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Remote sensing of spider mite damage in California peach orchards

Eike Luedeling [a], Adam Hale [a], Minghua Zhang [a,*], Walter J. Bentley [b], L. Cecil Dharmasri [c]

[a] *Department of Land Air and Water Resources, University of California, Davis, CA 95616, USA*
[b] *University of California Integrated Pest Management Program, Kearney Agriculture Center, Parlier, CA 93648, USA*
[c] *Syngenta Crop Protection, Inc., Greensboro, NC 27409, USA*

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ABSTRACT

Remote sensing techniques can decrease pest monitoring costs in orchards. To evaluate the feasibility of detecting spider mite damage in orchards, we measured visible and near infrared reflectance of 1153 leaves and 392 canopies in 11 peach orchards in California. Pairs of significant wavelengths, identified by Partial Least Squares regression, were combined into normalized difference indices. These and 9 previously published indices were evaluated for correlation with mite damage.

Eight spectral regions for leaves and two regions for canopies (at blue and red wavelengths) were significantly correlated with mite damage. These findings were tested by calculating normalized difference indices from the Red and Blue bands of six multispectral aerial images.

Index values were linearly correlated with mite damage ($R^2 = 0.47$), allowing identification of mite hotspots in orchards. However, better standardization of aerial imagery and accounting for perturbing environmental factors will be necessary for making this technique applicable for early mite detection.

1. Introduction

Remotely sensed information is increasingly being used in modern agricultural production systems. While most efforts to detect crop statuses or processes affecting crops have focused on field crops (e.g., Idso et al., 1977; Wiegand et al., 1979; Tucker et al., 1981; Carley et al., 2008), several recent studies have looked into applications of remote sensing techniques in orchards. Perez-Priego et al. (2005) and Suarez et al. (2008) used spectral signatures of olive leaves and canopies for detecting water deficiency, while Sepulcre-Canto et al. (2007) related spectral information with olive yield and fruit parameters. In citrus, Ye et al. (2007) related the electromagnetic reflectance of canopies to yields, whereas Min and Lee (2005) used remotely sensed vegetation indices to approximate leaf nitrogen content. Other researchers have used remote sensing to estimate the chlorophyll content of orchard crops (Zarco-Tejada et al., 2004), the extent of chilling injury on citrus fruits (Menesatti et al., 2005) or infection of apple leaves with the fungus *Venturia inaequalis* (Cooke) Wint., the causal agent of apple scab (Delalieux et al., 2007).

In California, remote sensing is widely used in field crop production (Zhang et al., 2002, 2003, 2005; Fitzgerald et al., 2004; Qin and Zhang, 2005; Wang et al., 2008), but has so far found little to no application in tree crops. Due to the large extent of the fruit and nut production area in the state and the high value of the crops that are produced, improved monitoring and management strategies are needed to remain competitive in the increasingly global market for tree and nut crops. Such innovations are also necessary to meet presumably rising irrigation water costs and to manage agricultural pests in the face of tightened pesticide regulation.

Growers of peaches (*Prunus persica* L.) in California are currently facing particular economic strains. Historically, profit margins have been high for California peach growers, because of the state's favorable climate and strong domestic demand for fresh and canned peaches. In recent years, however, competition by foreign producers has increased substantially, with the value of imports from Chile already amounting to a quarter of the value of the national production (CDFA, 2008; FAO, 2008). This competition has led to a 9% decrease in the peach production area and a 27% drop in total production in California between 2004 and 2006 (CDFA, 2008).

Since farm wages cannot realistically be expected to decrease, technological progress seems the most viable way forward to increase the competitiveness of peach production in California. Remote Sensing can be a valuable tool for thoroughly monitoring orchards at low cost at a spatial resolution that is high enough to allow site-specific, economically favorable management strategies. Such strategies offer potential to reduce monitoring costs and enhance resource use efficiency, thus lowering total production

* Corresponding author.
E-mail address: mhzhang@ucdavis.edu (M. Zhang).

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costs and increasing the profit margins of farming operations. In peach production, such monitoring could be particularly useful in controlling and managing web-spinning spider mite damage early in the season.

While most other pests can be controlled quite effectively with one combined pesticide application early in the season, spider mite populations are often promoted by the early season pesticides, because these diminish the populations of mite predators, which then lag in numbers behind the proliferating mites. Consequently mite damage, caused mostly by the Pacific Spider Mite (*Tetranychus pacificus* McGregor) and the Two-spotted Mite (*Tetranychus urticae* Koch) in California peaches, typically occurs in the middle or towards the end of the growing season, requiring an extra spray, which according to the standard costs manual for peach production in California incurs additional costs of about 150 US\$ ha^{-1} (Day et al., 2004).

In addition to being a cost factor, the typically applied and most effective miticides are classified as 'dangerous', and long Pre-Harvest Intervals (PHI) of up to 21 days have been imposed by the State of California (Fouche et al., 2000). For the most common miticide (active ingredient: propargite) used in California, the Restricted-Entry Interval (REI), during which the orchard can only be entered with protective clothing, is 21 days, more than ten times as long as for all other chemicals listed by Fouche et al. (2000). A miticide application can thus seriously disrupt the work flow in the orchard. Early detection of mite infestation would be highly desirable, since it would allow spraying against mites earlier in the season, allowing a better timing of late-season crop management and harvest. It would also facilitate more targeted control of mite hotspots in orchards or the more selective application of lower risk but more costly alternative miticides with shorter PHIs and REIs, thereby allowing growers to cut costs and reduce the orchard area that cannot be entered.

