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## QUANTITATIVE AND QUALITATIVE LAND SUITABILITY ASSESSMENT FOR RICE CULTIVATION, NORTH OF IRAN

*Received: 24.09.2018*

*Accepted: 27.05.2019*

*Abstract.* Evaluation of arable lands and agricultural potential to support current and future agricultural uses is one of the best agricultural policies for food security in developing countries. Hence, studies related to land suitability evaluation can lead to sustainable land use. The aims of this research were qualitative land suitability evaluation, land production potential prediction and quantitative land suitability evaluation on the basis of the FAO model for rice in Sangar region, northern Iran. Qualitative evaluation was carried out using the maximum limitation and parametric methods. Land production potential was determined by the agro-ecological zoning (AEZ) model. Land suitability classes according to maximum limitation, Storie and square root parametric methods are determined S3, S3-N1 and S2-S3, respectively. Rice radiation-thermal production potential was calculated as 7.65 t/ha; mean land production potentials, using Storie and square root formulas were predicted respectively, as 3.69 and 4.52 t/ha and mean actual yield was estimated as 2.81 t/ha. The results of this study showed that use of the square root formula is more appropriate than Storie formula as far as land production potential calculation is concerned. Soil limitations and weak management level have caused majority of land units to have moderate quantitative suitability (S2) for rice cultivation. Comparison between qualitative and quantitative suitability classes demonstrates that quantitative suitability classes are significantly increased due to crop adaptation with climate agents.

**Keywords:** land evaluation, parametric method, agro-ecological zoning model, production potential

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## INTRODUCTION

The ability of the world's natural resources to provide the needs of its growing population is a fundamental issue for the international community. Proper recognition of land capabilities and allocating of them to the best and most profitable and stable land use has special importance for preventing of ecosystem destruction. Sustainability of ecosystem productivity and biodiversity requires quantification of the quality and quantity of natural resources and their suitability for a range of land uses. The potential of land for agricultural use is determined by evaluating the components related to climate, soil and topographical environment and by understanding local biophysical restraints. The climatic conditions and soil quality of an area are the most important determinant parameters of land evaluations (Grassano *et al.* 2011).

Land suitability evaluation (LSE) 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 land evaluation framework has been the primary procedure employed worldwide to address local, regional and national land use planning (Manna *et al.* 2009). Land use planning (LUP) is one of the most important objectives of land evaluation based on the guidelines of the UN Food and Agriculture Organization (FAO) (FAO 1993; Niekerk 2010).

Inappropriate land use leads to inefficient exploitation of natural resources, destruction of the land resources, poverty and other social problems. Part of the solution of land use problem is land evaluation in support of rational land use planning and appropriate and sustainable use of natural and human resources (Rossiter 1996). Land evaluation is concerned with the assessment of land performance for specific land utilization and provides a rational basis for land use decision making for estimation of required inputs and predicted outputs (FAO 1976; Sys *et al.* 1991a). So, it is very important for agriculture development planning to take land resources assessment.

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 land characteristics (Sys *et al.* 1991a). 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 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).

Many studies regarding several aspects of land suitability for crop cultivation have been conducted on the basis of FAO framework in different areas. Jalalian *et al.* (2007) considered the qualitative, quantitative and economic land suitability of Mehran plain in Iran for wheat, maize and chickpea. Qualitative land evaluation showed that most of the land units were classified moderately suitable for given crops because of soil limitation. Quantitative classes were in the same or in higher classes than qualitative classes. Economic land suitability classification showed that the wheat production was the most economical land utilization type. Rahimi Lake *et al.* (2009) compared quantitative and qualitative land suitability methods for olive trees, but the different methods did not produce similar estimations. Bagheri Bogadghabadi *et al.* (2015) reported that the traditional land evaluation method used in Iran, called *land classification for irrigation* (LCI), provided reliable land suitability classes and also showed good relationships both with maximum limitation and parametric methods and with actual yields. Comparisons between qualitative and quantitative methods produced similar results for common crops (a barley–alfalfa–wheat–fallow rotation). They also suggested that using the FAO method to indicate LCI subclasses could help users or managers to recognize limitations for land-use planning. The accuracy of land suitability evaluations has also been determined by comparing the predictions with values for present crops or observed yields (Ceballos-Silva and Lopez-Blanco 2003, Chen *et al.* 2003, D’Haeze *et al.* 2005, Mandal *et al.* 2005, Saroinsong *et al.* 2007).

