Application of fuzzy logic to land suitability for irrigated wheat

P. Maleki[A], A. Landi[A], Gh. Sayyad[A], J. Baninemeh[B], Gh. Zareian[C]

[A]Shahid Chamran Universtiy of Ahvaz, Email maleki_1434@yahoo.com, foahmad@yahoo.ca, gsayyad@gmail.com
[B]Agricultural Research Center of Khuzestan, Email jamal_nn@yahoo.com
[C]Agricultural Research Center of Fars, Email zareian48@yahoo.com

Abstract
This paper aims to determine the quantitative impact of land qualities on irrigated wheat production, using fuzzy set (FS) theory. This theory was applied and compared with conventional Parametric-Storie (PS) method in a land suitability assessment for irrigated wheat production for two different regions, one in Sardasht-Behbahan area of Khuzestan province, southwest Iran, and the other in Neiriz-plain area of Fars province, south Iran.

The two methods performances was evaluated by comparing the relationships between observed yields and calculated land indices. Results showed that, for both regions, land suitability indices produced by FS method showed higher correlation with observed yields than those produced by conventional PS method. The coefficient of determination (R^2) between land suitability indices and observed irrigated wheat yield using FS and PS methods were in Sardasht-Behbahan 0.89 and 0.84, respectively. The same result, but with the sharp difference between two methods, were obtained in Neiriz-Fars-plain using FS (R^2=0.80) compared to PS method (R^2=0.34). Therefore, it can be calculated that even in situations where conventional methods can not well estimate crop yield, fuzzy method can improve the quality of land suitability assessment.

Key Words
Fuzzy logic, irrigated wheat

Introduction
Land evaluation is carried out to estimate the suitability of land for the specific use such as arable farming or irrigated agriculture. Land evaluation can be carried out on the basis of biophysical parameters and/or socioeconomic conditions of an area. Biophysical factors tend to remain stable, unlike socioeconomic factors that are affected by social, economic and political settings. Thus physical land suitability evaluation is a prerequisite for land-use planning and development. The accuracy of agricultural land evaluation depends on the significance of the chosen land qualities, with respect to their effects on crop production. Several procedures for estimating the impact of land qualities on crop production were established by field scientists, on the basis of reasoned intuition. A well-known, simple approach attributes a factor to each land quality that reduces the expected yield by a certain fraction. Example of this approach is "the Sys parametric approach".

It is realized that this conventional method fails to incorporate the fuzzy nature of much land resource data. Other disadvantages are: arbitrary selection of land qualities, poor definition of land productivity factors, experience-dependent decisions and spurious precision of results. Another new method is fuzzy logic which determines the quantitative impact of land qualities on land suitability so that a value of outside a specified range can be minimized. The Fuzzy method differs from the conventional land evaluation procedures by (1) the use of an explicit weight for the effect of each land quality on crop performance and (2) the way of combining the evaluation of land qualities into a final land suitability class or land suitability index. Soil condition can affect the result of land suitability assessment. This study was conducted to compare the performances of two Land evaluation methods, conventional (the Parametric-Stori approach: PS) vs. Land evaluation using Fuzzy set (FS) method, for irrigated wheat production in two different regions. The selected regions have different soil and climate conditions and are located in the southeast (Sardasht-Behbahan) and the south (Neiriz-plain-Fars) of Iran.

Materials and methods
Materials
Two regions were selected for the study. The first region (Sardash) covers approximately 6000 hectares and is located in the southeastern part of the Behbahan, Iran, between 30˚ 28´ to 30˚ 27´ NW and 50˚ 2´ to 50˚ 17´ WL. A total of 14 representative soil units from this region were considered for this study. Most of the soils belonged to the order of Inceptisols, and some were classified as Entisols. Based on eleven years

meteorological data (1993-2003), the mean monthly air temperature ranged from 6.9°C to 28.3°C, and the mean annual rainfall was 340.8 mm. The other study region, Neiriz-plain is located at 15 KM south of Shiraz between 54˚ to 54˚ 25´WL and 29˚8´ to 29˚ 27´ NW.A total of 10 representative soil units from the studied area were considered. Most of this soils belonged to the order of Inceptisols. Based on 15 years meteorological data (1991-2006), the mean monthly temperature ranged from 43°C to -8°C, and the mean annual rainfall was 204 mm.

