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Assessing the accuracy of hyperspectral and multispectral satellite imagery for categorical and quantitative mapping of salinity stress in sugarcane fields

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ABSTRACT

This study evaluates the feasibility of hyperspectral and multispectral satellite imagery for categorical and quantitative mapping of salinity stress in sugarcane fields located in the southwest of Iran. For this purpose a Hyperion image acquired on September 2, 2010 and a Landsat7 ETM+ image acquired on September 7, 2010 were used as hyperspectral and multispectral satellite imagery. Field data including soil salinity in the sugarcane root zone was collected at 191 locations in 25 fields during September 2010. In the first section of the paper, based on the yield potential of sugarcane as influenced by different soil salinity levels provided by FAO, soil salinity was classified into three classes, low salinity (1.7–3.4 dS/m), moderate salinity (3.5–5.9 dS/m) and high salinity (6–9.5) by applying different classification methods including Support Vector Machine (SVM), Spectral Angle Mapper (SAM), Minimum Distance (MD) and Maximum Likelihood (ML) on Hyperion and Landsat images. In the second part of the paper the performance of nine vegetation indices (eight indices from literature and a new developed index in this study) extracted from Hyperion and Landsat data was evaluated for quantitative mapping of salinity stress. The experimental results indicated that for categorical classification of salinity stress, Landsat data resulted in a higher overall accuracy (OA) and Kappa coefficient (KC) than Hyperion, of which the MD classifier using all bands or PCA (1–5) as an input performed best with an overall accuracy and kappa coefficient of 84.84% and 0.77 respectively. Vice versa for the quantitative estimation of salinity stress, Hyperion outperformed Landsat. In this case, the salinity and water stress index (SWSI) has the best prediction of salinity stress with an R^2 of 0.68 and RMSE of 1.15 dS/m for Hyperion followed by Landsat data with an R^2 and RMSE of 0.56 and 1.75 dS/m respectively. It was concluded that categorical mapping of salinity stress is the best option for monitoring agricultural fields and for this purpose Landsat data are most suitable.

1. Introduction

Soil salinity is one of the most common problems in arid and semi-arid regions that negatively affect crop production (Richards, 1954). Irrigation-fed agriculture is most susceptible to salinization. More than half of the existing irrigation systems of the world are affected by salinity (23%) and sodicity (37%) (Tanji and Wallender, 2012) and this problem increases every year as a result of secondary salinization.

Accumulated soluble salts in the soil decrease the osmotic potential of the soil which is inhibit plant access to soil water (Bernstein and Hayward, 1958) and led to lose the potential yield of crops or no crop production. Therefore soil salinity is the important threat for the sustainable food production (Lobell et al., 2010). To better management of this threat and enhance sustainability of agricultural lands and crop productivity, early identification and up-to-date assessment of salt-affected soil is essential (Bilgili et al., 2011). Therefore, monitoring of soil salinity for controlling the effects of salinization on irrigated lands is a matter of global importance, and mapping salinity stress during the growing season (or in vegetated area) is an important effort for dealing with this problem and increasing crop production.

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Traditionally, detection of salinity stress performed by some indirect criteria such as percentage of dead leaves, chlorophyll fluorescence, plant growth and seed yield (Altaf et al., 2004). But these in situ activities are time-consuming, costly, only applied locally, and their accuracy for regional salinity assessment is function of the density and distribution of the ground data. In contrast, remote sensing has been recognized as the most suitable technique for mapping soil salinity in large-scale areas (Metternicht and Zinck, 2003; Scudiero et al., 2015). The capability of remotely sensed data to estimating soil salinity, in different regions around the world, has been well documented for either direct estimation on bare soils and/or sparsely vegetated areas (e.g., Metternicht and Zinck, 1996, 2003; Farifteh et al., 2006; Dehaan and Taylor, 2003, 2002; Mulders, 1987; Szilagyi and Baumgardner, 1991; Verma et al., 1994) or indirectly through the vegetation properties and indices as a proxy of soil salinity (e.g., Mougenot et al., 1993; Wang et al., 2002; Lobell et al., 2007, 2010; Leone et al., 2007; Naumann et al., 2008, 2009; Song et al., 2011; Zhang et al., 2011, 2012; Hamzeh et al., 2012, 2013; Scudiero et al., 2014, 2015). Most of these studies have been conducted to find the best wavelength regions, vegetation indices and statistical models for quantitative mapping of soil salinity in agricultural fields. The accuracy of these methods is not so relevant for mapping salinity stress, and it may be more useful to produce salinity stress maps which show the categorical amount of soil salinity or classify salinity stress in major classes related to crop tolerance and yield potential as influenced by soil salinity (Hamzeh et al., 2012). Furthermore, agricultural land management is often done at farm level or small blocks, so the exact amount of soil salinity in each pixel is not so important, and classification of salinity stress in low, moderate and high salinity, or categorical maps, will satisfy farmers and agriculture consultants (Hamzeh et al., 2012). However, there are only few studies that show the accuracy of different classification methods for categorical mapping of soil salinity (Metternicht and Zinck, 2003; Hamzeh et al., 2012; Allbed and Kumar, 2013; Muller and Van Niekerk, 2016). The results presented by Hamzeh et al. (2012) indicate a high accuracy of supervised (or categorical) classification methods for mapping salinity stress using Hyperion satellite imagery. Also the results obtained by Muller and Van Niekerk (2016) showed the high accuracy of categorical classification of soil salinity using the high spatial resolution SPOT-5 multispectral data. Nevertheless, due to the scarcity of Hyperion and the costs of SPOT, usability of these satellite data for mapping salinity stress on a regional scale is limited.