Guilan province bordering to the Caspian Sea in the northern Iran is considered as one of the areas having high potential for rice production. Despite the economic importance of rice and its by-products, there is limited research about land suitability evaluation for this crop in study area. In this paper, the qualitative land suitability evaluation, land production potential prediction and quantitative land suitability evaluation on the basis of the FAO model were conducted for rice in the central Guilan province, Iran. Additionally, the qualitative land evaluation methods were compared with quantitative ones or with actual yields.

## MATERIALS AND METHODS

### *Study area*

The area under investigation with an approximate area of 1,300 hectares (37°23′–37°25′N, 49°51′–49°56′E) was located in the Sangar region, Guilan province, northern Iran (Fig. 1). The area has a mean annual rainfall of 1,448 mm, mean annual temperature of 17.7°C and mean relative humidity of 71.4%.

Based on U.S. Soil Taxonomy (Soil Survey Staff 2014b), the soil moisture and temperature regimes of the area are udic and thermic, respectively. This area has two main physiographic units: alluvial plain and low land. The major agricultural crops in paddy fields are rice (*Oryza sativa* L.) as a first crop, and vegetables as second crops in rice-based cropping system. Rice is irrigated by surface (gravity) irrigation.

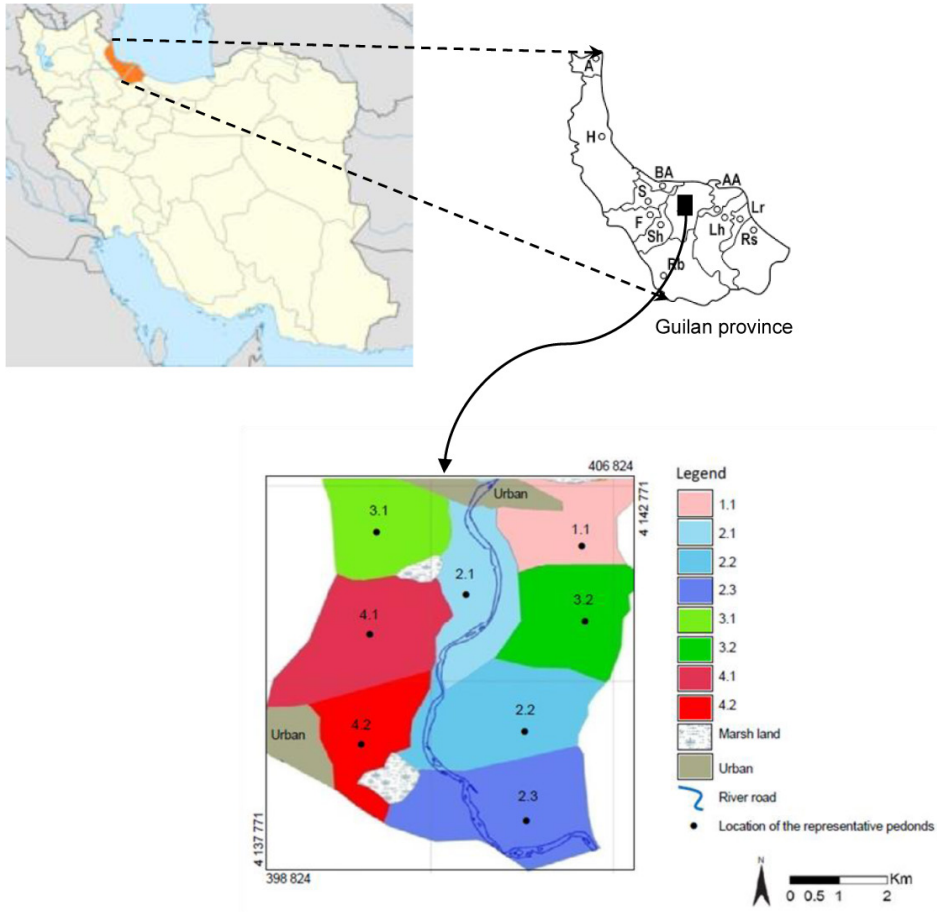


Fig. 1. Location of study area with the location of representative pedons in the Sangar region (Guilan province, Northern Iran)

### *Input data for land evaluation*

To determine the location of representative pedons, a topographic map (1:25 000 scale) and aerial photographs of the area were interpreted. The eight representative pedons were drilled and dissected across the area. The pedons were located with the aid of global positioning system (GPS) in the field. Fig. 1 shows

the location of the study area and the location of representative pedons in each land unit. Soils were classified according to Soil Taxonomy (Soil Survey Staff 2014b).