Methods

Parametric approach

In the parametric approaches, all individual land quality rating values are multiplied to produce one numerical index. According to the Storie method (Storie 1976), the land index is the product of the individual rating values of all land qualities, using the following formula:

$$LI = \left(\prod_{j=1}^{n} R_J \right).100$$

Where LI is the land index, n is the number of land qualities and R_j is the rating value of the jth quality.

Fuzzy set approach

The Fuzzy set theory (Zadeh 1965) is a body of concepts and a technique that gives a form of mathematical precision to human thought processes that are imprecise and ambiguous in manu ways. The application of the fuzzy set theory to determine the impact of land qualities irrigated wheat production comprises several steps:

- Detemination of membership functions
- Determination of membership values
- Determination of reference weight and reference suitability matrices
- Determination of weight values for different land qualities

In this study the membership function was defined as Kandel extention membership function as follows:

$$MF = \frac{1}{\left\{ 1 + \left(\frac{Z(x) - b1 - d1}{d1} \right) \right\}} \qquad \text{If } Z(x) < b_1 + d_1$$

$$MF = 1 \qquad \text{If } b_1 + d_1 \leq Z(x) \leq b_2 - d_2$$

$$MF = \frac{1}{\left\{ 1 + \left(\frac{Z(x) - b2 + d2}{d1} \right) \right\}} \qquad Z(x) > b_2 - d_2$$

In this function $b_1$and b_2 are lower and upper limits, and d_1 and d_2 are the width of transition regions. As the effect of each land attribute on wheat yield was different, the weight of each land attribute was calculated using multiple regression between observed yield and land attributes.

Results and discussion

The observed wheat yields and produced land indices using FS and PS methods for each land unit are given in table 1. The average irrigated wheat yields in the Sardasht-Behbahan and Neiriz-Fars were 3518±1684 and 3550±2321 kg ha^{-1}, respectively. For both regions, the produced FS indices for each land unit were more than those produced by PS method. The relationship between land indices obtained by the different methods and the observed yields are given in Figure 1. For both regions, land suitability indices produced by FS method showed more relationship with observed yields than those produced by conventional PS method. The coefficient of determination (R^2) between land suitability indices and observed irrigated wheat yield using FS and PS methods were in Sardasht-Behbahan 0.89 and 0.84, respectively. The same result, but with the sharp difference between two methods, were obtained in Neiriz-Fars-plain using FS (R^2=0.80) compared to PS method (R^2=0.34). Our results shows that even in regions where conventional PS method can not well estimate crop yield, fuzzy method can improve the quality of land suitability assessment. Although our results show the comparative advantages of FS than PS method, however the obtained correlation in FS method was still far of desired "one". Possibly because crop yield is not only dependents on land indexes but other factors like farm management is very important in this way and should be included in the land evaluation.

Table 1. Observed irrigated wheat yields and calculated land indices for the different land units in Sardasht-Behbahan(a) and in Neiriz-Fars-plain (b).

(a)

Land unit	Observed yield (kg/ha)	land index	
		Parametric method	Fuzzy method
1.1	3372	60.400	79.67
2.1	4300	72.400	80.60
2.2	5200	66.400	82.59
2.3	4720	75.400	78.30
2.4	3050	59.300	79.62
2.5	0	18.600	49.65
3.1	4200	65.900	79.54
4.1	5100	72.200	81.27
4.2	3965	76.400	80.39
4.3	4166	66.600	79.80
5.1	4530	55.900	81.18
5.2	2254	35.900	63.35
5.3	4400	76.400	81.64
5.4	0	27.200	54.32

(b)

Land unit	Observed yield (kg/ha)	land index	
		Parametric method	Fuzzy method
1.1	5200	59.2	71.62
1.2	5000	59.5	74.74
1.3	4500	38.9	76.27
2.1	7000	78.6	77.03
2.2	6500	70.2	73.03
3.1	1500	59.1	61.21
3.2	1800	58.8	61.89
3.3	1500	49.8	59
3.4	1500	57	61.89
3.5	1000	27.7	49.08

