Triantaphyllou and Lin (1996). They applied five fuzzy multiattribute decision making methods and concluded that the fuzzy AHP approach is more accurate than others. Besides, in this methodology, the expert knowledge is very important to obtain reliable results.

The multiple criteria and expert opinions were evaluated by fuzzy MCE–GIS combination in a consistent way in order to develop suitability maps. The results indicated that this combination was useful for providing reasonable manner to decision making in land evaluation.

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