Assessment of the FAO traditional land evaluation methods, A case study: Iranian Land Classification method

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Abstract

Land evaluation is a critical step in land-use planning. Although many methods have been developed since the formulation of the FAO framework for land evaluation, several of the more traditional approaches still remain in widespread use but have not been adequately evaluated. Contrary to more recent land evaluation systems, which need considerable data, these systems only require basic soil and landscape information to provide a general view of land suitability for major types of land use. As the FAO initially presented its qualitative framework for land-use planning, based on two previous methods developed in Iran and Brazil, in this study we assessed the reliability and accuracy of a traditional land evaluation method used in Iran, called land classification for irrigation (LCI), comparing its results with several qualitative and quantitative methods and actual yield values. The results showed that, although simpler than more recently developed methods, LCI provided reliable land suitability classes and also showed good relationships both with other methods analysed and with actual yields. Comparisons between qualitative and quantitative methods produced similar results for common crops (a barley–alfalfa–wheat–fallow rotation). However, these methods performed differently for opportunist crops (such as alfalfa) that are more dependent on income and market conditions than on land characteristics. In this work, we also suggest that using the FAO method to indicate LCI subclasses could help users or managers to recognize limitations for land-use planning.

Keywords: land evaluation, land suitability, land classification for irrigation, FAO framework

Introduction

Land evaluation based on the guidelines of the UN Food and Agriculture Organization (FAO) is a critical step in land-use planning (FAO, 1993). FAO (1976) presented a qualitative framework for land-use planning based on two methods developed in Iran and Brazil. In the three subsequent decades, other methods have also been developed, including the Sys method (Sys et al., 1991a,b), ALES (Rossiter & Van Wambekke, 1994), MicroLEIS (De La Rosa et al., 2004), Land Evaluation and Site Assessment (LESA; http://soils.usda.gov; Hoobler et al., 2003) and Agricultural Land Classification (ALC; http://www.defra.gov.uk; MAFF, 1988). Although quantitative methods for land evaluation have also been developed (e.g. Janssen et al., 1990; Van Lanen et al., 1992; Noguès et al., 2000; De La Rosa & Van Diepen, 2002; Zhang et al., 2004), qualitative methods are still widely used (Recatalá & Zinck, 2008; Fontes et al., 2009).

There are many studies in which qualitative land evaluation methods have been compared with quantitative ones or with actual yields. Hennebed et al. (1996) evaluated the FAO framework by comparing observed and predicted yields for five food crops in Burundi. They reported that the FAO framework was able to successfully predict the yield ranges of various crops based on climate, soil data and land-use technology. They also suggested that, as the FAO method correctly predicts mean regional farm yields, it could also be useful for land-use planning. Martínez-Casasnovas et al. (2008) compared land suitability and actual crop distribution in an irrigation district in Spain’s Ebro valley. Their results showed the existence of a significant relationship between
crop location and land suitability over time. In other cases, results were not very satisfactory. Rahimi Lake et al. (2009) compared quantitative and qualitative land suitability methods for olive trees, but the different methods did not produce similar estimations. 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 (Rahimi Lake et al., 2009). In contrast, Zali Vargahan et al. (2011) reported that better land suitability classifications resulted from using a quantitative method based on economic information than qualitative methods. Safari et al. (2013) compared a conventional method with a geostatistical approach to assess qualitative land suitability evaluation for main irrigated crops. The results showed that the overall accuracy was poor at the subclass level but improved at the class level.

The accuracy of land suitability evaluations has also been determined by comparing the predictions with values for present crops or observed yields (D’Angelo et al., 2000; Ceballos-Silva & Lopez-Blanco, 2003; Chen et al., 2003; D’Haeze et al., 2005; Mandal et al., 2005; Saroinsong et al., 2007).

Thus, different land evaluation approaches are clearly possible, with each having advantages and disadvantages from the viewpoint of methodology, input data requirements and outputs. A primary question therefore arises concerning which land evaluation method is the best when we consider economic costs, the complexity of the procedure and the benefits of working with that specific method. However, Manna et al. (2009) concluded that there is very little scientific literature to help to make this choice. These authors compared several different methods that were reported in the period after the FAO framework until the appearance of simulation models (from 1976 to 2005) and concluded that more complex methods had better predictive ability than more simplified approaches.

In addition to land evaluations based on the FAO framework, numerous countries still use more traditional evaluation systems. These include the local land evaluation systems established in USA, UK, Canada, Brazil, Netherlands and Iran. In 1974, the FAO (1974) published ‘Approaches to land classification’ in which these systems were described. Despite several limitations, these local methods play a major role in land evaluation because they are straightforward and use simple models. Contrary to more recent land evaluation systems, the traditional ones tend to be based on qualitative models that only require basic soil and landscape data. Furthermore, they provide a general view of the suitability of land for major types of land use, such as rainfed farming or irrigation. One example of these traditional evaluation systems is that used in Iran, where soil survey started in 1951. A land evaluation system called land classification for irrigation (LCI) was devised in 1970. It was based on existing survey reports and was compiled by a FAO expert (P.J. Mahler) and experienced staff. This system is still widely used in Iran for soil surveys and related projects.

Although this system has been applied for more than 40 years, no study has been conducted to evaluate its reliability or accuracy. None the less, it attracted the attention of the FAO during the formulation of the framework to land evaluation (FAO, 1976). Furthermore, an evaluation of such a qualitative method against parameters, such as actual crop yield, has not been carried out yet. The main objective of this study was to assess the performance of the land classification for irrigation (LCI) method and to compare it with the most recently developed qualitative and quantitative methods, as well as with actual crop yields, to determine its reliability.

