Assessment of land production potential for barley using geographic information system (GIS) method

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Abstract
The objective of this study is to assess a GIS-based model for barley production potential in Damghan plain of Iran. The assessment of Land Production Potential for barley, Using Geographic Information System method was used on the crop requirements, climatic and soil properties which will allow the prediction of crop yield. Integrating a crop growth model with GIS allowed studying the variability of barley production potential in different conditions at a regional scale. Regarding to FAO model, the estimated LPP values for the studied area varied between 353 to 5278 kg.ha⁻¹ respectively. This study shows that the average farmers' yield was higher than the calculated LPP values by GIS method. The computed values of net biomass production and yield showed that the barley production potential was almost suitable in Damghan plain. One notable limitation for this method is that it requires an accurate assessment of effective parameters on crop yield.

Keywords: Geographic Information System, Land Production Potential, FAO, AEZ.

Introduction
Different empirical modeling approaches have been described to predict Land Production Potential under wide range of weather, soil conditions and water (FAO, 1975; De Wit & Van Iculeen, 1987; Thomasson & Jones 1991: Tang et al., 1992; Darousin et al., 1993; Shahram Ashraf et al., 2011; Sailesh Samanta et al., 2011).

Agro-Ecological Zoning (AEZ) divides the land into smaller units, which have similar characteristics related to land suitability, production potential and environmental impact (FAO/IIASA, 1991). It involves the inventory, characteristics and classification of land resources for assessing the Land Production Potential. In its simplest form, the AEZ framework comprises three groups of compound activities: (1) Inventory of Land Utilization Types (LUT) and their ecological requirements (2) Definition and mapping of AEZ (3) Evaluation of the land suitability for each Agro-Ecological Zone.

For estimation of production potential, AEZ uses the concept of an attainable total biomass and yield. For a specified LUT, the maximum of production potential is determined by the radiation and temperature characteristics of a particular location by the photosynthetic efficiency of the crop and the fraction of net biomass that the crop can convert to useful yield economically. Although some LPP models have been developed, most of them are paid attention to regional model development. FAO (1978) introduced the production potential model to calculate the global potential of biomass and yield. In this model the photosynthetic efficiency and the maximum of gross production potential are calculated by a very simple equation for crops presented (De Wit, 1987). Geographic Information System is a computer-based information system for the capture, storage, retrieval, analysis and display of information related to geographic features (Clarke, 1997; Goodchild, 1992). GIS approach has been developed to search the areas that meet the requirements of environmental conditions such as temperature, precipitation and slope for different crops. These environmental conditions are spatial in nature, meaning that their distributions are related to their positions on the earth (Burrough, 1991). The objective of this study was to assess a GIS-based model for barley production potential in Damghan plain of Iran.

Materials and methods
Study area
The study area is located in the south of Damghan Plain in Semnan province of Iran spreading over 5400 ha between 36° 02’ 31.6" - 36° 08’ - 28.5" of the Northern latitude and 54° 21’ 56.7" E- 54° 27’ 24.1" of the Eastern longitude; semi-detailed survey for soil characteristics and illustration of soil maps only available.

The used methodology for the land suitability analysis was a multi-criteria evaluation based on FAO framework. The methodology consists matching land qualities against barley needs and assigning a suitability rating to each land characteristics (Ashraf et al., 2010). Data representation in the form of tables for exhibiting the soil physical (texture, soil depth and stoniness) and chemical (sum of basic cations, pH, organic carbon) properties are needed predicting the crop potential. This method is expressed by the following steps:
1- Factors determination  2- Rating determination 3- Weight calculation  4- score calculation
In this study, land suitability assessment was done by following formula1:

$$S = \sum_{i} W_{ji} \cdot X_{ji}$$

(1)

S: Suitability index (Score)
wi: Weight of criterion i
Ri: Rating of criteria i

Evaluation of the soil characteristics resulted in soil suitability index(S) for each individual soil unit. Then,
LPP for irrigated barley was determined using a model that considers following steps:

**Radiation-thermal production potential (RPP)**

The Radiation-thermal Production (RPP) was determined by the photosynthetic radiation. Calculating the RPP was based on the crop growth model of the AEZ project (FAO, 19781) and was derived using the equation 2.

\[
RPP = \frac{0.36 \times bgm.H \times KLAI}{(1/L) + 0.25 \times Ct}
\]

**Land Production Potential (LPP)**

The land production potential was calculated using the equation 3 which shows the effects of climate and selected soil characteristics on the crop production.

\[
LPP = RPP \times S
\]

S is a soil suitability index that obtained by multiplying a soil physical index with a soil chemical index. Both index values were calculated by matching of soil characteristics with the crop requirements and determining rating value to each characteristic (Sys et al., 1991, 1993). The used methodology for the determination of barley production potential requires a data consisting of mean, maximum & minimum temperature (°C) and rainfall (mm). The information such as temperature and precipitation were entered ArcGIS® as attributes. Using production potential biomass model, photosynthesis rate and photosynthetically active radiation were calculated and in the next step gross biomass production and net biomass production were determined. Then RPP were determined for attainable yield in each land unit. An overlay of both raster, using the multiply of RPP and S produced a new map with the LPP results.