Soil samples at all diagnostic horizons were collected up to a depth of 100 cm for LSE. The soil samples were taken to the laboratory, where they were air-dried overnight and then passed through a 2 mm sieve. Prepared samples were subsequently analyzed for required soil properties in LSE (Sys *et al.* 1993) using standard methods (Soil Survey Staff 2014a). Climatic data for LSE were obtained from Rasht Meteorological Station (Chaharmahal-Va-Bakhtiari Meteorological Administration 2014) for a 20-year period (1994–2014).

Agricultural systems and technologies used by farmers were essentially the same. Data for socio-economic land evaluation were obtained from responses to questionnaires from a random selection of farmers in the study area. Each questionnaire included questions about the costs and income associated with rice.

### *Qualitative and quantitative land suitability methods*

Different land suitability approaches for specific crops were used according to Sys *et al.* (1991b, 1993). These methods consisted of matching land characteristics with crop requirements. They include maximum limitation (or simple limitation), qualitative parametric approaches and quantitative socio-economic land suitability evaluation. Soil and land characteristics were matched, based on Sys *et al.* (1991a, b) and other tables proposed by the Iranian soil and water research institute (Givi 1997).

In qualitative parametric methods, a numerical rating with a scale of 0 to 1 is allocated for different suitability classes. If a land characteristic has no limitation for 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. A land index (LI) is calculated from the individual rating values of all the characteristics, multiplied by 100. This index can be calculated from several different procedures, which include the summation, Storie index and square root (SR) methods. In this study, we used Storie (1978) and square root (Khidir 1986) formulas to calculate the land index (LI); the relevant equations are as follows:

$$LI = A \times \frac{A}{100} \times \frac{B}{100} \dots \quad (1)$$

$$LI = R_{\min} \times \sqrt{\frac{A}{100} \times \frac{B}{100} \times \dots} \quad (2)$$

Where: *LI* is the specified land index; *A*, *B*, etc. are different ratings for each land characteristic, and  $R_{\min}$  is the minimum rank or value. The suitability classes and limiting factors (subclasses) are then determined (Sys *et al.* 1991a, b).

Based on qualitative parametric methods, land suitability classes were determined for rice crop. According to the results of measured land index (LI) suggested by Sys *et al.* (1991b), land having indices  $> 75$ , 50–75, 25–50 and  $< 25$  are in S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable) and N (non suitable) classes, respectively. Quantitative land suitability evaluation required to determine the potential, marginal, observed and predicted yields. Potential values were determined using a photosynthesis model which calculates crop photosynthesis response to temperature and radiation averaged over a growing season (FAO 1981). Predicted yields were derived from these values by employing yield-reducing factors related to soil constraints. The predicted yield for each representative pedon was compared to the maximum potential yield in Sangar region. In this study, to calculate potential yield based on the agro-ecological zoning (AEZ) model (Kassam 1977), the following were measured or calculated:

- Respiration coefficient was calculated as follows:

$$Ct = C_{30} (0.044 + 0.0019t + 0.001t^2) \quad (3)$$

Where:  $Ct$  is respiration coefficient;  $C_{30}$  of 0.0108 for non-legumes and  $t$  is mean daily temperature of the growing cycle ( $^{\circ}\text{C}$ ).

- Maximum gross biomass production ratio was calculated according to:

$$\text{bgm} = f \times \text{bo}(1 + 0.002y) + (1 - f) \times \text{bc}(1 + 0.005y) \quad (4)$$

$$y = (Pm - 20) \times 5 \quad (5)$$

Where:  $\text{bgm}$  is maximum gross biomass production rate ( $\text{kg CH}_2\text{O}/\text{ha.hr}$ );  $f$  is fraction of the daytime that the sky is overcast;  $\text{bo}$  is maximum gross biomass production on overcast days ( $\text{kg CH}_2\text{O}/\text{ha.day}$ );  $\text{bc}$  is maximum gross biomass production on clear days ( $\text{kg CH}_2\text{O}/\text{ha.day}$ ) and  $Pm$  is maximum leaf photosynthesis rate ( $\text{kg CH}_2\text{O}/\text{ha.hr}$ ).