Materials and methods

Study area

The study area (about 22 000 ha) was located in the Shahreza region (Isfahan province, Central Iran) (Figure 1), between 32° 0’ and 31° 15’ N and 51° 30’ and 51° 55’ E.

This area has three major physiographic units: plateaux, alluvial fans and a piedmont plain. The mean annual precipitation and the mean temperature in this region are 106.6 mm and 14 °C, respectively. The mean altitude is 1800 m.a.s.l. Irrigated wheat, barley and alfalfa are the main land uses in this area. According to Soil Taxonomy (Soil Survey Staff, 2010), the soil moisture and temperature regimes of the area are arid and mesic. The dominant soils, Aridisols and Entisols, were described by the Agriculture and Natural Resource Research Center of Isfahan at the 1:50 000 scale (Tables 1 and 2). The Entisols were located on the piedmont and alluvial plain, whereas the Aridisols were located on the plateaux.

Input data for land evaluation

Soil and climatic data. Basic soil physical and chemical properties (Table 1) and confirmation of the existing soil map were obtained by digging 30 soil profiles across the area, determined by a previous physiographic analysis. The locations were georeferenced with an Etrex Vista Garmin GPS. These soil profiles were consistent with the soils series reported on the soil map. Some soil series had several phases, for example soil series 2 (Janatabad) had three phases, 2.1, 2.2 and 2.3. Differences between phases relate to slope, gravel content, erosion and soil depth.

A 10-year time series of climate data obtained from the Kabootar-abad Isfahan synoptic meteorological station was
analysed for the requirements of the different land-use types considered.

**Socio-economic data.** There were five villages (Manochehrabad, Jafarabad, Garmafshar, Esfeh and Jalalabad) and a city (Shahreza) in the study area. Agricultural systems and technologies used by farmers were essentially the same. Data for socio-economic land evaluation were obtained from 100 responses to questionnaires from a random selection of farmers (representing ~15% of farmers in the study area). Each questionnaire included questions about the costs and income associated with each crop, together with any other relevant information. Costs included seeds, fertilizers and pesticides, labour, tillage operations and irrigation; economic benefits were determined from the average yield of each crop (based on harvest data). For each crop, the averages of values taken reported were used as input information for the socio-economic land evaluation.

**Land-use types.** The three major land utilization types (LUT) in the study area were 1 – winter wheat (LUT-I), 2 – winter barley (LUT-II) and 3 – alfalfa (LUT-III). All crops were
irrigated by surface (gravity) irrigation. These LUTs were considered for each soil unit. Two typical crop rotations in the study area were barley–alfalfa–wheat–fallow and barley–fallow–wheat–fallow (in saline areas).

**Land evaluation methods**

The four land evaluation methods most frequently used in Iran were considered. These included land classification for irrigation (LCI) and three methods for qualitative and quantitative assessments of land suitability (called Sys method, in Iran).

**Land classification for irrigation.** This is the traditional land evaluation approach developed by Mahler (1970). It was one of the two that the FAO used to develop its framework for land evaluation (FAO, 1976). LCI is still the system that is mainly used for land evaluation for irrigation projects in Iran. Using the LCI method, land is divided into six different categories for gravity or surface irrigation. The classification is based on increasing limitations of four major factors: soil, salinity–alkalinity, topography and erosion, and drainage (Table 3). Each major limiting factor is subsequently associated with a series of related subfactors, giving a total of 18 factors to be considered:

- **Soil (S):** 1: subsoil permeability, 2: subsoil stoniness, 3: topsoil texture, 4: topsoil stoniness, 5: soil depth, 6: limiting layer and 7: infiltration rate.
- **Salinity and alkalinity (A):** 8: salinity and 9: alkalinity.
- **Topography and erosion (T):** 10: overall slope angle, 11: transversal slope angle, 12: microrelief, 13: current (water and wind) erosion status and 14: present (water and wind) deposition status.

### Table 1 Summary of physical and chemical properties for representative pedons of dominant soil series in the study area

