Remote Sensing of Environment 171 (2015) 33–44

Contents lists available at ScienceDirect

Remote Sensing of Environment

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

Optimum spectral and geometric parameters for early detection of laurel wilt disease in avocado

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ARTICLE INFO

Article history:
Received 6 March 2015
Received in revised form 31 August 2015
Accepted 22 September 2015
Available online xxxx

Keywords:
Laurel wilt
Avocado
Spectral analysis
Aerial image
Vegetation indices
Early disease detection
Precision agriculture

ABSTRACT

Avocado (*Persea americana*) is a crop that is second in importance in Florida behind citrus with a wholesale value of $35 million and represents approximately 60% of the tropical fruit crop acreage. Laurel wilt (LW) is a lethal disease that has spread rapidly along the southeastern seaboard of the United States affecting commercial avocado production. This article evaluates the spatial and spectral requirements for quick and accurate detection of LW. Spectral data from healthy (H), Phytophthora root rot (PPR) and LW leaves were analyzed using ANOVA and two neural networks, multilayer perceptron (MLP) and radial basis function (RBF). The most effective wavelengths were identified and the filters were updated to a MCA-6 Tetracam camera (580–10 nm, 650–10 nm, 740–10 nm, 750–10 nm, 760–10 nm and 850–40 nm). Then, the MCA camera was used to take multispectral aerial images from a helicopter at three altitudes (180, 250 and 300 m) in an avocado field with trees at different stages of LW development, early, intermediate and late. The analyses were conducted based upon 2-class and 4-class systems. The 2-class system was designed to differentiate H and LW trees sufficient to identify trees for removal and the 4-class system was used to differentiate H plants and the three stages of LW development. Aerial image analysis proved the utility of the selected filters for successful identification of LW, even for trees in early stage of disease development with minimal symptoms. The ideal flight altitude of 250 m (15.3 cm pixel size) was selected according to the M-values and biological parameters such as canopy size and orchard size. The optimum VIs determined by higher M-values were $TCARI_{760-650}$ as well as GNDVI, NIR/G, Redge/G and VIGreen using any of the bands related to Redge (740 and 750 nm) or NIR regions (760 and 850 nm). Results reported on the utility of the 2-class and 4-class systems using the above VIs to discriminate LW; however it would be more convenient to develop the algorithm based on the 4-class system (H, early, intermediate and late). The early detection of LW through the methodology proposed in this research could allow farmers to control the movement of this disease through proper management strategies.

1. Introduction

Avocado (*Persea americana*) is an important fruit crop in Florida. It is second in importance in Florida behind citrus, with 30,700 t of fruit harvested in 2013 for a wholesale value of $35 million (Evans & Bernal Lozano, 2015). Fruit worth $24.4 million a year at the farm gate (USDA, 2013) are produced by 500 growers and handled by 30 registered avocado shippers (Flinn, 2014). This industry represents approximately 60% of the tropical fruit crop acreage in Florida (2800 ha), of which over 98% occurs in southeastern Miami-Dade County (Ploetz et al., 2012; USDA, 2014). Avocado production brings in substantial “new dollars” to Florida ($100 million per annum) (Evans & Bernal Lozano, 2015). Avocado trees form an important part of the urban canopy; backyard trees contribute economic, esthetic, and environmental benefits, adding as much as 10% to residential property values in South Florida (Evans & Crane, 2012). There are more than 250,000 urban avocado trees in the state of Florida (Pybas, 2009).

Avocado is the most important agricultural suscept of laurel wilt (Ploetz et al., 2011a). Laurel wilt (LW) is a lethal and complex disease that has spread rapidly along the southeastern seaboard of the United States since it was first reported in the Western Hemisphere in 2002 in Port Wentworth, Georgia (Ploetz, Hulcr, Wingfield, & de Beer, 2013; Rabaglia, Dole, & Cognato, 2006). In February 2011, LW was confirmed for the first time in Miami-Dade County, 10 miles north of Florida's main avocado production area in Homestead (Ploetz et al., 2011b). In 2012, it was first detected in the commercial avocado production area (CAPA) (Ploetz et al., 2013). By the end of 2014, the disease had been confirmed as far west as Claiborne County, LA, as far north as Sampson County, NC, and as far south as Miami-Dade County, FL (USDA, 2014). The rapid movement of LW has been due to the pathogen's mobile ambrosia beetle vectors, human transport of infested wood (e.g., firewood), and the presence of native and non-native plants susceptible to ambrosia beetle attack and laurel wilt throughout the

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http://dx.doi.org/10.1016/j.rse.2015.09.011

southeastern United States (Chemically Speaking Newsletter, 2009; Ploetz et al., 2011a).

