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Feasibility of ley-farming system performance in a semi-arid region using spatial analysis

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ABSTRACT

In order to assess feasibility of ley farming system performance in the Aq-Qala township, a semi-arid region in north of Iran, Multi-Criteria Analysis (MCA) method and Geographic Information System (GIS) techniques were integrated to evaluate the suitability of wheat, barley and annual alfalfa cultivation. The agronomic and ecological requirements of three crops were identified from available scientific literatures. In this study, environmental variables were included: 1) average, minimum and maximum temperatures, 2) precipitation, 3) slope, 4) slope aspects, 5) elevation and 6) soil characteristics such as organic matter, pH, electrical conductivity (EC), texture, nitrogen, phosphorus, potassium, calcium, iron, and zinc. Weights of these variables were extracted from analysis of Analytical Hierarchy Process (AHP) questionnaires. The suitability analysis was based on matching between land qualities/characteristics and crop requirements. It was done by the weighted overlay technique (WOT) in GIS. In order to assess the land suitability of ley farming system performance, the digital suitability layers of three crops were overlaid and integrated in GIS media by raster calculator functions, then zoning of region was done in 4 classes, including: Highly suitable, moderately suitable, marginally suitable and non-suitable. Our results indicated that 35.1% (35495.20 ha) of total areas of studied region is suitable for ley farming system. According to the generated agricultural suitability map, it was determinate that 15.2% (20681.77 ha) of the region is non-suitable for ley-farming performance, 19.5% (23245.74 ha) is marginally suitable and, 30.2% (33725.60 ha) is moderately suitable. Highly suitable, moderately suitable and marginally suitable lands were expected to have a crop yield of 80–100%, 60–80% and 40–60% of the yield under optimal conditions with practicable and economic inputs, respectively. It was found that the most areas of the southern and central parts of Aq-Qala are the highly and moderately suitable regions. The results demonstrated that the high EC, low OM and low rainfall are the key limiting factors in non-suitable areas.

1. Introduction

The term "ley" is derived from the old-English "lea" which means a grassy fallow vegetation on former crop fields (Glatzle, 1988). It refers to a land use system where arable crops alternate with vegetation used for livestock production. Accordingly, spontaneous fallow vegetation that is grazed by livestock prior to cropping, is an "unregulated" ley system as defined by Ruthenberg (1976). In the mid 1930's self-regenerating annual legume pastures were adopted into southern Australian cereal farming systems. The use of subterranean clover (*Trifolium subterraneum* L.) and various alfalfa (*Medicago* spp.) species, together with applications of superphosphate, improved soil fertility and led to increased cereal yields and greater sheep and cattle production (Puckridge and French, 1983). The ability of tillage systems to maintain sufficient alfalfa seed reserves (200 kg ha^{-1}) in the topsoil (0–50 mm) without decreasing the yields of the successive wheat (*Triticum aestivum* L.) crop is one of the major factors determining the success of alfalfa in ley farming systems with wheat (Kotzé et al., 1998).

The value of legumes as nutritious food and forage crops and for soil rehabilitation has been recognized for thousands of years, but the use of self-regenerating annual species of *Trifolium* and *Medicago* in rotations with cereal crops is an especially southern Australian development (Puckridge and French, 1983). The "ley" systems are widely used in countries such as Australia, Brazil,

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Colombia, Argentina, with positive results (Hohnwald et al., 2000; Ovalles et al., 2004). This alternation derives in multiple benefits such as a more profitable grain production, better forage quality for livestock, self regeneration of legume pastures, decreased use of inorganic fertilizers, improving soil quality and an overall benefit by increased carbon fixation (Hohnwald et al., 2000; Navas et al., 2011).

Legume characteristics that are particularly relevant for ley systems are as follows: 1. ease of establishment (high seed production potential), 2. ease of re-establishment, 3. high nitrogen fixation (a function of plant productivity and soil adaptation), 4. ease of control during the crop phase, 5. tolerance to drought, diseases and pests, 6. high animal production (Schultze-Kraft, 1995).

The effect of six methods of tillage commonly used in alfalfa and cereal farming in the southern Cape (South Africa), on the distribution of the alfalfa seed reserves in the soil profile and yields of successive wheat crops was investigated by Kotzé et al. (1998). Results revealed that tine implements, regardless of the depth of cultivation, maintained more seed in the topsoil, compared to the shallow-disc, deep- disc and moldboard ploughing. Also, seed reserves in the topsoil correlated with the regeneration and growth of the following alfalfa pastures. In study, Albizua et al. (2015) used data from four long-term (55 years) agricultural experiments in southern Sweden to assess the effects of two arable farming systems on a range of indicators of soil ecosystem services. One farming system used only annual commodity crops (ACC system) while the other integrated one year of ley (ley system) into the crop rotation. Nitrogen was applied annually in both farming systems at two rates (0 and 150 kg N ha^{-1}). The ley farming system had an addition of farmyard manure (FYM) once every fourth year. Results showed that yields of wheat were greatest in the plots that received N fertilizer, irrespective of farming system, while mycorrhizal fungal biomass was greatest in the ley system with no inorganic N fertilizer. The ley system with N fertilizer had significantly greater values of regulating and provisioning services relative to the other treatments. The results indicated that different farming systems could have large effects on ecosystem service flows, and that integrating leys into arable rotations can enhance the delivery of soil ecosystem services.