- Potential yield was calculated as follows:

$$Y = (0.36 \times \text{bgm} \times \text{KLAI} \times \text{Hi})/[1/L \times 0.25Ct] \quad (6)$$

Where:  $Y$  is potential yield ( $\text{kg}/\text{ha}$ );  $\text{bgm}$  is maximum gross biomass production rate ( $\text{kg CH}_2\text{O}/\text{ha.year}$ );  $\text{KLAI}$  is leaf area index at maximum growth rate;  $\text{Hi}$  is harvest index;  $L$  is growth cycle (day) and  $Ct$  is respiration coefficient.

Potential yield can be determined by climatic data (such as solar radiation and mean temperature) and plant characteristics. Marginal yield is the part of the yield in which there is neither profit nor loss. It is also the level of productivity that

results in total income being in equilibrium with the total cost. It can be calculated from the quotient of total cost and total income for each yield unit (kg).

The data of actual, or observed, yield in each land unit were obtained from the information of region farmers and also the local Agricultural Extension Service. For determination the limits of land classes, the pattern introduced by Sys *et al.* (1991a) was used as following:

The marginal value between classes S1 and S2 was equal to 75% of potential yield.

The marginal value between classes S2 and S3 was equal to 1.4 times the marginal yield.

The marginal value between classes S3 and N was equal to 90% of the marginal yield (0.9 times marginal yield).

The land production potential (LPP) was calculated using potential yield multiplied by the soil index (SI). It is worth noting that SI is as in land index (LI) but without the climate index (CI). The presence of significant relationship between observed yield and predicted yield prove the accuracy of selected land evaluation manner. After recognition of the accuracy of qualitative land suitability evaluation, a linear regression and correlation statistical analyses between soil index and observed yield were applied.

## RESULTS AND DISCUSSION

### *Qualitative land suitability evaluation*

Soils were classified as Inceptisols and Entisols. Table 1 illustrates the soil classification and basic soil physical and chemical properties for land evaluation.

The average values of essential climatic parameters for land suitability assessment and their suitability classes for rice are shown in Table 2. There was no optimal climatic condition for rice. The relative humidity at harvest and after milky stage caused a severe limitation (suitability class of S3) for rice, which made the region receive a marginal suitable class (S3) for this crop in the maximum limitation approach (Table 2). In this approach, plant requirements are compared with the corresponding qualitative land and climatic characteristics; the maximum limiting properties define land suitability class and subclasses. The calculated climatic indices ( $CI_s$ ) by Storie and square root parametric methods were as follows: 57.84 and 61.92, respectively. Because of the climatic limitation, the region received a marginally suitability (S3 class) for rice in the parametric methods (Table 2).

The suitability class of each soil property for rice cultivation was obtained using weighted average of the properties in 0–100 cm depth of representative pedons in each land unit. Finally, total suitability class and rating of soil were calculated according to maximum limitation, Storie and square root parametric

Table 1. Summary of physical and chemical properties and soil classification for representative pedons of land units in the study area

