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Assessing fruit-tree crop classification from Landsat-8 time series for the Maipo Valley, Chile

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ABSTRACT

Satellite image time series (SITS) provide spectral–temporal features that describe phenological changes in vegetation over the growing season, which is expected to facilitate the classification of crop types. While most SITS-based crop type classifications were focused on NDVI (normalized difference vegetation index) temporal profiles, less attention has been paid to using the complete image spectral resolution of the time series. In this work we assessed different approaches to SITS-based classification of four major fruit-tree crops in the Maipo Valley, central Chile, during the 2013–14 growing season. We compared four feature sets from a time series comprised of eight cloud-free Landsat-8 images: the full-band SITS, the NDVI and NDWI (normalized difference water index) temporal profiles, and an image stack with all the feature sets combined. State-of-the-art classifiers (linear discriminant analysis, LDA; random forest; and support vector machine) were applied on each feature set at different training sample sizes ($N = 100$, 200, 400, 800 and 2291 fields), and classification results were assessed by cross-validation of the misclassification error rate (MER). For all the feature sets overall results were good (MERs ≤ 0.21) although substantially improved classification accuracies were achieved when the full-band SITS was employed (MER 0.14–0.05). Classifications applied on the NDVI temporal profile consistently had the worst performance. For a sample size of 200 fields, LDA using the full-band SITS of image dates 1, 3, 6 and 8 produced the best tradeoff between the number of images and classification accuracy (MER = 0.06), being the green, red, blue and SWIR (short-wave infrared) bands of image date 1 (acquired at the early greenup stage) the most relevant for crop type discrimination. Our results show the importance of considering the complete image spectral resolution for SITS-based crop type classifications as the commonly used NDVI temporal profile and their red and near infrared bands were not found the most significant to discriminate the crop types of interest. Furthermore, in light of the good results obtained, the methodology used here might be transferred to similar agricultural lands cultivated with the same crop types, thus providing a reliable and relatively efficient methodology for creating and updating crop inventories.

1. Introduction

Passive optical remote sensing may provide meaningful information for monitoring and managing agricultural lands. A particularly significant application is the spectral classification of crop types from satellite-based multispectral images, which makes it possible to create or update crop inventories based on limited field data. It may furthermore help to direct management practices (e.g., site-specific water and nutrient supply) and assist in yield forecasting, particularly where little historical field data is available. Nonetheless, different vegetation species may show quite similar spectral behavior (or low inter-specific spectral variability), especially during some particular phenological stages and at the typical spectral resolution and bandwidth of satellite-based multispectral images (Esch, Metz, Marconcini, & Keil, 2014; Galvão, Epiphanio, Breunig, & Formaggio, 2012). This issue may strongly limit the accuracy of crop types classified from single image dates (Jewell, 1989; Lo, Scarpace, & Lillesand, 1986; Murakami, Ogawa, Ishitsuka, Kumagai, & Saito, 2001; Van Niel & McVicar, 2004).

The use of satellite image time series (SITS) arises as a promising approach in remote sensing-based crop type classification. By using SITS, spectral–temporal profiles of the crops of interest are retrieved from a set of multispectral images acquired within a temporal window of interest (usually the entire growing season). This multi-temporal spectral behavior is related to the phenology of the crop, i.e., their seasonal dynamics or intra-annual developmental stages, whose onset and offset dates usually differ from other crop types planted on the same agricultural land. Thus, distinctive spectral–temporal features of each crop type may be extracted from SITS, increasing the chances of classifying them correctly (Jakubauskas, Legates, & Kastens, 2002; Masialeti, Egbert, & Wardlow, 2010; Odenweller & Johnson, 1984;

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Ozdogan, 2010; Wardlow, Egbert, & Kastens, 2007). Within a growing season the main phenological stages driving the bulk spectral behavior of a crop are: (1) greenup: the date of onset of photosynthetic activity, (2) maturity: the date at which plant green leaf area is maximum, and (3) senescence: the date at which photosynthetic activity and green leaf area begin to rapidly decrease (Zhang et al., 2003).

Although there is a growing body of work and practical experience in agricultural land cover classifications using multi-temporal image sets as part of land use and land cover (LULC) mapping and monitoring (see references in Giri, 2012, and Xie, Sha, & Yu, 2008), we center our attention more narrowly on SITS-based classification of individual types of crop. While LULC classifications are often focused on tracking long-term changes of major classes, crop type classification primarily deals with finer thematic granularity and subtle spectral differences. In this case, the spectral separability between crop types is pursued by tracking their phenological differences across a set of images regularly acquired within a given growing season. SITS have been widely used to classify single and multiple crops types mainly by retrieving NDVI (normalized difference vegetation index) temporal profiles as indicators of crop phenology from coarse spatial resolution images such as MODIS (Moderate Resolution Imaging Spectroradiometer) (Arvor et al., 2011; Chenab, Sonb, Changab, & Chenb, 2011; Jakubauskas et al., 2002; Mingwei et al., 2008; Masialeti et al., 2010; Sakamoto et al., 2005; Shao, Lunetta, Ediriwickrema, & Liames, 2010; Sibanda & Murwira, 2012; Sun, Xu, Lin, Zhang, & Mei, 2012; Wardlow & Egbert, 2010; Xavier, Rudorff, Shimabukuro, Berka, & Moreira, 2006; Zhong, Hawkins, Biging, & Gong, 2011) and from finer spatial resolution images such as Landsat or SPOT (Satellite Pour l'Observation de la Terre) (Badhwar, Gargantini, & Redondo, 1987; Jewell, 1989; Murakami et al., 2001; Nguyen, De Bie, Ali, Smaling, & Chu, 2011; Simonneaux et al., 2007; Turker & Arikan, 2005; Zhong, Gong, & Biging, 2014; Zheng, Myint, Thenkabail, & Aggarwal, 2015). The NDVI is constructed from a red band (R) sensitive to foliar chlorophyll content, and a near infrared (NIR) band sensitive to canopy foliage amount, as (NIR − R) / (NIR + R). This spectral index represents in a convenient and synthetic fashion the physiological and structural condition of vegetation, often referred as greenness, which from a temporal perspective relates to vegetation phenology (Odenweller & Johnson, 1984; Jones & Vaughan, 2010). The widespread reliance on MODIS for crop type classification is mainly due to the free availability of 16- and 32-day NDVI image composites, as well as 8-day surface reflectance products that enable to construct 8-day NDVI composites. These composite products strongly increase the availability of cloud-free imagery while reducing the need for radiometric and geometric processing by the end user. Furthermore, they are particularly useful in agricultural lands with relatively large and homogeneous crop fields, considering MODIS spatial resolutions ranging from 250 to 1000 m (Murakami et al., 2001; Ozdogan, 2010; Roy et al., 2014; Wardlow et al., 2007; Zhong et al., 2011).

