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Developing a land evaluation model for faba bean cultivation using geographic information system and multi-criteria analysis (A case study: Gonbad-Kavous region, Iran)

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ABSTRACT

This study was carried out to assess the land suitability for rainfed faba bean (*Vicia faba* L.) cultivation in Gonbad-Kavous region (Golestan province, north of Iran) using geographic information system (GIS) and analytical hierarchy process (AHP), the most common methods for evaluation of land use suitability. Several parameters were considered in this study, including the annual average, minimum and maximum temperatures, annual precipitation, slope, elevation, and some soil properties such as organic matter, pH, EC, texture, phosphorus, potassium, calcium, iron, and zinc. The environmental parameters and the classification system used in the this work are inspired by the United Nations Food and Agriculture Organization (FAO) method dedicated to land suitability. In determining the weights of parameters, expert opinions were consulted and the final land suitability map was generated in five classes. As evidenced by the results, it was estimated that 23.48% of the study area (48,354.5 ha) is highly suitable for faba bean cropping, while 25.38% (52,237.37 ha) is moderately suitable and 25.03% (51,522.85 ha) is marginally suitable. In addition, our results indicated that just 26.11% of total agricultural lands are non-suitable for crop production. The currently non-suitable (49,778.80 ha) and permanently non-suitable (3997.09 ha) classes are located in the north and northwest parts of Gonbad-Kavous township. Soil salinity, low organic matter, low precipitation, high Ca content, and deficiency of P and Fe contents were found to be key limiting factors in this area.

1. Introduction

Faba bean is grown worldwide under different cropping systems as a dry grain (pulse), green grains/pods and a green-manure legume. It is cultivated under rainfed and irrigated conditions and is distributed in more than 55 countries (Maalouf et al., 2013). The harvest area is estimated to be aproximatly 2,040,542 ha, which produce 3,503,300 tons of dry grains. About 47% of these areas are located in Asia and this continent produces about 47.16% of faba bean grains (FAOSTAT, 2013). Faba bean is one of the main winter crops in Golestan province (northeast Iran), with an estimated production of about 106,284 tons green pods and 7256 tons dry grain while the harvesting land area was about 1838 ha in 2010 (Jihad-e-Agriculture Organization of Golestan Province, 2011). Key environmental benefits of faba bean are its ability to fix atmospheric nitrogen symbiotically under a broad spectrum of environmental conditions and making this renewable resource available, and exhibiting positive pre-crop effects in diversified crop rotations (Kopke and Nemecek, 2010).

In each part of a field, land units are demarcated through their properties, position, and usage and they each have their own potential and limitations. It is possible to grade land units according to their qualities (FAO, 1990). Due to the constant decrease in farmlands, it is important to identify the best lands useful for sustainable agriculture (Mendas and Delali, 2012). Evaluation of the environmental components and understanding of local biophysical restraints can help determine the areas suitable for agriculture. Topographic characteristics, climatic conditions and the soil quality of an area are the most important parameters to evaluate land suitability (Almashreki et al., 2011).

Land suitability determination for a particular agricultural crop requires consideration of many criteria (Abushnaf et al., 2013). A number of methods have been proposed for modeling the spatial

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distribution of land suitability potential for selecting crop cultivation areas. In recent years, geographical information system (GIS) has added a much-required spatial dimension to natural resource management and planning. GIS technology is useful for the integration of bio-climate, terrain and soil-resource-inventory information (Sarkar, 2008). GIS is able to perform numerous tasks using both spatial and attribute data. One of the most useful features of GIS is the ability to overlay different layers or maps (Ceballos-Silva and López-Blanco, 2003). However, the overlay procedure does not enable one to take into account that the underlying variables are not equally important (Janssen and Rietveld, 1990). In addition, the use of GIS allows the construction of models from which a new thematic map (e.g. land suitability map) can be formed from a set of thematic maps (Almashreki et al., 2011).

GIS is a powerful tool for analyzing spatial data and establishing a process for decision support (Mendas and Delali, 2012). In such conditions, many variables are involved, which should each be weighted according to their relative importance on the optimal growth conditions of crops through Multi-Criteria Evaluation and GIS. The integration of Multi-Criteria Decision Analysis Approaches (MCDA) in a geographical information system (GIS) provides a powerful spatial decision support system, offering an opportunity to produce land suitability maps efficiently (Janssen and Rietveld, 1990). Deriving weights for the selected map criteria (i.e. land characteristics map layers) is the base requirement for applying the Fuzzy, analytical hierarchy process (AHP) and TOPSIS methods (Malczewski, 1999).