| Soil series (abbreviations) | Soil series No. | Horizon | Depth (cm) | Sand | Silt | Clay | Gravel (2–75 mm) | CCEa | O.M. | Texture | pH | EC (per dSm) |
|-----------------------------|----------------|---------|------------|------|------|------|-----------------|------|------|---------|----|------------|
| **Talkhuncheh (Tal)**       | 1              | A       | 0–25       | 56   | 22   | 22   | 22              | 42   | 0.14 | SCL     | 7.9| 3.8        |
|                             |                | By1     | 25–65      | 78   | 2    | 20   | 20              | 49   | 0.03 | SCL     | 7.9| 3.6        |
|                             |                | By2     | 65–130     | 60   | 19   | 21   | 21              | 34   | 0.03 | SCL     | 8.0| 3.4        |
| **Janatabad (Jan)**         | 2              | Ap      | 0–15       | 73   | 14   | 13   | 20              | 64   | 0.13 | SL      | 8.1| 0.4        |
|                             |                | Bk1     | 15–55      | 71   | 14   | 15   | 25              | 64   | 0.10 | SL      | 8.0| 0.3        |
|                             |                | Bk2     | 55–80      | 69   | 12   | 39   | 30              | 63.5 | 0.10 | SL      | 8.1| 0.4        |
|                             |                | Bk3     | 80–120     | 49   | 12   | 39   | 30              | 50   | 0.10 | SL      | 8.1| 0.4        |
| **Ghombovan (Gho)**         | 3              | Ap      | 0–20       | 17   | 46   | 37   | 20              | 45   | 0.53 | SiCL    | 7.4| 17.3       |
|                             |                | Bk1     | 20–45      | 15   | 34   | 51   | 30              | 35   | 0.19 | C       | 7.5| 15.0       |
|                             |                | Bk2     | 45–75      | 17   | 48   | 35   | 30              | 60   | 0.16 | CL      | 7.3| 27.0       |
|                             |                | By1     | 75–100     | 21   | 42   | 3   | 40              | 65.5 | 0.13 | CL      | 7.4| 32.0       |
|                             |                | By2     | 100–150    | 23   | 68   | 9    | 10              | 67   | 0.13 | SiL     | 7.8| 42.0       |
| **Najafabad (Naj)**         | 4              | Ap      | 0–10       | 38   | 40   | 22   | 5               | 45   | 0.16 | L       | 7.7| 1.7        |
|                             |                | C1      | 10–50      | 50   | 24   | 26   | 20              | 44   | 0.16 | L       | 8.0| 0.4        |
|                             |                | C2      | 50–140     | 86   | 6    | 8    | 75              | 74   | 0.32 | LS      | 8.0| 0.4        |
| **Parzan (Par)**            | 5              | Ap1     | 0–5        | 48   | 30   | 22   | 5               | 34   | 0.19 | L       | 7.8| 2.2        |
|                             |                | Ap2     | 5–20       | 42   | 32   | 26   | 40              | 38   | 0.15 | CL      | 8.0| 2.0        |
|                             |                | C1      | 20–50      | 52   | 15   | 33   | 50              | 42   | 0.13 | SCL     | 7.7| 2.2        |
|                             |                | C2      | 50–120     | 53   | 15   | 32   | 51              | 43   | 0.10 | SCL     | 7.7| 2.2        |
| **Shahreza (Sha)**          | 6              | Ap      | 0–30       | 12   | 42   | 46   | 20              | 37   | 0.40 | SiC     | 7.8| 3.2        |
|                             |                | Bk1     | 30–60      | 13   | 37   | 50   | 15              | 39.5 | 0.12 | C       | 7.8| 6.6        |
|                             |                | Bk2     | 60–140     | 12   | 46   | 42   | 15              | 47   | 0.10 | SiC     | 8.1| 2.3        |
| **Manocherabad (Man)**      | 7              | Ap      | 0–15       | 57   | 36   | 7    | 20              | 41.5 | 0.51 | SL      | 7.6| 6.3        |
|                             |                | C1      | 15–60      | 31   | 34   | 35   | 45              | 40   | 0.01 | CL      | 7.8| 6.0        |
|                             |                | C2      | 60–90      | 43   | 30   | 27   | 40              | 41   | 0.05 | L       | 7.8| 5.6        |
|                             |                | C3      | 90–110     | 55   | 24   | 21   | 50              | 42   | 0.00 | SCL     | 7.8| 4.1        |
| **Jalalabad (Jal)**         | 8              | Ap      | 0–30       | 40   | 34   | 26   | 5               | 49   | 0.22 | L       | 7.8| 4.8        |
|                             |                | Bk1     | 30–65      | 44   | 30   | 26   | 0               | 36   | 0.10 | L       | 7.8| 8.0        |
|                             |                | Bk2     | 65–95      | 28   | 44   | 28   | 10              | 37   | 0.10 | CL      | 7.6| 5.6        |
|                             |                | Bk3     | 95–100     | 40   | 46   | 14   | 15              | 48.5 | 0.10 | L       | 7.7| 4.6        |

aCalcium carbonate equivalent.
Drainage (W): 15: groundwater depth, 16: other drainage limitations such as hydromorphic features, 17: ponding hazard and 18: flooding hazard.

Each limitation, when present, is rated separately, and it is given a rating symbol. Some basic land characteristics, which may or may not be limiting, are also rated in all cases, including the factors 1, 3 and 10 above. These symbols are placed in a rating formula according to a standard sequence, called limitation formula. S and A are in the numerator and T and W in the denominator (Figure 2).

Table 3 shows the classes and subclasses in the LCI, which were determined based on maximum limitation factors.

Table 2 Classification of representative pedons of dominant soil series in the study area based on Soil Taxonomy (Soil Survey Staff, 2010)

| Soil series symbol | Soil Taxonomy                      | Land units |
|--------------------|-----------------------------------|------------|
| Tal                | Loamy – skeletal, gypsic, thermic | Typic Haplogypsids 1.1 |
| Jan                | Loamy – skeletal, carbonatic, thermic | Typic Haplocalcids 2.1, 2.2, 2.3 |
| Gho                | Clayey – skeletal, gypsic, thermic | Typic Calcigypsids 3.1 |
| Naj                | Sandy – skeletal, carbonatic, thermic | Typic Torriorthents 4.1 |
| Par                | Loamy – skeletal, carbonatic, thermic | Typic Torriorthents 5.1 |
| Sha                | Fine, carbonatic, thermic         | Typic Haplocalcids 6.1 |
| Man                | Fine – loamy, carbonatic, thermic | Typic Torrifluvents 7.1, 7.2, 7.3, 7.4 |
| Jal                | Fine – loamy, mixed, thermic      | Typic Haplocalcids 8.1 |

Figure 2 Limitation formula: S (soil), A (salinity-alkalinity), T (topography) and W (drainage) factors refer to the main limitations and numbers are symbols for the related limitation factors.