LW is a recently introduced vascular disease caused by the Asian fungus *Raffaelea lauricola*, which has ambrosia beetle vectors, including *Xyleborus glabratus* (Fraedrich et al., 2008; Ploetz et al., 2012; Harrington, Fraedrich, & Aghayeva, 2008). The presence of the LW pathogen results in vascular plugging of the xylem, beginning as soon as three days after infection, thereby impeding the flow of water and nutrients (Ploetz et al., 2013). Wilting occurs soon after, with leaves rapidly changing from an oily green color to brown, and defoliation occurs within 2–3 months of the onset of symptoms (Ploetz et al., 2012). Many symptoms of LW are similar to those caused by other diseases or factors, such as freeze damage, Phytophthora root rot, Verticillium wilt, lightening and fruit stress (overbearing), which makes visual diagnosis of the disease difficult (Sankaran, Ehsani, Inch, & Ploetz, 2012). In addition, it is difficult to manage the disease once plants display external symptoms, since they develop only after significant colonization of the host by the pathogen occurs and fungicide movement and efficacy is dramatically reduced in such trees (Inch & Ploetz, 2012; Ploetz et al., 2011b). Thereby, the early detection of LW (trees with minimum symptoms) could be a valuable source of information for executing proper disease control measures to prevent the development and the spread of the disease (Sankaran, Mishra, Ehsani, & Davis, 2010).

While other diseases can kill avocado trees, none of them develop as quickly as LW (Ploetz et al., 2012). In Florida, it is estimated that losses of $27 to 54 million could occur if reliable control strategies are not developed (Evans, Crane, Hodges, & Osborne, 2010; Ploetz et al., 2012), while the cost to replace trees destroyed by the disease would be around $423 million (Evans & Crane, 2012). Moreover, there is a major concern that LW will spread to California, the leading producer in the United States, and Mexico, the world's top producer (Evans et al., 2010; FAO, 2010; Ploetz et al., 2012).

Sanitation is an important step in managing LW (Ploetz & Carrillo, in press), but accurate and rapid measures are lacking (Sankaran et al., 2012). Currently, symptomatic trees are detected, infection by *R. lauricola* is confirmed via laboratory analyses, and positive trees are removed and destroyed as quickly as possible. An early detection technique to replace this time-consuming and expensive method could be quite useful in mitigating the development and spread of this disease (De Castro, Ehsani, Ploetz, Crane, & Buchanon, 2015). Sankaran et al. (2012) proved that LW could be detected with visible-near infrared spectral reflectance data from leaves of *R. lauricola*-infected plants, even asymptomatic or trees with minimum symptoms.

By applying multivariate analysis tools, such as neural networks, it is possible to detect significant spectral difference and classify spectral data into agronomical classes (De Castro, Jurado-Expósito, Peña-Barragán, & López-Granados, 2012; Han, Kamner, & Pei, 2012). Neural networks, together with naïve Bayesian classifier, support vector machines, and decision trees, are considered the more advanced techniques for data classification (Han et al., 2012). Neural networks allow the exploration of relationships or models that could not be detected using traditional statistical procedures (Rzempoluck, 1997). Furthermore, neural networks offer some advantages over those advanced techniques, such as high flexibility and adaptability to the results, high tolerance of noisy data and errors, ability to classify non-trained patterns, capacity to work when low knowledge of relationships between attributes and classes conditions exist, and high computation process speed (Han et al., 2012). Those advantages contribute to make neural networks one of the most useful classification predictors in data mining (Rogan et al., 2008). Neural networks and spectral data have been previously used in a wide array of real-world data, such as estimating crop areas (Heremans, Bossyns, Eerens, & Van Orshoven, 2011), mapping land-cover modifications (Rogan et al., 2008), and selecting a subset of several wavelengths or vegetation indices for detection of biotic and abiotic stresses in plants (De Castro et al., 2012; Estep, Terrie, & Davis, 2004; Wu, Liu, Zhou, Yan, & Zhang, 2012).