LU <sup>a</sup>	Horizon	Depth (cm)	percentage					CCE <sup>b</sup>	Texture	pH	EC (dS/m)
			Sand	Silt	Clay	Gravel	O.C.				
Typic Endoaquepts											
1.1	Apg	0–20	16	15	39	3.6	1.71	11.5	SiCL	7.5	1.2
	ABg	20–45	15	42	43	4.6	1.22	12.5	SiC	7.5	0.77
	Bg	45–80	16	43	41	5.2	0.25	12.1	SiC	7.4	0.46
	BCg	80–130	21	20	49	7.8	0.29	11.5	C	7.6	0.87
Fluventic Endoaquepts											
2.1	Apg	0–18	24	38	38	5.2	1.62	10.6	CL	7.4	1.62
	ABg	18–35	11	42	47	7.3	0.58	12.8	SiC	7.6	1.32
	Bg1	35–75	23	37	41	6.6	1.1	11.1	C	7.7	0.78
	Bg2	75–110	19	38	43	6.5	0.11	10.5	C	7.4	0.95
	BCg	110–160	47	17	36	12.5	0.23	14.6	SC	7.3	0.95
Typic Eutrudepts											
2.2	Ap	0–12	25	36	39	8.2	2.12	12.3	CL	7.6	1.54
	AB	12–36	18	32	50	7.5	1.27	13.3	C	7.1	0.42
	Bw	36–78	20	34	46	6.3	0.17	14.1	C	7.2	0.78
	CBg	78–140	50	13	37	11.2	0.15	12.8	SC	7.4	0.85
Typic Endoaquepts											
2.3	Apg	0–18	7	63	30	4.5	1.25	12.2	SiCL	7.0	1.1
	Bg1	18–42	6	62	32	5.2	0.95	13.1	SiCL	7.2	0.95
	Bg2	42–77	9	64	27	3.2	0.19	14.2	SiCL	7.5	0.97
	BCg	77–90	8	50	42	8.9	0.23	9.3	SiCL	7.1	0.72
	Cg	90–140	9	45	46	10.3	0.12	8.5	SiCL	7.2	0.83
Typic Fluvaquents											
3.1	Ap	0–15	55	33	12	7.2	2.05	9.2	SL	7.1	0.95
	ABg	15–32	53	36	11	6.3	1.6	7.7	SL	7.7	0.63
	Bg	32–86	13	60	61	8.2	0.31	8.6	SiL	7.4	0.52
	Cg	86–140	65	33	2	9.9	0.45	12.7	SL	7.3	0.42
Typic Epiaquepts											
3.2	Apg	0–15	24	40	36	6.3	2.32	14.2	CL	7.3	0.86
	Bg1	15–52	25	35	41	5.2	1.71	9.9	C	7.1	0.65
	Bg2	52–92	19	38	43	7.5	1.62	7.8	C	7.4	0.52
	Cg	92–145	52	13	35	8.9	0.35	8.6	SC	7.3	0.51
Fluventic Endoaquepts											
4.1	Apg	0–19	28	32	40	2.1	1.36	11.1	CL	7.4	1.01
	ABg	19–35	25	36	39	2.5	1.12	11.5	CL	7.5	0.69
	Bg1	35–70	19	38	43	3.1	0.36	13.5	C	7.2	0.85
	Bg2	70–105	12	28	60	2.5	0.75	8.4	C	7.5	0.52
	BCg	105–155	54	13	33	10.3	0.45	16.2	SC	7.1	0.65
Typic Eutrudepts											
4.2	Ap	0–16	27	36	41	4.3	1.45	9.6	CL	7.2	0.85
	AB	16–47	18	34	48	6.5	1.41	13.2	C	7.2	0.89
	Bw	47–88	20	34	46	6.8	0.72	15.3	C	7.3	0.65
	Cg	88–140	56	19	27	12.6	0.65	14.2	SCL	7.4	0.55

<sup>a</sup> land unit<sup>b</sup> calcium carbonate equivalent



Table 2. Average values of essential climatic parameters for land suitability assessment and their suitability classes for rice

Climatic parameter	Value	Suitability class	Total climatic suitability class		
			Maximum limitation	Parametric (Storie)	Parametric (square root)
Mean temperature of the growing cycle (°C)	23.17	S2	S3	S3	S3
Mean temperature of the developing stage (°C)	23.48	S2			
Mean temperature of the ripening stage (°C)	25.3	S1			
Mean minimum temperature of the ripening stage (°C)	20.3	S1			
Mean daily maximum temperature of the warmest month (°C)	30.2	S1			
Relative humidity (tillage + developing stage) (%)	77.23	S1			
Relative humidity after milky stage (%)	87	S3			
Relative humidity at harvest stage (%)	89	S3			
n/N for growing cycle	0.45	S1			
Climatic index (CI)				57.84	61.92

methods (FAO 1976) (Table 3). Since some of the soil and landscape properties (soil depth, slope, micro-relief, soil texture and structure, equivalent  $\text{CaCO}_3$ , cation exchange capacity (CEC), base saturation percentage, exchangeable sodium percentage (ESP), etc.) had no limitation for the studied crop (data not showed), they were not considered in recognition of soil and landscape suitability class. Besides, adding soil organic matter as animal manure to the studied soils is a reason to ignore its limitation for LSE. Table 3 showed that the depth of chroma of 2 or less and the water table depth are the most soil limitation factors for rice cultivation in Sangar region.