Table 4 shows the limitation formula for each land unit, and Table 5 explains the main soil-limiting factors. The details of this process are explained in Mahler (1970), Sys et al. (1991b), Roozitalab (1995) and Bagheri Bodaghabadi (2011).

In this method, subclasses are determined by the four major limiting factors: soil (S), salinity–alkalinity (A), topography (T) and drainage (W). These symbols are added after the appropriate land class. For example, if a unit which has a land classification of II but is limited by topography or erosion, it is classified as IIT. For further clarification, the results of the LCI have been presented with the corresponding FAO subclass nomenclature. For example, in an IIT unit, the limiting factors can be slope, microrelief, water erosion, wind erosion or deposition, or some combination of these factors. In LCI, the symbol T can refer to any of these limitations, but in the FAO framework, each limiting factor can only be shown by a single symbol. For instance, S2e indicates that the major limiting factor is erosion. Classes I, II, III, V and VI are shown as S1, S2, S3, N1 and N2, respectively. Class IV, which is based on the expert knowledge, is shown as S3 or N1 (Table 3). In contrast, if the limiting factor has a direct influence on the crop (e.g. soil depth or salinity), class IV is shown as N1, unless S3 is preferred. Although there is not a generally accepted standard framework, these land classification criteria are widely used by researchers in Iran (Bagheri Bodaghabadi, 2011).

Qualitative and quantitative methods. Three 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. 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 (Givee, 1997).

In the maximum limitation approach, plant requirements are compared with the corresponding qualitative land and climatic characteristics; the maximum limiting properties define land suitability class and subclasses.
Table 4  Results of land evaluation methods

| Traditional land evaluation (LCI) | Wheat | | Barley | | Alfalfa |
|---|---|---|---|---|---|---|
| LU | LF | C(T) | FAO | ILS | SL | I | C(I) | Y* | Y | C(qn) | SL | I | C(I) | Y* | Y | C(qn) | SL | I | C(I) | Y* | Y | C(qn) |
| 1.1 | 3GH| g | 2P | IIS | S3s | 27.97 | S3s | 31.35 | S3s | 3.05 | 3.00 | S3 | S3s | 33.00 | S3s | 3.05 | 3.00 | S3 | S3s | 28.45 | S3s | 7.19 | 8.50 | S3 |
| 2.1 | 3GH| g | 2P | IIS | S3s | 37.18 | S3s | 40.90 | S3s | 3.98 | 3.80 | S3 | S3s | 43.07 | S3s | 3.99 | 3.50 | S2 | S3s | 37.95 | S3s | 9.64 | 9.50 | S2 |
| 2.2 | 4GK| 4P | IIS | S3s | 14.90 | N1s | 14.23 | N1s | 1.38 | 2.50 | N | N1s | 15.02 | N1s | 1.39 | 2.50 | N | N2s | 15.59 | N1s | 3.96 | 5.00 | N |
| 2.3 | 2GL| 4P | IIS | N1s | 13.28 | N1s | 12.82 | N1s | 1.21 | 2.00 | N | N1s | 16.76 | N1s | 1.55 | 3.00 | N | N2s | 13.59 | N1s | 3.43 | 5.00 | N |
| 3.1 | 3gM| 2P | IIS | S3s | 13.71 | N1n | 17.78 | N1n | 1.73 | 2.00 | N | N1n | 22.76 | Nn | 2.11 | 2.50 | N | N2n | 13.18 | N1n | 3.35 | 5.00 | N |
| 4.1 | 3gM| 3Z | IIS | S3s | 47.72 | S2cs | 48.71 | S3s | 4.74 | 4.20 | S2 | S2s | 50.44 | S3s | 4.67 | 4.50 | S2 | S2cs | 49.45 | S3s | 12.56 | 12.50 | S2 |
| 5.1 | 3GH| g | IIS | S3s | 36.97 | S3s | 34.62 | S3s | 3.37 | 3.00 | S3 | S3s | 36.73 | S3s | 3.54 | 3.50 | S3 | S3s | 38.78 | S3s | 9.85 | 9.50 | S2 |
| 6.1 | 4V| g | IIS | S2s | 50.03 | S2cs | 59.91 | S2s | 5.85 | 4.50 | S2 | S2s | 64.31 | S2s | 5.95 | 5.00 | S2 | S2cs | 50.10 | S3s | 12.73 | 12.50 | S2 |
| 7.1 | 3GM| F2 | IISA | S3sn | 27.66 | S3s | 29.40 | S3s | 2.86 | 3.00 | S3 | S3s | 33.01 | S3s | 3.05 | 3.00 | S3 | S3s | 28.24 | S3s | 7.18 | 9.00 | S3 |
| 7.2 | 3GMS| 1 | IISA | S3s | 34.44 | S3s | 37.77 | S3s | 3.66 | 3.50 | S3 | S3s | 41.07 | S3s | 3.80 | 3.50 | S3 | S3s | 35.06 | S3s | 8.91 | 8.00 | S2 |
| 7.3 | 3GM| 1Z | IISA | S3s | 35.96 | S3s | 37.77 | S3s | 3.82 | 4.00 | S3 | S3s | 41.31 | S3s | 3.82 | 4.00 | S3 | S3s | 36.88 | S3s | 9.37 | 9.00 | S2 |
| 7.4 | 4GV| 1Z | VIA | N2n | 9.93 | N2n | 10.81 | N2n | 1.05 | 1.50 | N | N1n | 10.91 | N2n | 1.01 | 1.80 | N | N2n | 10.20 | N2n | – | – | N |
| 8.1 | 3M| g | S1 | IISA | S2sn | 48.37 | S2cs | 46.61 | S3s | 4.54 | 4.50 | S2 | S2s | 53.93 | S3s | 4.99 | 4.80 | S2 | S2cs | 50.11 | S3s | 12.73 | 12.50 | S2 |

