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Using spectrotemporal indices to improve the fruit-tree crop classification accuracy

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ABSTRACT

This study assesses the potential of spectrotemporal indices derived from satellite image time series (SITS) to improve the classification accuracy of fruit-tree crops. Six major fruit-tree crop types in the Aconcagua Valley, Chile, were classified by applying various linear discriminant analysis (LDA) techniques on a Landsat-8 time series of nine images corresponding to the 2014–15 growing season. As features we not only used the complete spectral resolution of the SITS, but also all possible normalized difference indices (NDIs) that can be constructed from any two bands of the time series, a novel approach to derive features from SITS. Due to the high dimensionality of this "enhanced" feature set we used the lasso and ridge penalized variants of LDA (PLDA). Although classification accuracies yielded by the standard LDA applied on the full-band SITS were good (misclassification error rate, MER = 0.13), they were further improved by 23% (MER = 0.10) with ridge PLDA using the enhanced feature set. The most important bands to discriminate the crops of interest were mainly concentrated on the first two image dates of the time series, corresponding to the crops' greenup stage. Despite the high predictor weights provided by the red and near infrared bands, typically used to construct greenness spectral indices, other spectral regions were also found important for the discrimination, such as the shortwave infrared band at 2.11–2.19 μm, sensitive to foliar water changes. These findings support the usefulness of spectrotemporal indices in the context of SITS-based crop type classifications, which until now have been mainly constructed by the arithmetic combination of two bands of the same image date in order to derive greenness temporal profiles like those from the normalized difference vegetation index.

1. Introduction

Remote sensing-based crop classification refers to the procedure through which different crop types are discriminated from imagery based on their spectral behavior throughout the optical spectrum. If the classification result is accurate enough, this procedure may contribute to efficiently designing and updating crop inventories. Nonetheless, to achieve that goal may be challenging as many crop types may exhibit similar spectral behavior during some phenological stages, particularly at the spectral resolution and bandwidth of multispectral images often used to perform the classification (Esch et al., 2014; McCoy, 2005). The accuracy of such procedures may therefore be strongly limited if just a single image acquired within a spectrally unsuitable temporal window is used (Jewell, 1989; Lo et al., 1986; Murakami et al., 2001; Van Niel and McVicar, 2004).

To deal with this shortcoming, a temporal sequence of images acquired at different dates across the entire growing season of the crops of interest (usually from spaceborne optical sensors) may be used, i.e., a satellite image time series (SITS). By using SITS the chances of successfully classifying crop types may increase as at different phenological stages they may exhibit distinct timings, which will likely translate into spectrotemporal separabilities that will favor their discrimination (Lo et al., 1986; Chen et al., 2008). SITS have been used widely to classify crop types, taking advantage of the spatially and temporally frequent image acquisitions made by the increasing number of Earth-observing satellites. The most common approach has been the retrieval of NDVI (normalized difference vegetation index) temporal profiles from a time series

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corresponding to the crops' growing season, thus providing a synthetic measure of the vegetation vigor or greenness across its main phenological stages (Odenweller and Johnson, 1984; Jones and Vaughan, 2010).

Most of the NDVI temporal profiles used for crop type classification purposes have been constructed from MODIS-derived NDVI composites, prepared and distributed by the Center for Earth Resources Observation and Science (EROS) of the USGS (United States Geological Survey) (Jakubauskas et al., 2002; Sakamoto et al., 2005; Xavier et al., 2006; Shao et al., 2010; Mingwei et al., 2008; Masialeti et al., 2010; Wardlow and Egbert, 2010; Arvor et al., 2011; Chenab et al., 2011; Zhong et al., 2011; Sibanda and Murwira, 2012; Sun et al., 2012). There are several reasons explaining the wide use of these products, among these: they record 16- or 32-days NDVI maximum, which increases the chances of depicting cloud-free areas. They are radiometrically processed, so no further corrections are needed. They cover large areas, reducing the need to mosaicking images with different illumination levels. Lastly, they are available for free from the website of the MODIS Science Team. In spite of these advantages, the use of MODIS-derived NDVI temporal profiles may be restrictive where crop fields are smaller than the MODIS image pixel size; ranging from 250 to 1000 m, depending on the NDVI composite. To overcome this limitation, an alternative may be to derive these profiles from a set of optical images with higher spatial resolution, like the ones acquired by the Landsat satellites (Badhwar et al., 1987; Turker and Arikan, 2005; Simonneaux et al., 2007; Zhong et al., 2014; Zheng et al., 2015). However, the Landsat's revisit period of 16 days increases the chances of missing some image dates due to excessive cloudiness, especially in humid climates. This issue may produce gaps across the NDVI temporal profile that could hinder the pursued classification.