Table 3. Weighted average values of soil properties in 0–100 cm depth and their suitability classes and ratings for rice

LU	Soil property	Suitability class	Suitability rating
1.1	Depth of chroma of 2 or less (cm)	S2	72.5
	Water table depth (cm)	S2-S3	60
	Coarse fragments in 0–25 cm (%)	S1	85.5
	Coarse fragments in 25–100 cm (%)	S2	83.7
	pH	S1	89.5

LU	Soil property	Suitability class	Suitability rating
2.1	Depth of chroma of 2 or less (cm)	S2	72.5
	Water table depth (cm)	S2	67.5
	Coarse fragments in 0–25 cm (%)	S1	92.9
	Coarse fragments in 25–100 cm (%)	S1	97.3
	pH	S1	91.3
2.2	Depth of chroma of 2 or less (cm)	S2	84.3
	Water table depth (cm)	S1	96.1
	Coarse fragments in 0–25 cm (%)	S1	91.5
	Coarse fragments in 25–100 cm (%)	S1	98.4
	pH	S1	89.5
2.3	Depth of chroma of 2 or less (cm)	S2	74.3
	Water table depth (cm)	S2	76.7
	Coarse fragments in 0–25 cm (%)	S1	93.9
	Coarse fragments in 25–100 cm (%)	S1	92.5
	pH	S1	95.8
3.1	Depth of chroma of 2 or less (cm)	S1	96.5
	Water table depth (cm)	S2	80.4
	Coarse fragments in 0–25 cm (%)	S2	76.25
	Coarse fragments in 25–100 cm (%)	S2	76.45
	pH	S1	95
3.2	Depth of chroma of 2 or less (cm)	S2	72.5
	Water table depth (cm)	S1	90.3
	Coarse fragments in 0–25 cm (%)	S1	92.5
	Coarse fragments in 25–100 cm (%)	S1	97.7
	pH	S1	91.9
4.1	Depth of chroma of 2 or less (cm)	S2	69.4
	Water table depth (cm)	S2	70.1
	Coarse fragments in 0–25 cm (%)	S1	96.3
	Coarse fragments in 25–100 cm (%)	S1	98.5
	pH	S1	91.8
4.2	Depth of chroma of 2 or less (cm)	S2	79.2
	Water table depth (cm)	S1	96.9
	Coarse fragments in 0–25 cm (%)	S1	94.6
	Coarse fragments in 25–100 cm (%)	S1	97.9
	pH	S1	92.3

Total suitability classes of the studied area were obtained by combining the resultant suitability class from climate and soil analyses (Table 4). Total suitability classes given in Table 4 indicated that climatic limitations were important in recognition of land suitability subclass by maximum limitation method in all cases; so, the fact that these limitations had a high effect on qualitative suitability class, i.e. a marginally suitable class (S3), which is caused just by climatic limitations, was observed. Table 4 indicates that the range of land suitability classes according to Storie and square root parametric methods are S3-N1 and S2-S3, respectively.

Table 4. Results of qualitative land suitability evaluation for various land units

LU	Qualitative suitability class				
	Maximum limitation	Parametric (Storie)		Parametric (square root)	
		Land index	Land class	Land index	Land class
1.1	S3cw	16.12	N1cw	32.17	S3cw
2.1	S3c	23.36	N1c	39.35	S3c
2.2	S3c	37.76	S3c	50.03	S2c
2.3	S3c	27.43	S3c	42.64	S3c
3.1	S3c	24.85	N1c	40.59	S3c
3.2	S3c	31.45	S3c	45.60	S3c
4.1	S3c	24.50	N1c	40.30	S3c
4.2	S3c	37.94	S3c	50.15	S2c

### *Quantitative land suitability evaluation*

Regarding to AEZ model, the estimated rice potential yield was about 7.65 t/ha. Table 5 shows the required plant characteristics and climatic parameters for calculation of rice radiation thermal production potential. Actual yields, soil index, estimated yields (land production potential, LPP) and quantitative land suitability classes in each land unit had been demonstrated in Table 6. The estimated yield values for the study area by Storie and square root parametric methods varied between 2.13 to 5.02 t/ha and 3.13 to 5.67 t/ha, respectively. Because of soil limitations, no land unit reached the potential value and, under the best conditions, based on the questionnaires forms, the maximum actual yield was 3.62 t/ha. Marginal yields were calculated from the questionnaires completed by farmers and using the costs and incomes obtained from them. According to this, the marginal yield was 2.42 t/ha, for rice. As shown in Table 6, some land units had actual yields that were smaller than the marginal values, but this land was still cultivated. In these cases, it is supposed that farmers do not expect to

