Geoderma 310 (2018) 178–190

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Application of SAW, TOPSIS and fuzzy TOPSIS models in cultivation priority planning for maize, rapeseed and soybean crops

Javad Seyedmohammadi[a,*], Fereydoon Sarmadian[b], Ali Asghar Jafarzadeh[a], Mohammad Ali Ghorbani[c,d], Farzin Shahbazi[a]

[a] Soil Science Department, Faculty of Agriculture, University of Tabriz, Tabriz, Iran
[b] Soil Science Department, College of Agriculture and Natural Resources, Faculty of Agricultural Engineering and Technology, University of Tehran, Karaj, Iran
[c] Water Engineering Department, Faculty of Agriculture, University of Tabriz, Tabriz, Iran
[d] Engineering Faculty, Near East University, 99138 Nicosia, North Cyprus, Mersin 10, Turkey

ARTICLE INFO

Handling Editor: A.B. McBratney

Keywords:
Cultivation priority
Fuzzy AHP
Fuzzy TOPSIS
SAW
TOPSIS

ABSTRACT

Cultivation priority planning is a very important and vital step in suitable and sustainable revenue of agricultural land. The growth of urban areas and industrial intensification has contributed to a reduction in valuable agricultural lands and to various environmental impacts including climate change. This reduction in agricultural land severely impacts food production and food security. In order to effectively address this issue, spatial analytical and optimization methods based on evaluating multiple criteria decision are needed to evaluate the capability and suitability of available lands for current and future food production. The objective of this study is to implement the GIS and multi-criteria decision analysis (MCDA) techniques as an improved method of multi-criteria decision making for evaluating areas suitable for cultivation priority planning of maize, rape and soybean crops. For this purpose, 12,000 ha land which is located in Ardabil province, west-north of Iran was investigated by excavation of 167 soil profiles and 313 augers. After soil sampling and analysis, soils were classified in Aridisols. 24 soil series and 66 land units were identified and separated in study area. The several criteria had limitation for maize, rape and soybean cultivation in studying lands which the most limiting evaluation criteria including soil depth, slope, climate, pH, electrical conductivity, exchangeable sodium percentage, calcium carbonate and gypsum were selected for usage in prioritization models by principal component analysis and multi-dimensional scaling methods. Selected criteria were very important in growth of maize, rape and soybean. Simple additive weighting (SAW), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Fuzzy TOPSIS methods were used for cultivation priority planning of maize, rape and soybean crops in land units. Analytical Hierarchy Process (AHP) and Fuzzy AHP approaches were used to determine weight values of the criteria. Multivariate variance analysis proves significant difference among three methods at 0.05 probability level. With attention to allocated scores by prioritization models, crops cultivation priority was determined as maize, rape and soybean in land units, respectively and maize crop was preferred to other plants. The statistical analysis results with regard to mean comparison derived from least significant difference (LSD) test showed that Fuzzy TOPSIS method set cultivation priority planning of maize, rape and soybean crops for land units more accurately than the others, due to fuzzy TOPSIS method used appropriate values of criteria weights, twin comparing nature of alternative (crop) from positive and negative ideal, data standardization, mathematical equations and matrixes as well as fuzzy logic relations and principles for calculation of process performing. This study emphasizes the successful application of MCDA in dealing with complicated issues in the context of cultivation priority planning management. It is anticipated that, the integration of this developed framework in the planning policies of cultivation priority in developing countries as an effective tool for integrated regional land use planning can help in conducting better control over soil, land and environment losses.