LU, land unit; LF, limitation formula (bold letters show main limiting factors), C(T), land classes in LCI; FAO, land classes in LCI based on FAO method; ILS, index of land suitability; SL, simple limitation method, I, land index (SR); C(I), land classes in qualitative method; Y*, estimated yield (Ton/ha); Y, actual yield (based on the aggregated values from farmer-questionnaires; Ton/ha) and C(qn), land classes in quantitative method.
Table 5: Description of the main soil-limiting factors in the limitation formula

| Symbol | Maximum class | Limitation | Description |
|--------|---------------|------------|-------------|
| S4     | VI            | Soil salinity | EC (dS/m) > 32 |
| S3     | IV            | Soil salinity | 32 > EC (dS/m) > 16 |
| 4P     | IV            | Soil depth | < 25 cm by a lime layer |
| G      | III           | Topsoil stoniness | 35–75% of coarse gravel |
| 3Z     | III           | Soil depth | 25–50 cm by a gravelly layer |
| F      | III           | Subsoil stoniness | 35–75% of fine gravel |
| S2     | III           | Soil salinity | 16% EC (dS/m) > 8 |
| S1     | II            | Soil salinity | 8% EC (dS/m) > 4 |
| (g)    | II            | Subsoil stoniness | 3–15% of coarse gravel |
| 4V     | II            | Subsoil permeability and soil texture | 0.1–2 cm/h and very heavy texture |

In the parametric method, limitation levels are rated on a numerical scale ranging between a maximum value of 1 (or 100%) and a minimum value of 0. A land index (I) 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 SR to calculate the land index (I); the relevant equation is as follows:

\[ I = R_{min} \times \sqrt{\frac{A}{100} \times \frac{B}{100} \times \ldots} \]

where, I is the specified land index, A, B, etc., are different ratings for each soil property, and \( R_{min} \) is the minimum rank or value. The suitability classes and limiting factors (subclasses) are then determined as shown in Table 6; see Sys et al. (1991a,b) and Bagheri Bodaghabadi (2011) for further details.

Marginal, observed and predicted yields are required to determine quantitative land suitability. In this study, the agro–ecological zoning (AEZ) model was used to calculate potential yield (Kassam, 1977). The equation is as follows:

\[ Y = \frac{0.36 \text{ bgm} \times KLAI \times Hi}{\left(\frac{L}{2}\right) \times 0.25 \text{ Ct}} \]

where, \( Y \), potential yield (kg/ha); bgm, maximum gross biomass production rate (kg CH₂O/ha/year); KLAI, leaf area index at maximum growth rate; Hi, harvest index; L, growth cycle (day) and Ct, respiration coefficient (see Appendix for more information).

Potential yield can be determined from 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). For example, the total cost and total income for wheat were about 374.68 ($ per ha) and 0.14 ($ per kg), respectively. The marginal yield therefore can be calculated as:

\[ \text{Marginal yield} = \frac{374.68}{0.14} = 2676.28 \text{ kg/ha}. \]

The data required and the actual, or observed, yield for each land unit were obtained from the questionnaires completed by farmers and also from the local Agricultural Extension Service.

Land classes were then calculated as follows:

- 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).

Predicted yield can be obtained from potential yield multiplied by the soil index (SI). It is worth noting that SI is as in I (land index) but without the climate index (CI); on the other hand: \( I = SI \times CI \). For example, in the study area, \( CI_{wheat} = 0.82 \) and for unit 1.1, \( SI_{wheat} = 0.38 \), then \( I_{1.1} = 0.82 \times 0.38 = 0.31 \). Additional regression and correlation statistical analyses were applied, using observed yield and predicted yield to determine the accuracy and statistical significance of the selected land evaluation method.
Comparison of land evaluation methods

Index of land suitability. To compare the quantitative and qualitative land suitability methods with the LCI method, it was necessary to obtain average land suitability values for the main crops grown in the study area. The numerical values of the land indexes (I) were assigned to all the crop rotation combinations. Then, an index of land suitability (ILS) as defined by Bagheri Bodaghabadi (2011) was used to compute the average of the different I ranges. The ILS formula is as follows:

$$\text{ILS} = \sum_{i=1}^{n} \frac{I_i \cdot \text{PC}_i}{\text{C}_{\text{tot}}}$$

where, $I_i$ = land index for the $i$th crop, $\text{PC}_i$ = planting cycle of the $i$th crop and $\text{C}_{\text{tot}}$ = total time or duration of the crop rotation. For example, the usual crop rotation in the study area is ‘barley, alfalfa, wheat and fallow’, in which the $\text{PC}$ is as follows: 0.6, 7.0 and 0.6 years, respectively, for crops with an additional 0.3 years for fallow; the total $\text{C}_{\text{tot}}$ is therefore 8.5 years. For example, ILS in unit 1.1 can be calculated as following:

$$\text{ILS}_{1.1} = \frac{(31.35 \times 0.6 + 28.45 \times 7.0 + 33.00 \times 0.6)}{8.5} = 27.97.$$  

Accuracy analysis. The performance of the land evaluation methods was quantitatively assessed by map overlaying and computing of error matrices. The error matrix permits the calculation of a range of measures that describe the accuracy of one method with respect to the other. The overall accuracy (OA) (Congalton & Mead, 1983; Bagheri Bodaghabadi et al., 2015) is the percentage of correctly classified or predicted areas with respect to the total number sampled.

$$\text{OA} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} X_{ij} - \sum_{i=1}^{n} \sum_{j=1}^{n} X_{ij} \cdot n_{\text{tot}}}{\sum_{i=1}^{n} \sum_{j=1}^{n} X_{ij} \cdot n_{\text{tot}}}$$

where, $X_{ii}$ = diagonal elements in the error matrix, or similar land evaluation classes, $X_{ij}$ = the surface area in the $i$th row and the $j$th column, $i$ = rows which show the first method (from 1 to $n$), $j$ = columns which show the second method (from 1 to $n$), $n$ = the number of classes and $n_{\text{tot}}$ = the total surface area in the error matrix.