Mite hotspots often occur near the overwintering sites of adult females in protected places on trees or in litter, trash and weeds on the orchard floor. After becoming active in spring, mites begin feeding on weeds or lower parts of the peach trees (Pickel et al., 2006). They are favored by hot, dry conditions, and as temperatures rise during the spring and summer, they multiply and move up to the center of the tree, until the entire tree is infested. Dusty conditions in orchards often accelerate economically consequential mite damage, since mites are transported onto higher leaves with dust particles (Pickel et al., 2006). Consequently, mite infestations often occur first near dusty orchard roads.

Fitzgerald et al. (2004) showed that detection of mite damage in cotton (*Gossypium hirsutum* L.) caused by the strawberry spider mite (*Tetranychus turkestani* Ugar. & Nik.) using hyperspectral imagery is technically possible, and Peñuelas et al. (1995) detected damage caused by European Red Mites (*Panonychus ulmi* Koch) on apple trees.

The objective of this study was to test the feasibility of using remote sensing techniques for the detection of spider mite damage in peach orchards. To achieve this, we aim to identify suitable spectral wavelengths, the reflectance at which is correlated to mite damage on the leaf and on the canopy level. Furthermore, we will test, whether mite damage can be detected on multispectral aerial images. Finally, we will discuss the potential and limitations of applying remote sensing techniques to detect mite damage in California peach orchards.

2. Materials and methods

2.1. Study sites

This study was conducted in eleven peach orchards in Fresno and Kings Counties in California (Fig. 1). Three orchards were located at the University of California's Kearney Agriculture Center (KAC). All other orchards were privately managed by four growers. One of these growers operated two orchards (sites A and B in Fig. 1), and another grower's property was split into four subsections because of different varieties and planting densities in the orchard. These four orchards (site E in Fig. 1) were managed organically.

2.2. Sample collection and analysis

2.2.1. Leaf samples

A total of 1132 peach leaves were collected from nine orchards throughout the growing season of 2007. Leave samples were collected during calendar weeks 23, 25, 27, 30 and 32 (May 17th to July 19th). Because of the large number of study sites, not all orchards could be sampled at all points in time. To ensure comparability between the sampled leaves, all leaves were picked at a height of 2.5 m or less and from all regions of the canopy. Leaves that appeared abnormal, physically damaged or affected by pests other than mites were excluded from sampling. Only full-sized mature leaves were selected for further analysis. Care was also taken to select leaves from all areas of the orchards to make sure that all variation in environmental, microclimatic and soil conditions within the orchards was covered by leaf samples. All leaves were placed in sealed plastic bags and stored on ice until analysis.

Spectral data was collected under controlled conditions using an ASD FieldSpec Pro Field Spectroradiometer (Analytical Spectral Devices Inc., Boulder, CO, USA), which measures spectral reflectance between 350 and 2500 nm. The spectral resolution of this instrument is 3 nm at wavelengths between 350 and 1000 nm, and 10 nm for longer wavelengths, with spectral sampling intervals of 1.4 and 2 nm, respectively (ASD, 1999). Reflectance is expressed relative to the reflectance of a standardized white calibration surface. For measuring the leaf reflectance, a specially designed plant probe and leaf clip assembly device was attached to the instrument's fiber-optic cable to ensure standardized environmental conditions for reflectance measurement.

After calibrating the spectroradiometer according to the manufacturer's instructions, all leaf samples were reinspected for meeting the above requirements for comparability. For assessing the damage of each leaf, we then selected a region centering on the middle rib of the leaf. For this circular region with a diameter of 2.1 cm (area of 3.5 cm^2), we assessed the damage as an estimated percentage of the area that had sustained mite damage. Damage percentages were assigned in increments of 5 percentage points, except for very minor mite damage, which received a damage score of 1%. We preferred this damage assessment method over plant stress-based approaches, such as chlorophyll fluorescence (Bounfour et al., 2002), since methods based on damaged leaf surface area have been shown to more accurately describe the severity of mite damage (Skaloudova et al., 2006). A visual assessment was preferred over a computer-based approach (Skaloudova et al., 2006), since it allowed a larger number of samples to be analyzed and a clearer distinction between leaf damage caused by feeding spider mites vs. other plant stressors. Spider mites feeding on peach leaves cause a distinct mottling of the leaves, which can easily be distinguished from discolorations due to nutrient and water deficiency and most other pests and diseases (Pickel et al., 2006). Subsequently, the leaves were placed in the leaf clip device, and spectral reflectance patterns were determined as an average of three replicate measurements. To remove a jump in the spectral datasets at 975 nm, probably caused by spectral overlap between the three spectrometers included in the spectroradiometer (ASD, 1999), we used the jump correction algorithm in the software Spectral