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Identification of purple spot disease on asparagus crops across spatial and spectral scales

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ABSTRACT

Purple spot caused by the fungus *Stemphylium vesicarium* is a disease that causes heavy damage in asparagus crops. It infects the leaves and stem and results in degradation of the quality in the harvested asparagus shoots, lowering their commercial value. Precautionary spraying with fungicides is practiced to prevent its appearance, posing a threat to consumers and the environment. The aim of this work was to evaluate the ability of visible and near-infrared field spectroscopy (UNISPEC-DC) to identify the appearance of the purple spot symptoms at the level of asparagus plants and the ability of very high resolution (Pleiades-1A) and wide area (Landsat 8) satellite images to map fungal distribution within asparagus fields and across the river plain, respectively. Field measurements were used as reference to select the optimum infection identification models. Results indicate that field spectroscopy and wide area remote sensing can be used to create sufficiently accurate quantification models of disease severity in asparagus plants (R^2 = 0.83 and RMSE = 9.68%) or across asparagus fields (R^2 = 0.85 and RMSE = 8.26%). The accuracy drops when using satellite data to quantify infection within field (R^2 = 0.34 and RMSE = 13.13%). The contributing wavelengths, bands and indices can be utilized to provide timely information to farmers and agronomists in order to support precision plant protection applications.

1. Introduction

Plant pathogens are the cause of major losses in production and economy in agriculture worldwide. Plant infections from pathogenic fungi, such as *Stemphylium vesicarium* (Wallr.) E.G. Simmons (1969) (teleomorph: *Pleospora herbarum* (Pers.) Rabenh. (1857)), affect photosynthesis, respiration and transpiration (Agrios, 2005). *S. vesicarium* is a fungal pathogen that causes heavy damage in *Asparagus officinalis* L. (1753) crops (Koike et al., 2007). It infects the leaves and results in degradation of the quality in the gathered asparagus shoots, causing significant loss of farmers' income. The applied fungicides are used preventively and precautionary and result in high costs, potential threats to consumer health and pollution of the agricultural and natural ecosystems. Thus, reliable and accurate assessments of disease identification are very important to anticipate the damage and take the necessary measures (Pethybridge et al., 2008). At the same time, accuracy of visual in-situ disease assessments carried out by different expert raters is subjective which often leads to overestimation or underestimation of disease severity levels (Guan and Nutter, 2003; Nutter et al., 2006).

Many attempts have been made during the past years to develop reflectance spectroscopy as an accurate method for the early detection of plant diseases (Moshou et al., 2005). The emphasis of these efforts is often to apply precision agriculture. Specifically, precision plant protection focuses in temporal and spatial accuracy and speed in detection, resulting in more efficient treatment with the use of agrochemicals. This has an immediate environmental and economic effect. Moshou et al. (2004) concluded that some crop diseases usually appear in patches in the field, resulting in unnecessarily sprayed spaces. During recent years there has been increasing pressure to reduce phytochemical inputs and plant disease protection would be much more effective if the aforementioned infected patches could be identified and individually sprayed. Recent advances in remote spectral sensor technologies and mapping can support methods for the immediate detection of leaf diseases (di Gennaro et al., 2016).

Proximal sensing is one of the many tools utilized in precision agriculture to achieve low-input farming, and is being used for various applications such as variable-rate fertilization, pesticide sprayings and plant disease identification and quantification, as well as forecast. The above-mentioned applications rely on sensors to record spectral

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reflectance from plant canopy, and attribute the collected data variance on the physiological alterations due to fluctuations in environmental factors. According to Zhang et al. (2003) the physiological reaction of infected plants results in alterations of spectral reflectance because of the continuous depletion of chlorophyll and the modification of internal tissue structure. Chlorophyll concentration is known to be reduced when a plant is under disease stress and the reflectance is increased in the red region of the spectrum. High spectral reflectance in the near infrared spectral range is attributed to the internal structure of healthy leaves. Plants subjected to disease stress reveal various scales of internal (cellular) structure changes, a process that results in the subsequent increase in spectral reflectance in the red region (620–750 nm). The reverse effect occurs in the near infrared (NIR) part of the spectrum (750–2500 nm), where reflectance is higher from healthy plants and lower from infected plant tissues (Zhang et al., 2003). Spectral sensors can provide useful information about changes in plant vitality, based on reflectance alterations, due to changes in biophysical and biochemical plant tissue characteristics. Infections may cause variations to tissue color and leaf shape, to transpiration rate and to foliage morphology and density, and therefore change the optical characteristics of the plant. These reaction patterns depend on the host-pathogen relationship, consequently the wavelengths relevant to disease detection are dependent on respective symptoms (Mahlein et al., 2012).

The visible and near-infrared (NIR) regions (750–2500 nm) of the spectrum provide the majority of the required information concerning physical stress levels in plants (Muhammed, 2005; Xu et al., 2007), thus these wavelengths are likely to be useful for disease assessment. In their research, Sankaran et al. (2011) used visible and NIR spectroscopy techniques in a citrus orchard to detect and classify the Huanglongbing (HLB) disease caused by the phloem-limited bacterium *Candidatus liberibacter asiaticus*, that causes chlorosis in leaves. A portable spectrometer was used for reflectance measurements. The recorded data were normalized, pre-processed and Principal Component Analysis (PCA) was applied. Various algorithms were tested to identify the optimum model (Linear Discriminant Analysis (LDA), Quadratic Discriminant Analysis (QDA), Partial Least Squares – Discriminant Analysis (PLS-DA), k-nearest neighbour, SIMCA analysis (Soft Independent Modelling of Class Analogy)). The highest possible result in detecting HLB infected leaves was reached using 2nd derivatives of the spectra in data pre-processing along with QDA, with 98% accuracy.