The phenology of a given crop type may change in space and time in response to variation in environmental conditions (e.g., temperature, precipitation, soil type and humidity) and management practices (e.g., fertilization, irrigation, crop rotation). As a result, spectral–temporal profiles extracted from fields corresponding to the same crop type may show some intra-annual differences (within-crop phenological variability) as well as inter-annual differences (early or delayed onset of phenological stages), even at local scales (Arvor et al., 2011; Masialeti et al., 2010; Odenweller & Johnson, 1984; Wardlow et al., 2007). Intra-annual variation in the amplitude of the NDVI temporal profiles of two fields of the same crop type (with phase unchanged) indicates different vegetation conditions. Meanwhile, intra-annual variation in the phase of temporal profiles (with amplitude unchanged) of fields of the same crop type indicates shifts in developmental stages (Jakubauskas et al., 2002). To support and enhance the crop type classification based on NDVI temporal profiles, reference field data about crop phenology have been used (Sakamoto et al., 2005; Shao et al., 2010; Sibanda & Murwira, 2012; Zheng et al., 2015; Zhong et al., 2011, 2014), although the success of these approaches may strongly depend on the quality and quantity of such data (Masialeti et al., 2010).

Although the use of the complete spectral resolution of SITS in the realm of agricultural land cover classifications is not a new approach (see early references in Lo et al., 1986), quantitative assessments of its potential are still lacking, and it is necessary to update earlier results considering the state of the art in data mining and statistical learning. Full-band Landsat-7 time series were previously used by Van Niel and McVicar (2004) to classify four cereal crop types in the Coleambally Irrigation Area, Australia. In their study the SITS only included image dates that previously yielded the highest classification accuracies for each single crop in an iterative multi-date classification process of the whole time series. So, even though they did not utilize all the images of the SITS, their results showed per-class accuracies mostly above 80%.

The scarce attempts to classify crop types by full-band SITS may be attributed to some extent to the general assumption that using the complete spectral resolution of a multispectral image (e.g., from blue to short-wave infrared, SWIR, bands) may provide redundant or little additional information about crop condition compared with a synthetic measure such as the commonly used NDVI. However, the underlying assumption of an autocorrelation between band absorption and reflection features may not necessarily hold true for all vegetation types. For instance, throughout the phenological stages of some vegetation targets it has been found that variations in foliar chlorophyll and water content (sensitive at SWIR wavelengths) may not necessarily be proportional due to the numerous environmental factors affecting their physiological and structural properties (Ceccato, Flasse, & Gregoire, 2002; Ceccato, Flasse, Tarantola, Jacquemoud, & Grégoire, 2001). On the other hand, some image bands are usually avoided for many applications because they may contain a large amount of noise (e.g., blue and SWIR bands) even after atmospheric correction, yielding unreliable spectral signals (Jones & Vaughan, 2010; Peña & Altmann, 2009; Roberto et al., 2012). However, new satellite remote sensing technologies provide improved signal-to-noise ratios, and the capabilities of novel atmospheric correction algorithms to remove extraneous path radiance under a wide range of environmental conditions have been continuously enhanced (Liang, Li, & Wang, 2012; Roy et al., 2014). These advances have improved the quality of bands traditionally considered noisy.

In this paper we assessed the SITS-based classification of four major fruit-tree crop types in a study area located in central Chile during the 2013–14 growing season. We used all the cloud-free Landsat-8 images available for the season of interest. Three state-of-the-art statistical-learning classifiers were selected and applied at different training sample sizes on the full-band SITS, as well as on NDVI and NDWI (normalized difference water index) temporal profiles, and their accuracies were then assessed. The methods to be employed for the study area must consider the relatively small field size of the crops of interest, which precludes the use of MODIS products, as well as the absence of reliable auxiliary data on the phenology of the crops of interest. We expect to find optimal combinations of feature sets, classification techniques and training sample sizes to classify the crop types of interest, which may be transferable to nearby similar agricultural lands. This could result in the construction of less costly and more frequent crop inventories, which are currently updated in our study area at least every four years mostly by field campaigns.

2. Materials and methods

2.1. Study area

The study area is located in the Maipo River basin (15,157 km^2) in the Metropolitan Region of Chile south of the capital Santiago. The Mediterranean climate in which the basin is located is characterized by hot, dry summers and cool, wet winters, which results in hydrological regimes controlled by snowmelt in the Andean headwaters in spring