Regardless of the optical images used, crop type classifications based on NDVI temporal profiles have yielded good results employing different classification algorithms (Arvor et al., 2011; Masialeti et al., 2010; Murakami et al., 2001; Ozdogan, 2010; Van Niel and McVicar, 2004; Zheng et al., 2015). Nonetheless, most of these studies have targeted graminaceous crops. These crops commonly have annual growth cycles with planting dates that may differ according to the species. As a consequence, they may exhibit distinctive budburst and greenup timings that facilitate their discrimination. Many of these crops are furthermore cultivated in annual rotations or double cropping systems. Therefore, they may exhibit distinctive harvesting and regrowth timings, which also aid in their discrimination. Instead, the classification of perennial crops like fruit-trees using NDVI temporal profiles has been addressed less frequently (Simonneaux et al., 2007; Zhong et al., 2011; Peña and Brenning, 2015). Unlike graminaceous crops, different fruit-tree crops may exhibit more similar mean timings in their phenological stages, making their discrimination a more challenging task, particularly if the image acquisition dates do not match with the stages at which inter-class spectral separability is maximized (Zhong et al., 2011).

It is noteworthy the lack of studies addressing crop type classifications by using the complete spectral resolution of SITS. Albeit it is not a new approach (see early references in Lo et al., 1986), few studies have been carried out during the last years (e.g., Van Niel and McVicar, 2004). It is reasonable to suppose that better classification accuracies can be achieved if all image bands (or spectral samples) throughout the time series are used as feature set instead of a greenness-related spectral index constructed from only two bands per image. This is simply because the full optical spectrum comprises wavelengths sensitive to vegetation properties other than greenness. For instance, short-wave infrared (SWIR) bands have been widely used as indicators of foliar water content and there are findings supporting their uncorrelatedness with greenness-related bands (Ceccato et al., 2001, 2002). Moreover, many optical sensors allow to construct a water content spectral index named NDWI (normalized difference water index), which is formulated in a similar way as the NDVI, but replacing the red band with a SWIR band centered around 1.24 μm (Gao, 1996). However, the application of this spectral index for SITS-based crop type classification purposes has been largely disregarded (Peña and Brenning, 2015).

Although using the full-band SITS may increase the chances of discriminating crop types, it also poses the challenge of efficiently processing large and eventually high-dimensional feature sets. In recent years, machine learning techniques have shown good capabilities to extract meaningful information from hyperspectral remote sensing data, which require dealing with hundreds of correlated bands, usually using limited training sets (Mountrakis et al., 2011; Bioucas-Dias et al., 2013). SITS are prone to producing spectral redundancies with increasing image and thus feature numbers. In SITS-based crop type classifications, correlations between bands may vary in time, depending on the image acquisition frequency and the phenology of the depicted crops. As with hyperspectral imaging, machine learning techniques may be applied to extract information from SITS-derived feature sets (Peña and Brenning, 2015). However, these techniques have been mostly used to detect changes on a limited number of land use/-cover types from a few image dates (Rodriguez-Galiano et al., 2012; Gómez et al., 2016) rather than to discriminate intraspecific classes, such as crop types, using larger SITS-derived feature sets.

Peña and Brenning (2015) classified four major fruit-tree crop types in central Chile applying different machine learning techniques and training sample sizes on a Landsat-8 time series. They used as feature sets both NDVI and NDWI temporal profiles, as well as the complete spectral resolution of the SITS. Classification accuracies, measured by cross-validation of the misclassification error rate (MER), were the best when using the full-band SITS (MER = 0.13–0.05), while NDVI temporal profiles had the worst overall performance (MER 4–13% higher than for full-band SITS and up to 3% worse than NDWI temporal profiles).

The present study assesses the classification of six major fruit-tree crop types in the Aconcagua Valley, central Chile, using a Landsat-8 time series corresponding to the 2014–15 growing season. The valley is inserted in the same climate region as the one studied by Peña and Brenning (2015), but exhibits different agrometeorological settings as well as fruit-tree species. We used as feature sets the full-band SITS and all the normalized difference indices (NDIs) possible of being constructed from any two bands of the SITS. The assumption regarding this NDI-based feature set was that it might contribute to improving the crop type classification as it comprises an extensive number of arithmetic band combinations from which distinct spectral signals may arise for different crop types.

Feature sets comprising all possible NDIs have been constructed from hyperspectral data to empirically relate them to canopy structure variables of native forest species (Peña et al., 2012) or to different crop diseases (Mahlein et al., 2013). Nonetheless, to our knowledge this is the first time that this type of feature set is used in the context of SITS-based classifications. Considering the findings of Peña and Brenning (2015), we decided to perform the classifications of interest using only linear discriminant analysis (LDA), as it had a superior performance than some other state-of-the-art machine learning techniques. In that study LDA was applied to classify similar crops as the targeted by us (fruit-trees) and from a time series comprised of Landsat-8 images as well. Nonetheless, to deal with the collinearity of the high-dimensional NDI-based feature set, in the present study we additionally consider two penalized LDA (PLDA) variants, which have shown their suitability to deal with hyperspectral imagery