Remote sensing, employing both satellite and Unmanned Aerial Vehicle (UAV) sensors, has been successfully used in a number of works (experimental and control techniques) for mapping plant diseases. The results vary depending on the resolution and the sensitivity of the employed sensor. Calderón et al. (2013) succeeded in creating an early detection system for infection by pathogen *Verticillium dahliae* in olive orchards by utilizing a combination of spectral, structural and physiological indices, and thermal imaging and chlorophyll data. In their study, Candiago et al. (2015) investigated the ability of UAV remote sensing to assess vegetation health in vineyards and tomatoes. Data derived from a UAV-mounted, multispectral camera (Tetracam) were used to create vegetation indices (NDVI, GNDVI, SAVI) in order to examine vegetation vigour. Results pointed out that fast, multi-temporal, high-resolution, accurate and low-cost vegetation health assessment can be achieved by usage of UAV multispectral data. Santoso et al. (2011) investigated the ability of QuickBird satellite images to identify rot symptoms in oil palm trees and map the disease caused by the fungus *Ganoderma boninense*. Preliminary tests were made concerning the distinction of the disease on palm trees and different objects, based on red band data. Six different vegetation indices, from the visible and NIR bands, were used to identify infected oil palm trees. Finally, in-situ sampling was used to assess and validate the remote sensing method of identification. Their results show that they succeeded in mapping infected regions with 84% precision. The tested indices had various success rates per field applied, ranging from 59% to 67%. This research suggests that high-resolution imagery from satellites (QuickBird, Pleiades, Worldview etc.) offer a fast, detailed and accurate identification method to map the location and extent of the disease in oil palm trees.

Host population, biotic and abiotic risk factors and yield output data can be mapped, overlaid and displayed in various scales (at plant, crop, field, cooperative or wider levels), thus clarifying correlations (external stimulus – reaction) between data levels (Hijmans et al., 2000; Liu et al., 2008; Nutter et al., 2006, 2010; Pethybridge et al., 2009). However, according to Auernhammer (2001), plant disease mapping and sensor monitoring are not broadly applied with remote and proximal sensing, due to technical difficulties in its application such as unsatisfactory accuracy, difficulty utilizing data from remote sensors in plant-level applications and large volume of calculations that hinders the development of real-time systems. Although recent works have contributed to the optimization of the aforementioned drawbacks, such as accuracy problems concerning the spatial and spectral analysis of monitoring instruments, most still remain, specifically in the creation of identification models for crop diseases. This is because identification requires specific data and field measurements for each pathogen and each crop in which they are to be applied, demanding laborious and lengthy operations.

Despite its importance for the agricultural sector, the identification of *S. vesicarium* infection on *A. officinalis* with remote and proximal sensing has not been studied. The aim of the study was to provide models of the highest accuracy possible for the quantification of the effects of the fungal infection on three scales: **at plant level**, **within each field** and **across asparagus fields on the Nestos river plain**. The specific objectives were: (i) to evaluate the ability of visible and NIR spectroscopy (portable spectrometer, UNISPEC-DC) to identify the presence of the purple spot disease caused by *S. vesicarium*, (ii) to evaluate the ability of Very High Resolution (VHR) satellite images (Pleiades-1A) to map the disease incidence within asparagus fields and (iii) to evaluate the ability of wide area satellite images (Landsat 8 OLI) to map the appearance of the disease across the Nestos river plain.

2. Materials & methods

2.1. Study area

The Nestos river plain is located in Eastern Macedonia – Thrace, in northern Greece (Fig. 1). It covers an area of approximately 675 km^2. The elevation is 8 m above mean sea level, the topography is approximately flat and the soil is sandy clay, with 1.5% organic matter content, the climate is Mediterranean, with hot, dry summer and rainy spring and autumn. Mean annual precipitation is 560 mm. Irrigation water is diverted from the river and delivered through irrigation canals, or pumped from the shallow aquifer. Asparagus is one of the main economically important cultivated crops in the study area, together with rice, fruits, maize, alfalfa and other vegetables.

The first symptoms of infection by the fungal pathogen *S. vesicarium* appear in July or August in the study area, depending on temperature and humidity. Since there is no available information concerning early warning or spread of the disease, farmers in the study area are forced to utilize large quantities of fungicides (ROVRAL Aquaflo 50 SC, BASF – active ingredient: Iprodione) annually, applied regularly and uniformly.

2.2. Datasets

2.2.1. Estimation of infections – reference data

Three test fields (Field 1 – 1.8 ha, Field 2 – 1.5 ha, Field 3 – 0.8 ha) were selected for detailed measurements (Fig. 2), where asparagus cv. 'Dariana' was in the fourth year of cultivation. The field surveys took place on 20/08/2014, when the symptoms of the purple spot were at their peak.

The method of simple random sampling was used for 20 locations in each of the 3 fields. For the aboveground part of each plant the disease