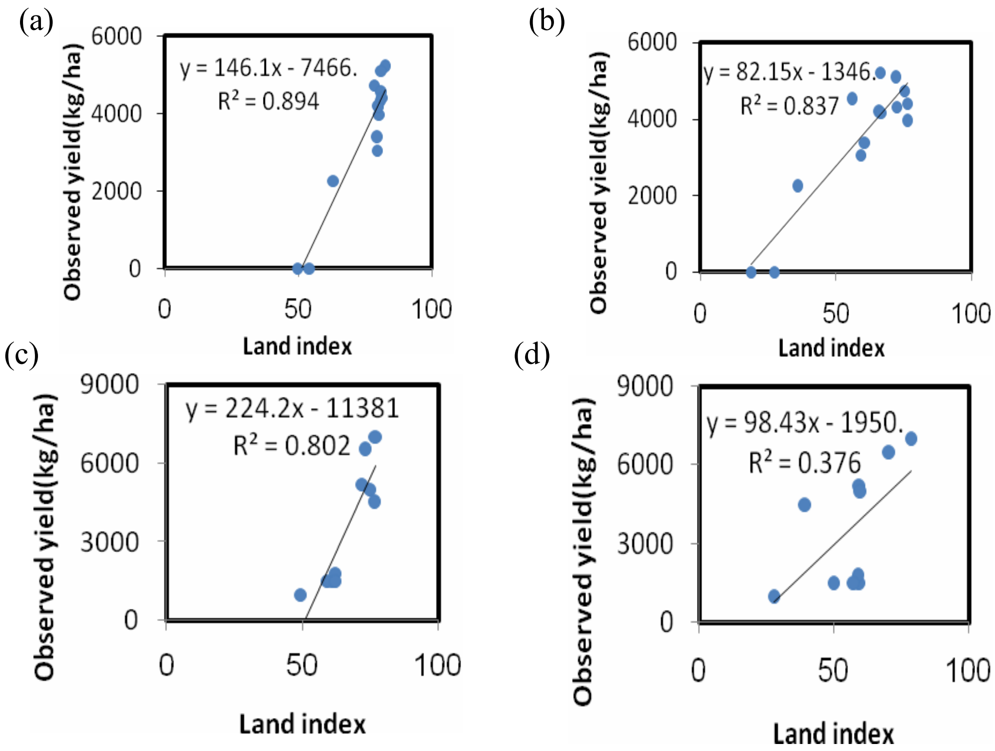

Figure 1. Linear regrression between the land indices and observed irrigated wheat yields in Sardasht-Behbahan obtained with (a) the fuzzy set, (b) the parametric methods and in Neiriz-Fars-plain using, (c) the fuzzy set and (d) the parametric methods.

References

Burrough PA (1989) Fuzzy mathematical methods for soil survey and land evaluation. *J. Soil Sci.* **40**, 477-942.

Burrough PA, et al. (1992) Fuzzy classification methods for determining land suitability from soil profile observations and topography. *J. Soil Sci.* **43**, 193-210.

Chang L, Burrough PA (1987) Fuzzy reasoning a new quantitative aid for land evaluation. *Soil Survey and Land Evaluation* **7**, 69-80.

De Baets B, Kerre E (1994) A primer on solving fuzzy relational equations on the unit interval. *J. Uncertainty Fuzziness and Knowledge- Based Systems* **2**(2), 205-225.

FAO (1976) A Framework for Land Evaluation. FAO Soils Bulletin 32, Rom,72 pp.
Soil Survey Staff (1992) Keys to Soil Taxonomy 5th Editor (SMSS Technical Monograph, No 19. Pocohontas Press, Blacksburg VA). 556 pp.
Sys C (1978) Land Evaluation. ITC Lectures Notes, University of Gent, Belguim), 189 pp.
Sys C (1985) Land evaluation, Parts I, II and III. (ITC Lecture Notes, University of Ghent, Belguim, 343 pp.
Tang H, Van Rust E (1992) Testing of fuzzy set theory in land suitability assessment for rainfed grain maize production. *Pedologie XLII* **2**, 129-147.
Tang H, et al. (1991) Land suitability classification based on fuzzy set theory. *Pedologie XLI* **3**, 277-290.