1. Introduction

Land consolidation is considered as the most effective land management planning approach for solving land fragmentation, a problem that prevents rational agricultural development and rural sustainable development more generally (Demetriou, 2016). The

* Corresponding author.
E-mail address: seyedmohammadi.javad@tabrizu.ac.ir (J. Seyedmohammadi).

http://dx.doi.org/10.1016/j.geoderma.2017.09.012
Received 4 November 2016; Received in revised form 27 June 2017; Accepted 10 September 2017

decline of worthy agricultural land, as a result of constant urban and industrial growth, directly affects the ability to produce food at a large scale. So, agricultural production must be moved to other available land or land currently used for other purposes in order to meet global food demand (Lambin and Meyfroidt, 2011). This problem is more aggravated by the effects of global climate change and regional sensitivity increases (Montgomery et al., 2016). Moreover, increases in the frequency of risks such as drought, flooding, soil degradation, and regional shifts in crop production expense can seriously change economic markets, trade, and socioeconomic development (Schmidhuber and Tubiello, 2007). Consequently, urbanization and climate can severely impact on global food security (Montgomery et al., 2016).

Analysis of agricultural planning includes the consideration of a number of factors, including natural system constraints, compatibility with existing land uses, existing land use policies, and the availability of community facilities. The suitability techniques analyze the interaction between location, development actions, and environmental elements to classify the units of observation according to their suitability for a particular use (Malczewski, 2004). In reality, not all the conflicting objectives due to economic development, community or conservation interests are always taken into consideration, which could cause to political and manipulative, decisions. Modern planning theories such as communicative planning and actor-network theory focus on the fact that effective planning decisions should essentially consider all participants with a variety of discourse types and values (Mosadeghi et al., 2015). This encourages approaches for integrating very heterogeneous data, making them available to the various stakeholders to allow them to make more informed and less subjective decisions (Greene et al., 2010).

In the 1960s, the first multi-criteria decision making (MCDM) techniques were developed to facilitate difficulties in conforming different ideas and managing large amounts of complicated information in the decision-making process (Zopounidis and Pardalos, 2010). These capabilities have encouraged planners to combine MCDM with other planning tools such as geographical information system (GIS). Multi-criteria decision making involves a multi-stage process of i) defining objectives, ii) choosing the criteria to measure the objectives, iii) specifying alternatives, (iv) assigning weights to the criteria, and (v) applying the appropriate mathematical algorithm for ranking alternatives. MCDM allows accommodating the need for unbiased integration of modern planning objectives for independent identification and ranking of the most suitable planning solutions (Mosadeghi et al., 2009).

These spatial MCDM techniques are able to improve the transparency and analytic difficulty of the land use decisions (Hajkowicz and Collins, 2006). Practical applications of such spatial MCDM techniques have become more widespread in land suitability studies (Chang et al., 2008; Chen et al., 2010; Greene et al., 2010; Arciniegas et al., 2011; Kordi and Brandt, 2012; Elaalem, 2012; Akinci et al., 2013). Recent studies which show application of MCDM techniques in identifying the extent of future land-use zones are rare at local scale (Mosadeghi et al., 2013). The majority of previous MCDM applications mainly focus on using MCDM to rank the priority of predefined management options or planning scenarios (Xevi and Khan, 2005; Hajkowicz and McDonald, 2006; Ananda and Herath, 2008; Hajkowicz, 2008). Spatial MCDM, however, can be used not only to rank the priority of options and performing scenario analysis, but also to provide insight into the spatial extent of the alternatives (Arciniegas et al., 2011). This capability can help local land use planners to identify land use zones for future agriculture and urban development. It can be particularly useful in situations where planning instruments do not provide prescriptive guideline for local planning decisions.

Advanced MCDM methods including SAW, AHP, TOPSIS, Fuzzy set theory and Random set theory provide more sophisticated algorithms to process uncertain or inaccurate data (Zhang and Achari, 2010; Mosadeghi et al., 2015; Nguyen et al., 2015; Prakash and Barua, 2015; Wang, 2015; He et al., 2016; Kaliszewski and Podkopaev, 2016; Montgomery et al., 2016; Onat et al., 2016). The Fuzzy set theory techniques are considered the most common techniques for dealing with imprecise and uncertain problems (Zarghami et al., 2008; Zhang and Achari, 2010; Mosadeghi et al., 2013, 2015; Montgomery et al., 2016). Most of the empirical studies have applied Fuzzy techniques without a comparative analysis to study whether using more sophisticated techniques like Fuzzy AHP will correctly make a significant difference comparing conventional AHP. On the other hand, the few studies that have done comparative analysis in land suitability applications (Ertugrul and Karakasoglu, 2008; Elaalem, 2012; Kordi and Brandt, 2012; Elaalem, 2013) have mainly focused on arithmetic aspects such as differences in criteria weights, option rankings, or the effects of introducing uncertainty into their models. This need for comparative analyses carries an even greater imperative in the context of applying spatial MCDM methods to real-world cultivation priority planning decisions, where transparency and simplicity of the decision-making model is a key element during consultation with the stakeholders (Mosadeghi et al., 2015).