Therefore, exploring the capability of other multispectral data, such as Landsat which is continuously acquired and available free of charge, for mapping salinity stress in irrigation-fed agriculture fields is essential. Hence, this research aims to answer the following major research questions:

(1) Can salinity stress within irrigation-fed agriculture fields be appropriately identified and classified by using satellite imagery?
(2) If the answer of the above question is yes, then which kind of satellite data and mapping method performs best for this purpose?

In respect to the above questions, the main objective of this research is to explore the capability, advantages and limitations of hyperspectral (Hyperion) and multispectral (Landsat7 ETM+) satellite imagery for both categorical and quantitative mapping of salinity stress in sugarcane fields, in order to find the most relevant satellite data and mapping method to deal with this problem.

2. Materials and methods

2.1. Study site

The field experiment was conducted during summer 2010 in the Hakim Farabi Farming and Industrial Lands, one of the seven farming and industrial lands of sugarcane located in the Khuzestan province in the southwest of Iran, between latitudes 31° 00′ 30″ N–32° 30′ 00″ N and longitudes 48° 15′ 00″ E–48° 40′40″ E (Fig. 1). The study area was uniformly divided into rectangular fields with an area of 25 ha (1000 m × 250 m) for each fields and total area of 774 km^2. Planting, irrigation and drainage systems, harvesting and other operations were similar in all fields. The area has an arid and semi-arid climate with an average annual precipitation of 266 mm and annual evaporation from open pans of 2788.3 mm yr-1 (Research centre of sugarcane, 2010). Geomorphologically the region has been created from a flat plain without significant topographic features, which is mainly composed by the sediments of the Karun, Tigris and Euphrates rivers. The current sedimentation

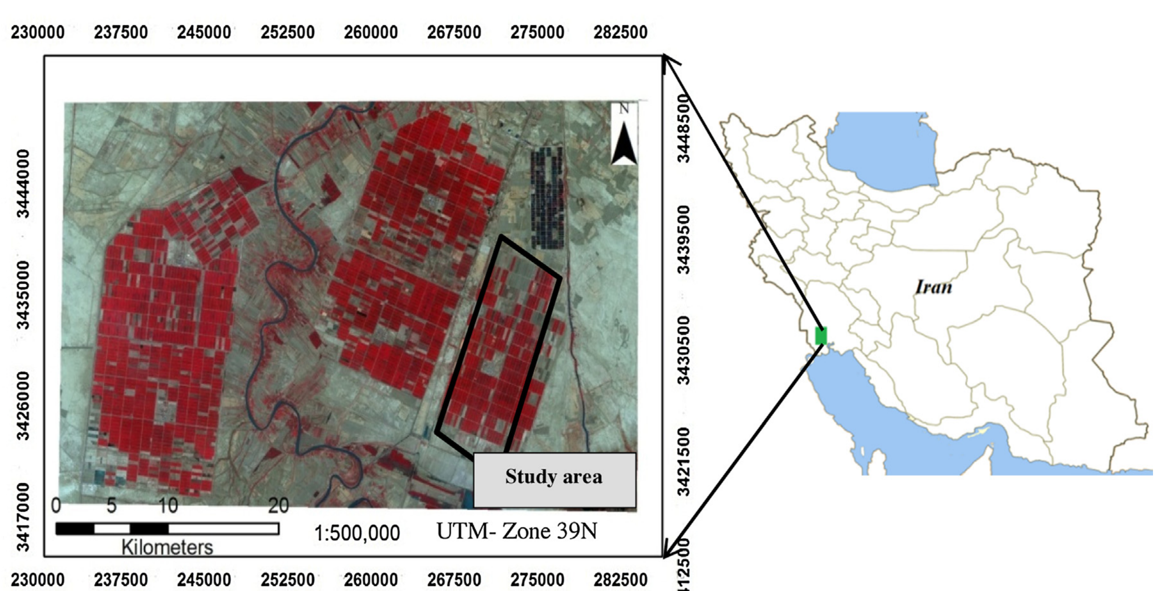

Fig. 1. Study site in the Khuzestan province, southwest of Iran.