On the eastern plains of Venezuela, a study was carried out to evaluate the behavior of local forage legume species and its influence on chemical and biochemical properties of soil with the ultimate goal of identifying which one of these species had the potential to be used as cover in the establishment of a ley farming system. For this propose, a study was conducted on an Oxisol and used five local species from the genus *Centrosema* which were established as cover for a period of 3 years. The results indicated that dry matter production varied among the different legume covers, and *C. macrocarpum* had the greatest productivity (1340 kg h^{-1}). Thus, the legume crop covers influenced positively the soil quality. *C. macrocarpum* was the legume cover that showed the greatest soil improvement, having the best potential to be used as forage cover to establish a ley farming system in this region (Navas et al., 2011).

Agricultural intensification has contributed substantially to the increase in food production, but has come at the expense of soil degradation and environmental problems. Management of soil based ecosystem services needs to be considered in agricultural management since intensive management implies not only costs to the farmer but also to society (Albizua et al., 2015). It is essential to allocate crops to the most suitable land areas precisely for the best production since the arable land area has been decreasing (Zhang et al., 2015). Selecting the most appropriate algorithm for land suitability assessment is important for current and future land use planning. Several approaches have been attempted to conduct land suitability assessment. Geographic Information System (GIS) technology is useful for integration of bio-climate, terrain and soil-resource-inventory information (Sarkar, 2008). Parametric method is one of the traditional methods of land suitability assessments, in which land characteristics are matched against the crop requirement, producing suitability rating for each land characteristic (Sys et al., 1991). Also, land evaluation framework of FAO (1976) was widely used, in which land suitability for crops can be evaluated in terms of suitability ratings ranging from highly suitable to not suitable based on climatic, topographic data and soil properties (Zhang et al., 2015). Bhagat et al. (2009) analyzed and evaluated the land suitability for cereal production in Himachal Pradesh (India) using GIS. The considered different parameters such as climatic (precipitation and temperature), topographic (elevation), soil type and land cover/land use. They could discriminate suitable areas for growing these crops and proposed that the method can be harnessed efficiently for achieving long term sustainability and food security.

A key step of land suitability assessment for crop production is to determine the weight of each factor which influences the land suitability. The presence of various and multiple criteria makes land suitability assessment complicated because factors influencing land suitability have unequal levels of significances (Elsheikh et al., 2013). The integration of Multi-Criteria Analysis (MCA) methods such as Analytical Hierarchy Process (AHP) with GIS is a trend in land suitability analysis. This combination could be useful in solving conflictive situations for individual or groups interested in spatial context and is also a powerful approach to land suitability assessments (Malczewski 1999; Elsheikh et al., 2013). AHP 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 the best alternative, resource allocations, resolving conflicts, optimization, and numerical extensions of AHP (Vaidya and Kumar, 2006). Kazemi et al. (2016) concluded that a combination of GIS and AHP is a practical and applicable method for determining land suitability for faba bean crops. An MCE approach, within a GIS environment, was used by Ceballos-Silva and López-Blanco (2003) identify suitable areas for oat 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. Lai et al. (2002) applied AHP in group decision making, which has proved to be more beneficial than the conventional techniques such as the Delphi techniques. The AHP method, as compared to Delphi, allows participants to evaluate and discuss tasks more comprehensively. In general, the participants are more satisfied with the AHP than with Delphi, not only in the decision process but also with the outcome of the decision.

Suitable areas for agricultural use are determined by an evaluation of the climate, soil, and relief environment components, and the understanding of local biophysical restraints. In this kind of evaluation, many variables are involved and each on should be weighted according to their relative importance on the optimal growth conditions for crops (Ceballos-Silva and López-Blanco, 2003). Many studies have focused on land suitability evaluation based on Geographic Information System (GIS) and Multi-Criteria Analysis (MCA) (Elsheikh et al., 2013; Rahman and Saha, 2008; Trong Due, 2006; Nekhay et al., 2009; Menas and Delali, 2012; Akinci et al., 2013; Abushnaf et al., 2013; Houshyar et al., 2014; Kazemi et al., 2015). However, there have been few studies which evaluate the land suitability for forage legume and ley farming system. The present study was therefore carried out with the objective land suitability analysis for feasibility of ley-farming system performance in semi-arid region using geographical information system