**Results**

The values of Rating and Weight of land suitability criteria are shown in Table 1. The highest weight was related to salinity and alkalinity (0.23) and the lowest was slope (0.003). The results of land suitability evaluation for barley cultivation showed that land units 1.1 and 1.2 (S2) had most suitable whereas the lowest suitable was related to map units 3.1, 3.2 and 3.3 (N2). The map of Land Production Potential and land suitability evaluation in the region by means of GIS method.

The lowest values were found in the map units 3.1, 3.2 and 3.3 where soil conditions were unfavorable due to high salinity and alkalinity. These units are located the Southern part of the studied area. The highest estimated LPP values by same method are located side of the Northern of the studied area. Table 3 and Figure 2 showed correlation between estimated and observed yield by GIS method that was \( r = 0.982 \). Also, Figure 3 showed the graph of observed yield and estimated yield for barley in land units.

### Table 1. The determine of rating and weight for each factor

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Lime</th>
<th>Gypsum</th>
<th>Fertility (pH)</th>
<th>EC (Salinity)</th>
<th>ESP (Alkalinity)</th>
<th>Rainfall</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (Wi)</td>
<td>0.121</td>
<td>0.021</td>
<td>0.061</td>
<td>0.230</td>
<td>0.230</td>
<td>0.120</td>
<td>0.031</td>
</tr>
<tr>
<td>Rating (Ri)</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
</tr>
<tr>
<td>Slop</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
</tr>
<tr>
<td>Drainage</td>
<td>0.003</td>
<td>0.05</td>
<td>0.10</td>
<td>0.041</td>
<td>0.060</td>
<td>0.042</td>
<td></td>
</tr>
<tr>
<td>Soil physics</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td></td>
</tr>
<tr>
<td>Surface Stoniness</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td></td>
</tr>
<tr>
<td>Gravel</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
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</tr>
<tr>
<td>Soil depth</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td>1.579</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2. Results of the qualitative suitability evaluation of different land units for barley by using GIS methods

<table>
<thead>
<tr>
<th>NO</th>
<th>Unit</th>
<th>Land class</th>
<th>Observed yield</th>
<th>Yield estimated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.1</td>
<td>S2</td>
<td>5100</td>
<td>4759</td>
</tr>
<tr>
<td>2</td>
<td>1.2</td>
<td>S3</td>
<td>5100</td>
<td>4759</td>
</tr>
<tr>
<td>3</td>
<td>1.3</td>
<td>N1</td>
<td>2250</td>
<td>2379</td>
</tr>
<tr>
<td>4</td>
<td>2.1</td>
<td>S3</td>
<td>2870</td>
<td>2430</td>
</tr>
<tr>
<td>5</td>
<td>2.2</td>
<td>S3</td>
<td>4050</td>
<td>5287</td>
</tr>
<tr>
<td>6</td>
<td>2.3</td>
<td>N2</td>
<td>5870</td>
<td>5750</td>
</tr>
<tr>
<td>7</td>
<td>3.1</td>
<td>N2</td>
<td>5870</td>
<td>5750</td>
</tr>
<tr>
<td>8</td>
<td>3.2</td>
<td>N2</td>
<td>5870</td>
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<tr>
<td>9</td>
<td>3.3</td>
<td>N2</td>
<td>5870</td>
<td>5750</td>
</tr>
</tbody>
</table>
Discussion
There were high differences in estimated yields of barley in various areas. Also, Ashraf, (2011) showed that there were differences between estimated yield of wheat in studied areas of Damghan plain by GIS method. They also showed that the changeability of soil properties in short distances will lead to significant differences in wheat production. The considerable variability of soil characteristics over short distances will undoubtedly lead to important local differences in barley productivity as well. The results illustrated that the average farmers' yields was upper than the LPP values (Fig. 3) that can be caused by calculating incorrectly rating and weight of effective factors on barley growth. The GIS method needs to calculate effective parameters on crops accurately and if many important factors are deleted the results may be inaccurate. The lowest LPP values were found in the map units 3.1, 3.2 and 3.3 where soil conditions were unfavorable due to high salinity and alkalinity. The higher LPP values were found in Northern areas (1.1, 1.2, 1.3,2.1,2,2,2and 2.3) where soil properties were more suitable than other areas. The good accordance between estimated yield potential and observed yield potential in GIS method approves that the method has suitable accuracy.

Conclusion
Integrating a crop growth model with GIS method allowed studying the variability of barley production potential in different conditions at a regional scale. A combined application of a crop growth model and GIS is a very useful tool for land-use planning especially, in developing countries where data on climate and soil are limited. The land physical evaluation by GIS method emphasized that majority of map units had moderately and marginally suitable for barley cultivation. This can be related to barley resistance against environmental condition especially soil and water salinity tolerance. One notable limitation for this method is that it requires an accurate assessment of effective parameters on crop yield. This can be carried out to some extent using the pairwise comparison method. To set the correct relative preference level without personal bias in this study required not only reliable soil information and the writer's experience, but also the experience of a number of senior researchers.

References