Table 5. Required plant characteristics and climatic parameters for calculation of rice potential yield

Parameters*	Data
Mean temperature of the growing cycle (°C)	23.17
Leaf area index (m <sup>2</sup> .m <sup>-2</sup> )	4.6
Harvest index	0.45
Mean <i>bo</i> of the growing cycle (kg CH <sub>2</sub> O ha <sup>-1</sup> h <sup>-1</sup> )	251.54
Mean <i>bc</i> of the growing cycle (kg CH <sub>2</sub> O ha <sup>-1</sup> h <sup>-1</sup> )	476.05
Mean <i>f</i> of the growing cycle	0.55
Ct	6.75×10 <sup>-3</sup>
Growth cycle (day)	132

\* the mean of temperature, *bo*, *bc* and *f* over the growing days (132 days) were calculated based on the latitude of the study area.

obtain any profit from these land units. A first question therefore arises: why are these land units cultivated? One reason is that farmers pay very low salaries or use family labour, which reduces the marginal yield. Irrigation water is very cheap too, which also favours a reduction in the marginal yield. However, these costs should be included in the land evaluation analysis for socio-economic land suitability (Bagheri Bodaghsbadi *et al.* 2015). Similar results were also obtained from other studies (e.g. Rahimi Lake *et al.* 2009, Zali Vargahan *et al.* 2011, Pakpour Rabati *et al.* 2012). Soil limitations and low-to-intermediate management level (Table 6) have caused majority of land units to have moderate quantitative suitability (S2) for rice cultivation.

Table 6. Results of quantitative land suitability evaluation for various land units

LU	Storie		Square root		Quantitative land suitability class	Actual yield (t/ha)	Management index (Square root)
	Soil index	Estimated yield (t/ha)	Soil index	Estimated yield (t/ha)			
1.1	27.85	2.13	40.89	3.13	S3	1.97	0.63
2.1	40.39	3.09	52.21	3.99	S2	2.17	0.54
2.2	65.28	4.99	74.18	5.67	S2	3.21	0.56
2.3	47.42	3.63	59.36	4.54	S2	3.12	0.68
3.1	42.97	3.29	57.24	4.38	S2	2.95	0.67
3.2	54.37	4.16	62.79	4.80	S2	3.12	0.65
4.1	42.36	3.24	54.22	4.15	S2	2.31	0.55
4.2	65.60	5.02	72.08	5.51	S2	3.62	0.66

Fig. 2 and 3 show the relationship between estimated yield (LPP) and average of actual yield and land index. The coefficients of determination ( $R^2$ ) for the linear regressions between actual yields and the estimated yield using soil indices based on Storie and square root parametric methods were high: 0.785 and 0.805, respectively, with  $p$ -value  $< 0.001$ . The Pearson's test was also significant at the 0.001 level, which indicated a strong relationship between the two yields. The Pearson's correlation coefficients were 0.936 and 0.961, respectively. The accuracy of the evaluation method was therefore improved by these high values of significant  $R^2$  and Pearson's correlation coefficients. There were also high correlations between the land indices according to Storie and square root parametric methods and actual yields: 0.785 and 0.810, respectively, which confirmed the last result. The correlation coefficients between the mentioned parameters in square root method were higher than Storie method. Hence, the use of the square root formula is more appropriate than Storie formula as far as land production potential calculation is concerned.

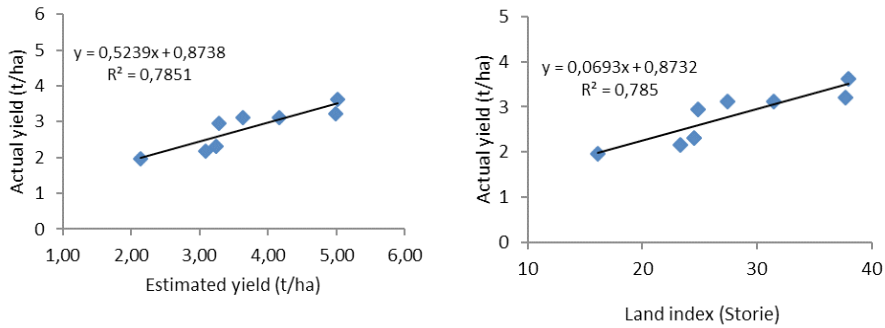


Fig. 2. Relationship between actual yield and estimated yield and land index using Storie parametric method