Results and discussion

Table 4 shows the results for the different methods employed for land evaluation. The most frequent land suitability classes used in the study area are the marginal (S3) and nonsuitable (N1). Although some land units are moderately suitable (S2), they may have land indexes that border on being marginally suitable (Table 4). The climatic evaluation showed that the area had moderate suitability (S2) for all of the major crops selected for the study. The main limitation was imposed by the mean temperature of the growing cycle (data not shown). Table 5 shows the main soil-limiting factors. These include soil salinity, soil depth and topsoil stoniness.

Potential yield was estimated for the major crops. These values were as follows: 8.9, 9.0 and 22.1 ton/ha for wheat, barley and alfalfa, respectively. Because of soil limitations, no land unit reached these potential values and, under the best conditions, based on the questionnaires forms, the maximum actual yields were follows: 4.5, 5.0 and 12.5 ton/ha for the previously mentioned crops. Marginal yields were calculated from the questionnaires completed by farmers and using the costs and incomes obtained from them. According to this, the marginal yields were as follows: 2.7, 2.7 and 6.0 ton/ha, respectively, for the studied crops. As shown in Table 4, 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 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. Similar results were also obtained from other studies, but none of them explained why land was dedicated to agricultural use when the actual yield was less than the marginal one (e.g. Rahimi Lake et al., 2009; Zali Vargahan et al., 2011; Pakpour Rabati et al., 2012).

Figure 3 shows the relationship between estimated yield and average of actual yield. The coefficients of determination ($R^2$) for the linear regressions between the estimated and actual yields for each crop were high: 0.914, 0.895 and 0.950 for wheat, barley and alfalfa, 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, respectively, 0.956, 0.946 and 0.975. 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 indexes and actual yields (Pearson’s correlations = 0.97), which confirmed the last result. It is worth noting that for the land units that were not suitable (N1 and N2), that is land units 2.2, 2.3, 3.1 and 7.4, the actual yields were higher than the potential ones. On these nonsuitable land units, farmers have learned how to manage land resources well and accept when they cannot obtain any return. Under better

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conditions, as in the case of land units belonging to classes S2 and S3, actual yield is usually less than predicted.

A comparison of the land evaluation classes is presented in Table 7. With the exception of the socio-economic land evaluation of alfalfa, all the land evaluation methods had high OAs. As there was a good price for alfalfa in the study area at the time, the quantitative method calculated better land evaluation classes than for other crops. Similar results have also been reported by other authors, who stated that socio-economic land evaluation is highly dependent on the market (e.g. Rahimi Lake et al., 2009; Zali Vargahan et al., 2011; Pakpour Rabati et al., 2012). In fact, the price of alfalfa varies a little, depending on the location and the distance between farms and the market. Furthermore, alfalfa has a local price, while wheat and barley have prices regulated by the government, which means that they are less dependent on the market than alfalfa. Consequently, quantitative and qualitative land evaluations produced approximately similar results (Table 4) and high OAs (Table 7).

In contrast to the more recently developed land evaluation methods, which evaluate land units for each crop separately, the land evaluation (LCI) method presents a general view of the land suitability for major crops. To compare LCI with reality, it is therefore necessary to know the average potential of the land. In this case, the ILS was calculated on the basis of the main crop rotations in each land unit (Table 4). Figure 4 shows the relationship between the ILS and LCI classes. As the correlation between actual yield and the ILS for each crop was significantly high (Pearson’s correlations equal to 0.96, 0.94 and 0.97 for wheat, barley and alfalfa), the ILS could be considered to be an index that indicates the actual land suitability of the land units. On the other hand, the relationship between the ILS and LCI classes is indicative of the relationship between the real value of land destined for agricultural uses and the LCI classes. There was a high $R^2$ between the ILS and LCI classes

Figure 3 Relationship between estimated (Sys method) and actual (observed) yield.

| Methods | Wheat | Barley | Alfalfa |
|---------|-------|--------|---------|
| SL & C(I) | 77.12 | 76.22 | 48.24 |
| C(I) & C(qn) | 77.12 | 73.34 | 56.5 |
| SL & C(qn) | 100 | 97.12 | 82.76 |

SL, simple limitation method; C(I), land classes in qualitative method; C(qn), land classes in quantitative method and LCI, land classification for irrigation (Iranian method).

Table 7 Overall accuracy (OA) comparing qualitative and quantitative methods

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Table 8 Overall accuracy (OA) comparing the LCI and other methods.

| Methods       | Wheat | Barley | Alfalfa |
|---------------|-------|--------|---------|
| LCI & SL      | 89.41 | 88.45  | 63.92   |
| LCI & C(I)    | 87.77 | 87.77  | 84.33   |
| LCI & C(qn)   | 89.41 | 86.53  | 72.17   |

SL = simple limitation method; C(I) = land classes in qualitative method; and C(qn)= land classes in quantitative method.