Analytical hierarchy process (AHP) was first developed by Thomas Saaty (1980) and has been modified by various researchers. Since its invention, AHP has been a tool in the hands of decision makers and researchers. It is one of the most widely used multiple criteria decision-making tools. This technique is based on ranking and the importance of factors affecting the goal by attributing relative weights to factors with respect to comments provided in the questionnaires. Many outstanding works have been published based on AHP, among which are: applications of AHP in different fields such as planning, selecting best alternative, resource allocations, resolving conflicts, optimization, and numerical extensions of AHP (Vaidya and Kumar, 2006).

Agricultural land use suitability analysis of the Yusufeli district in Turkey, has been carried using GIS and AHP. Results of this study showed that the soil depth is inadequate for agricultural production. In addition, the slope in the area and therefore the erosion degree is too high. Only 0.08% of the study area (177.87 ha) was found to be highly suitable for agricultural production (Akinci et al., 2013). Similarly, Feizizadeh and Blaschke (2012) investigated the optimal use of land resources for agricultural use such as irrigated farming and rainfed farming. They integrated GIS with the AHP method and used the eight environmental variables for agricultural use suitability in Tabriz region, northwest Iran. The agro-climatic resources of Giba catchment in northern Ethiopia were assessed for teff (*Eragrostis tef*) and barley (*Hordeum vulgare* L.) by Araya et al. (2010). Results showed that quick maturing and drought-resistant varieties of teff and barley could be grown in the center and in the east, while medium-maturing cultivars should do well in the south-west. A multi-criteria evaluation (MCE) approach, within a GIS environment, was used to identify suitable areas for oat (*Avena sativa* L.) crop production in Central Mexico. According to the weighting vectors, the results signified the precipitation, altitude and soil depth as the most important variables affecting the growth of oat crop (Ceballos-Silva and López-Blanco, 2003). Bhagat et al. (2009) analyzed and evaluated the land suitability for cereal production in Himachal Pradesh (India) using GIS. They could discriminate suitable areas for growing these crops and proposed that the method could be harnessed efficiently for achieving long-term sustainability and food security. In another study, Mustafa et al. (2011) assessed the suitability of agricultural land in the Kheragarh Tehsil area of India for several crops that can be cultivated in both summer and winter seasons.

To develop successful cropping systems it is necessary to understand how a crop such as faba bean responds to biological, chemical, physical, and climatic variables, and how this response can be influenced by management (Jensen et al., 2010). There have been a few studies that assess land suitability for crop production by using the integrated approach of GIS and AHP. However, few studies have been published on the land use suitability analysis of pulse production in Iran. In addition, MCE-GIS integration has not been utilized in Iran to identify suitable areas for faba bean. There are also a few studies conducted on land suitability for leguminous foods (pulse crops such as faba bean) worldwide. Another contribution of the present study is the importance of the main variables used in terms of faba bean production and the detailed explanation of the scoring approach used for sub-parameters as distinct from other studies in the literature. A systematic method as outlined in this research may act as a guide for other field crops in the same region or for the same crop in regions elsewhere. The present study was therefore carried out with the objective of land suitability analysis for rainfed faba bean cropping in GIS by evaluation of environmental variables using AHP in agricultural fields of Gonbad-Kavous township in the northeast of Iran. This land suitability assessment has resulted in the development of land suitability maps for this crop by combining several factors of various natures and of differing importance. Accordingly, farmers can improve their production in this district and at the end of the study the distribution and areas of land suitable for faba bean cultivation in Gonbad-Kavous were determined. In addition, this research provides information at a local level that could be used by farmers to select cropping patterns in accordance with suitability results.

2. Materials and methods

2.1. Study area

One of the most important areas for crop production in Iran is Golestan province. In addition, one of the most important areas for crop cultivation in Golestan province is the Gonbad-Kavous region. This area is located between latitude 37°3.6′ to 38°6.3′N and between longitude 54°31.7′ to 55°39.1′E. The study area covers approximately 507,103 ha with 205,890 ha currently in agricultural use (Fig. 1). In Gonbad-Kavous district, the mean annual maximum temperature ranges from 23.13 to 24.36 °C and the mean annual minimum temperature ranges from 11.85 to 13.25 °C. Rainfall is lowest in the north and northeast of the study area and highest in the south (Fig. 3). In addition, annual rainfall increases from north to south regardless of the altitude. Most of the areas are used for rainfed farming, such as wheat, barley, canola and soybean. In Gonbad-Kavous, faba bean is cultivated under rainfed and irrigated conditions (Golestan Province Government, 2009).

2.2. Data used in the study

Determination of overall land suitability of an area for a particular agricultural crop will require consideration of many criteria. In this study, various physical resources such as soil, climate and topography were evaluated. Soil samples were randomly taken from 305 locations. Samples were taken at depths of 0–30 cm and air-dried to remove stones and coarse crop residues. Three samples from each sampling site were collected from the surface soil layer and samples were thoroughly mixed and one sample ground to pass through a sieve, then stored in plastic bags prior to analysis. In this research, the spatial distribution of soil characteristics was