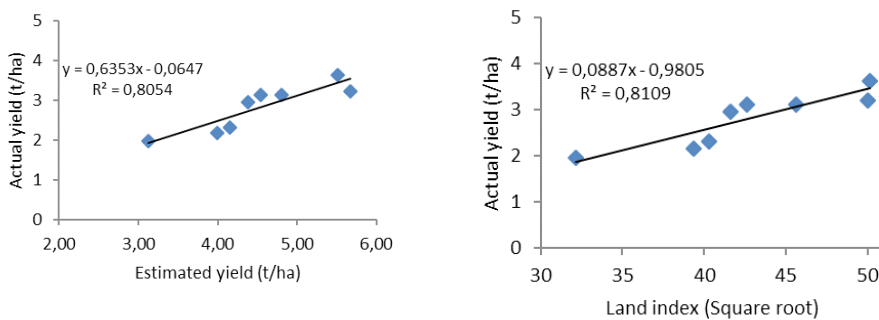


Fig. 3. Relationship between actual yield and estimated yield and land index using square root parametric method

These regression equations will describe the boundaries between various land classes using land index. Hence, with measurement of land index in other lands units or similar areas, estimating of yield level by using these equations was possible. Also, accomplishment of economical calculations with this estimated yield can lead to the finding most profitable lands for each crop.

#### *Comparison of land evaluation methods*

According to the comparison of different methods of qualitative land suitability, evaluation can be concluded that the parametric methods, especially the square root methods, will lead to more reasonable results, because the land index calculated by square root was highly correlated with actual yield (Fig. 2 and 3). Similar results were expressed by Givi and Haghghi (2015). They reported that the good accordance between estimated yield and actual yield in square root parametric method approve that this method is more accurate and efficient than Storie method.

Our result is in line with the research done by Khormali *et al.* (2007) and Rahimi Lake *et al.* (2009). They indicated that using of parametric method instead of maximum limitation method will provide realistic results. Similarly, Mandal *et al.* (2005) reported that land index calculated by square root parametric method was highly correlated with actual cotton yield in Nagpur district in India. Jafarzadeh and Abbasi (2006), Behzad *et al.* (2009) as well as Ashraf and Normohamadan (2011) emphasized square root parametric method and suggested that the use of square root is more appropriate for the qualitative land suitability evaluation than others. It is worth noting that for the land units that have the less soil indices (1.1, 2.1, 3.1 and 4.1) the actual yields were at least (Table 6). Thus, it can be stated that climate is not an important limiting factor for rice production in the study area. This is logical because based on farmers' experiences, crops that are cultivated in a given region are adopted according to its climate conditions.

Comparisons of qualitative and quantitative land suitability evaluations produced different results. Quantitative evaluations produced more suitable results than qualitative ones. It emphasizes that climatic characteristics of the study area is not an important limiting factor for productivity of land in the study area which declines the quantitative land suitability class. The similar results were reported by Zali Vargahan *et al.* (2011). They showed that better land suitability classifications resulted from using a quantitative method based on economic information than qualitative methods. In contrast, Rahimi Lake *et al.* (2009) concluded that quantitative evaluations produced less suitable results than qualitative ones. The reason for this could be the use of a socio-economic quantitative approach to determine land suitability. This made the results very variable because the land suitability classes were greatly influenced by cost and income, being land suitability also dependent on the market.

## CONCLUSIONS

1. Use of square root parametric method is the most perfect and spread method in qualitative evaluation and using the results of this method in quantitative evaluation is more reasonable.
2. Moderate limitation of drainage condition in the soils is the origin of a difference between the estimated radiation thermal production potential and the land production potential.
3. The estimated yields were more than the actual yields in each land unit that can be caused by low-to-intermediate management level and land physical limitations which are effective on the rice production.
4. Comparison of qualitative and quantitative suitability classes demonstrates that quantitative suitability classes are significantly increased due to crop adaptation with climate agents.

5. An important problem for succeeding of land suitability evaluation in Iran is the incoherence of plant requirements tables with climate, soil and landscape conditions of Iran.
6. The considerable variability of soil characteristics over short distances will undoubtedly also lead to important local differences in productivity which should be considered in land suitability evaluation.

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