Multiple criteria decision analysis studies use a multitude of criteria and weights derived from expert knowledge in a spatial context and using geospatial datasets (Yu et al., 2011). Multiple criteria decision analysis outputs can be used for planning purposes and to facilitate decision-making processes and tools (Stauder, 2014; Malczewski and Rinner, 2015). Multi-criteria analysis has also been used for the development of spatial decision support systems to assist decision makers in addressing complex spatial problems and to analyze the trade-offs between alternatives for a given problem (Montgomery et al., 2016).

Maize, rape and soybean are important, strategic and principal as well as the major crops that are found in agricultural production systems. Cereals represent the major source of dietary protein for humans (Rótolo et al., 2015), and production figures for 2012 show that maize represented 34% of total global cereal production (FAO/STAT, 2014). Cereals such as maize are a key source of genetic material for food production, and integrate the net benefits of natural and human systems interaction through managed agro-ecosystems that we call agriculture (Rótolo et al., 2015). Soybean is grown world-wide as an important staple and commercial crop. The reserved area for planting soybean around the world is 99,501,101 ha (FAO/STAT, 2009). Soybean accounted for 56% of production of the main world oilseed crops in 2011 with a total production of 251.5 million tons (ASA, 2012). Rape seed contains both high oil and protein content. Rape is one of the main winter grain crops in Iran and world (Kamkar et al., 2014). The vast majority of maize, rape and soybean oil is used in the food industry, about one third in spreads and cooking oil and about two thirds in the commercial food service sector. These crops meal, the main by product of crushed seeds, is used as a high protein feed for intensive livestock, mainly in the pig, poultry and dairy industries.

Maize grows in the temperature range of 14–40 °C with optimum range 18–32 °C on many types of soils. It grows in the pH range 5.2–8.5 and optimum 5.8–7.8. Any yield reduction doesn't occur at an electrical conductivity (EC) < 1 dSm^{-1} (IIASA and FAO, 2012). Optimum values of available phosphorus and potassium for maize growth are 14 mg kg^{-1} and 220 mg kg^{-1}, respectively (Gheibi et al., 2014). Soils are suitable for maize production that have exchangeable sodium percentage (ESP) < 6%, gypsum < 4% and calcium carbonate < 15% in useful soil depth (IIASA and FAO, 2012). The mean temperature range for a proper growth of oilseed rape is 8–30 °C, the optimum range being 12–22 °C. Rape can be produced on a wide variety of soils with optimum values of pH, EC, ESP, gypsum, calcium carbonate, available phosphorus and potassium, 5.6–7, < 2 dSm^{-1}, < 8%, < 2%, < 12%, > 18 mg kg^{-1} and > 195 mg kg^{-1}, respectively (IIASA and FAO, 2012; Noorgholipour et al., 2014). The temperature range for the growth of soybean is 15–40 °C. The growth is optimal at temperature between 20 and 30 °C. Soybean can be grown on soils with vast variety that have optimal values of pH 5.5–7.5, EC < 5.5 dSm^{-1}, ESP < 8%, gypsum < 0.2%, calcium carbonate < 15% (IIASA and FAO, 2012), available phosphorus > 13 mg kg^{-1} and potassium > 160 mg kg^{-1} in useful soil depth (Warncke et al., 2004).