(Figure 4), which proves that the LCI estimations had a high correlation with reality. Manna et al. (2009) also showed that different methods had different correlations between biomass and suitability classes. According to the regression equation between the ILS and LCI classes, the average value for ILS classes S2, S3, N1 and N2 were as follows: 49.7, 34.2, 18.7 and 3.3, respectively. In contrast, class S2 was very similar to class S3 in the study area. One reason for this could be alfalfa, which is an opportunist crop. However, it seems that profit maximization is one of the main factors determining crop choice. Although the qualitative land suitability for alfalfa was almost marginally suitable (S3), the quantitative land suitability was S2 (Table 4). Farmers therefore prefer to cultivate this crop because it provides higher incomes. A similar result was reported by Martinez-Casasnovas et al. (2008) for opportunist crops, such as sunflower in Spain, which was very much influenced by European Union subsidies during the study period.

The LCI system was also compared with more recently developed ones (Table 4). Although it can be seen that this method can be used for land evaluation, there were some problems with class IV. As previously mentioned, LCI class IV is shown as S3 or N1, based on the FAO method (Bagheri Bodaghabadi, 2011). For example, the main limiting factor for land units 2.2 and 2.3 is soil depth and salinity for land unit 3.1. As these limiting factors have direct influences on crops, class IV is shown as N1. The results of this transformation are also presented in Table 4. The transformed LCI classes showed a highly significant relationship with others that were calculated using more recent land evaluation methods. Table 8 shows the OA between the LCI and the other methods. Except for alfalfa with the simple limitation (SL) and quantitative (C(qn)) methods, the OA was high for the different land utilization types considered. Even so, it can be seen that the LCI system had a significant relationship with more recent methods and also with reality.

As the main limiting factors in the study area refer to soil physical properties and salinity, a complete comparison between subclasses could not be carried out. As Table 4 shows, the subclasses were almost similar for all of the different land evaluation methods; even so, it should be remembered that the LCI system cannot show climatic limitations because it was developed for soil and land but not for climate. However, numerous studies have shown that climate is not an important limiting factor, nor one of the main ones. This is logical because based on farmers’ experiences, crops that are cultivated in a given region are adopted according to its climate conditions. Furthermore, it seems that using only four symbols for the major types of limiting factors, one cannot explain the type of each specific limitation very well; this therefore needs some revision. For example, in land unit 6.1, classified as IIS, the limiting soil factor, S, refers to a complex limitation of permeability, soil texture and topsoil stoniness, but in land unit 8.1, classified as IISA, the S only refers to topsoil stoniness. However, based on the FAO approach, each limiting factor is identified with a single symbol (FAO, 1976; Bagheri Bodaghabadi, 2011).

Conclusions

The present study compared the efficiency and reliability of a traditional land evaluation method: the land classification for irrigation (LCI) system, with other more recently developed methods. Actual yields were used as an independent data set for evaluating the methods.

Comparisons of qualitative and quantitative methods produced very similar results for typical crops; however, for opportunistic crops (such as alfalfa in the study area), the methods produced different results. This is because such crops are more dependent on market conditions than on land characteristics.

The outcomes of the accuracy analysis demonstrated that simple limitation and quantitative methods produced approximately the same estimations but that the root square method produced some different results; even so, the results were acceptable in all the analysed cases.

According to the OA between the LCI system and more recently developed methods, the LCI had highly significant relationships with the other predictions and also with the
actual yields. Furthermore, even though the LCI is simpler to apply than the other methods compared, it still provides reliable land suitability classes. However, the LCI exhibited several problems, especially when it came to identifying limitations (subclasses). The LCI system considers 18 soil and land properties, which can be easily measured, but only uses four major symbols (S, A, T and W) to show 18 properties. Thus, we suggested using the FAO method for subclasses, as each limiting factor can be shown with its own symbol. Then, the transformation of the LCI system results to the FAO method provides users or managers with precise information to recognize potential limitations. Furthermore, it could probably be provided access to information relating to land-use planning.

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Appendix

How to calculate potential yield using the agroecological zoning (AEZ) model

In this appendix, we explain how to calculate potential and predicted yields for winter wheat, step by step. In the study area, the start and the end of the growing cycle for the winter wheat is 6th Nov. and 23rd Jun., respectively. The growing days are from 6th to 31th Dec. and again from 29th Feb. to 23th Jun. Table 9 shows the growing days and some climatic data during the growing cycle.

Step 1: Calculation of the climatic parameters for the study area over the growing days (170 days)

As the mean latitude of the study area is 32°7′30″ (=32.125°), it is necessary to calculate AC, bc, bo and N at mean latitude 32°.