Usha and Singh (2013) and Sankaran et al. (2010) reviewed the potential for image-based remote sensing to detect diseases of crops. Multispectral aerial imaging has been used to detect, monitor and quantify diseases of tomatoes (Zhang, Qin, & Liu, 2005), winter wheat (Dammer, Möller, Rodemann, & Heppner, 2011), creeping bentgrass (Raikes & Burpee, 1998), cranberries (Pozdnyakova, Oudemans, Hughes, & Giménez, 2012), olives (Calderón, Navas-Cortés, Lucena, & Zarco-Tejada, 2013) and citrus (Du, Chang, Yang, & Srilakshmid, 2008; García-Ruiz et al., 2013). Remote sensing tools can significantly improve disease detection if the spectral and spatial properties of remote sensing equipment are sufficient to detect differences in spectral reflectance (López-Granados, 2011). Some authors have evaluated image spatial and/or spectral properties required for agriculture applications. For example, García-Ruiz et al. (2013) studied the effect of image resolution on classification performance by comparing a multi-band imaging sensor with a hyperspectral imaging system to detect Huanglongbing in citrus; better accuracies in classification were obtained when high-resolution multi-band images where used. Sankaran, Khot, Maja, and Ehsani (2013) and Torres-Sánchez, López-Granados, De Castro, and Peña-Barragán (2013) tested spectral and spatial properties of imagery sets taken at different altitudes to detect stress in citrus orchards and discriminate weed seedlings. Gray, Shaw, Gerard, and Bruce (2008) concluded that high spatial and spectral resolutions were needed to detect early season weeds in multispectral images of soybean fields. Successful image analyses clearly rely on defining the correct spatial and spectral resolution.

De Castro et al. (2015) reported on the utility of red-edge, green and blue aerial images to detect LW on avocado. They confirmed that the contrast between visible bands was enough for the accurate discrimination of a tree affected by LW once external symptoms had fully developed. However, they suggested that a higher spectral resolution camera with a greater band number and narrower wavelengths would be needed to detect infection by *R. lauricola* before symptoms developed.

The objective of the present study was to evaluate the spatial and spectral requirements for quick and accurate detection of LW for the future purpose of developing a LW classification algorithm. The research was divided in two parts; in the first part of this study, spectral analysis was carried out under controlled conditions, and in the second part, image analysis was performed at canopy level in a commercial avocado field. The specific goals were to: i) select the best multispectral wavebands to efficiently discriminate affected trees and select those filters to attach to a multiband camera; ii) quantify the influence of image spatial resolution (i.e. flight altitude) in the detection of affected trees; and iii) establish the best vegetation indices and number of classes in order to develop the classification algorithm.

2. Material and methods

2.1. Part 1: laboratory data—spectral analysis

2.1.1. Host inoculation

Leaves were obtained from potted 'Simmonds' avocado trees grown in a temperature-controlled greenhouse at the University of Florida's Tropical Research and Education Center (TREC) in Homestead. To induce LW, 10 plants were inoculated approximately 5 cm above the soil level by drilling four small holes around the circumference of the trunk, each of which received 750 conidia of *R. lauricola*, for a total of 3000 plant^{-1}. By 14 days after inoculation (DAI), slightly early symptoms of LW had begun to develop in some of the leaves. To induce Phytophthora root rot (PRR), 10 plants were inoculated by infesting each of 10 pots with 6 g of wheat seed colonized with *Phytophthora cinnamomi*. After 14 days, early symptoms of PRR appeared in the form of yellowing of some leaves. For comparison, healthy (H) leaves were obtained from potted plants grown in full sun.