Table 9 Growing days and climatic data during the growing cycle of the winter wheat

| Months      | November | December | January | February | March | April | May | June | Sum  | Average over 170 days |
|-------------|----------|----------|---------|----------|-------|-------|-----|------|------|-----------------------|
| Growing days/month | 24       | 31       | 0       | 1        | 31    | 30    | 31  | 22   | 170  |                       |
| $T_{\text{max}}$  | 17.3     | 11.8     | 10.0    | 12.2     | 15.6  | 20.2  | 26.1 | 33.2 | 3422.3 | 20.13                 |
| $T_{\text{min}}$  | 2.1      | -1.3     | -2.6    | -0.8     | 2.5   | 6.8   | 11.4 | 15.6 | 987.4  | 5.80                  |
| $T_{\text{mean}}$ | 9.7      | 5.3      | 3.7     | 5.7      | 9.0   | 13.5  | 18.6 | 24.4 | 2200.2  | 12.94                 |
| $n$          | 6.94     | 5.73     | 6.04    | 7.56     | 7.40  | 8.35  | 9.42 | 11.59 | 1352.54 | 7.95                  |
| $\text{AC}_{30}$ | 151      | 118      | 131     | 190      | 260   | 339   | 396  | 422  | 4726   | 278.01                |
| $\text{bc}_{30}$ | 241      | 204      | 218     | 283      | 353   | 427   | 480  | 506  | 62156  | 365.62                |
| $\text{bo}_{30}$ | 112      | 91       | 99      | 137      | 178   | 223   | 253  | 268  | 31593  | 185.84                |
| $\text{AC}_{30}$ | 210      | 179      | 191     | 245      | 303   | 363   | 400  | 417  | 52691  | 309.95                |
| $\text{bc}_{30}$ | 299      | 269      | 281     | 333      | 385   | 437   | 471  | 489  | 66252  | 389.72                |
| $\text{bo}_{30}$ | 148      | 130      | 137     | 168      | 200   | 232   | 251  | 261  | 34433  | 202.55                |
| $N_{35}$      | 10.3     | 9.8      | 10.1    | 11.0     | 11.9  | 13.1  | 14.0 | 14.5 | 2076.9 | 12.22                 |
| $N_{30}$      | 10.6     | 10.2     | 10.4    | 11.1     | 12.0  | 12.9  | 13.6 | 14.0 | 2070.3 | 12.19                 |

$T_{\text{max}}$, mean monthly maximum temperature (°C); $T_{\text{min}}$, mean monthly minimum temperature (°C); $T_{\text{mean}}$, mean monthly temperature (°C); n, mean daily sunshine hours (h); AC, photosynthetic ally active radiation on very clear days (cal/cm²/day); bc, daily gross photosynthesis rate of crop canopies on very clear days (kg/ha/day); bo, daily gross photosynthesis rate of crop canopies on overcast days (kg/ha/day); N, astronomically possible hours of bright sunshine or day length. AC, bc, bo and N have been calculated at different latitudes by De Wit (1965).
this location (Table 9). To do that, a linear interpolation is needed. Bagheri Bodaghabadi (2011) presented following formula to interpolate between the two values:

\[ y = a + \frac{(b - a)(x - c)}{d - c} \]

where \( a \) and \( b \) are the ratings for the \( c \) and \( d \) values; \( x \) is a measured value between \( c \) and \( d \) and then, \( y \) is the rating for the \( x \) value. For example, the rating for AC at 32.125° located between 30° and 40° values can be calculated as following \( x = 32.125; \ c = 30; \ d = 40; \ a = 309.95; \ b = 278.01)\):

\[ y = 309.95 + \frac{(278.01 - 309.95) \times (32.125 - 30)}{(40 - 30)} = 303.16 \]

As the same as above, \( AC_{32.125} = 303.16, bo_{32.125} = 199.0, bc_{32.125} = 384.6 \) and \( N_{32.125} = 12.20 \) (all ratings have been calculated over the 170 days).

**Step 2:** Calculation of the maximum leaf photosynthesis rate (Pm). To do that, using \( T_{\text{mean}} \) and Figure 5 Pm is determined (FAO, 1981). As wheat belongs to the crop group I and \( T_{\text{mean}} \) is 12.94, then \( Pm = 20 \) (kg CH2O/ha/year).

**Step 3:** Calculation of the maximum gross biomass production rate (bgm). Based on the value of Pm, one of the following formulas is used:

1. If \( Pm \geq 20 \) then \( bgm = f \cdot bo \cdot (1 + 0.002y) + (1 - f) \cdot bc \cdot (1 + 0.005y) \)
2. If \( Pm \leq 20 \) then \( bgm = f \cdot bo \cdot (1 - 0.025y) + (1 - f) \cdot bc \cdot (1 - 0.01y) \)

where \( f \) = fraction of the daytime that the sky is overcast calculated as: \( f = 1 - (n/N) \) and \( y \) = the ratio of Pm variation calculated as: \( y = \frac{(Pm - 20) \times 5}{199} \)

\[ f = 1 - \frac{(7.95/12.20) \times 0.384}{0.348} = 0.00254 \]

**Step 4:** Calculation of the respiration coefficient (Ct) as following:

\[ Ct = C_{30} \times 0.0108 \times 12.94 + 0.00197 \times 12.20 \]

where \( C_{30} = 0.0108 \) for non-legumes and \( C_{30} = 0.0283 \) for legumes.

As wheat is not a legume: \( Ct = 0.0108 (0.044 + 0.0197 \times 12.94 + 0.00197 \times 12.20) = 0.00254 \)

**Step 5:** Calculation of KLAI

KLAI is determined based on the leaf area index (LAI) of the crop and Figure 6 (FAO, 1981). For wheat, \( LAI = 5 \) m²/m², thus KLAI = 1.

**Step 6:** Calculation of potential yield:

\[ Y = \frac{0.36 \times 320.06 \times 1 \times 0.45}{(170) \times 0.25 \times 0.00254} = 7954.2 \text{ (kg/ha)} \]

**Step 7:** Calculation of predicted yield

Predicted yield = Y * SI. For example, soil index (SI) for unit 1.1 is 38.35%, then:

Predicted yield (unit 1.1) = 7954.2 * 0.3835 = 3050.4 kg/ha = 3.05 ton/ha