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Reflectance characteristics of Russian wheat aphid (Hemiptera: Aphididae) stress and abundance in winter wheat

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Abstract

The Russian wheat aphid (*Diuraphis noxia* (Mordvilko)) infests wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and other small grains and grasses. Russian wheat aphid infestations are unpredictable in time and space. In favorable conditions, Russian wheat aphid feeding can result in heavy damage to wheat and barley in a short period of time. A repetitive monitoring strategy that allows for rapid assessment of aphid infestation and damage over the growing season is critically needed. Tracking the irregular infestation patterns of Russian wheat aphid in order to optimize control efforts is central to the successful management of this aphid. One method that has been shown over a number of years to be useful for monitoring some insect outbreaks is to measure the light reflected by the infested canopy, plant, or leaf. Hence, this research was designed to investigate: (1) the potential use of remotely sensed data to discern and identify differences in spectral reflection patterns (spectral signatures) of winter wheat canopies with and without Russian wheat aphid infestation, and (2) the relationship between spectral indices and Russian wheat aphid abundance in wheat canopies growing in field conditions. Russian wheat aphid-infested wheat canopies had significantly lower reflectance in the near infrared region and higher in the visible range of the spectrum when compared with noninfested canopies. Linear regression analyses showed that there were varying relationships between Russian wheat aphid density and spectral vegetation indices, with coefficients of determination (r^2) ranging from 0.91 to 0.01. These results indicate that remote sensing data have the potential to distinguish damage by Russian wheat aphid and quantify its abundance in wheat. However, success for Russian wheat aphid density estimation depends on the selection of spectral vegetation indices.

Keywords: Aphid infestations; Remote sensing; Russian wheat aphid; Spectral signatures; Spectral indices; Wheat

1. Introduction

One of the major insect pests of wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and other small grains and grasses worldwide is the Russian wheat aphid, *Diuraphis noxia* (Mordvilko) (Vandenberg et al., 2001). Plant stress from the Russian wheat aphid is a combination of developmental, biochemical, physiological, and morphological responses. Plant growth stages, time and duration of the feeding, nutritional status of the host plants, aphid abundance,

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and environmental factors affect plant responses to aphid infestation (Macedo et al., 2003). While feeding, Russian wheat aphid injects a toxin into the plants. This toxin is responsible for many of the stress symptoms, the most characteristic of which are white or reddish-purple longitudinal streaks on the leaves and sometimes the stem (Kazemi et al., 2001; Unger and Quisenberry, 1997; Burd and Burton, 1992). Heavily infested plants are stunted leading to reductions in dry weight, leaf area, and chlorophyll concentration (Riedell and Blackmer, 1999; Gilchrist et al., 1984; Burd et al., 1994; Miller et al., 1994).

Although the Russian wheat aphid is widely distributed, the economic impact to small grains mostly and frequently occurs in South Africa, the US, and Canada (Lage et al., 2004; Archer and Bynum, 1992). Since its discovery in Texas, it has rapidly spread across the US and infested wheat and barley fields of 17 western states and three Canadian provinces (Legg et al., 1994; Kindler et al., 1992; Jones et al., 1989). Studies indicated that economic injury levels due to Russian wheat aphid feeding in small grains can vary within a given region (Randolph et al., 2003; Archer and Bynum, 1992; Archer et al., 1998; Gray et al., 1990). Therefore, the economic injury levels were calculated for areas in which Russian wheat aphid frequently and significantly damages to wheat and barley. Archer and Bynum (1992) reported that there were 0.46 and 0.48% yield losses for each 1% increase in damaged and infested tillers, respectively, at the pre-heading growth stage in TX. The economic injury level for the spring infestations was 0.9 aphid per seven plants at seven tiller growth stage in Kansas (Girma et al., 1993). Archer et al. (1998) reported that the yield losses were ≈1% and 0.67% per percentage infested or damaged tiller at two tiller growth stage in Montana and Washington, respectively. Archer et al. (1998) reported that the yield losses were 0.5% per percentage infested or damaged winter wheat tillers at the growth stages 31 in Colorado. Winter wheat yield loss due to Russian wheat aphid infestation was 37% in the Canadian Prairies (Butts et al., 1997).

Cumulative economic losses from Russian wheat aphid infestation in wheat and barley in the US have been estimated at nearly $1 billion since 1987 (Webster et al., 2000). Of this damage, nearly 60% has occurred in the Texas and Oklahoma Panhandles, northeastern Colorado, western Kansas, and southwestern Nebraska (Smith et al., 2004). The Russian wheat aphid infestations are unpredictable in time and space (Elliott et al., 2005). In favorable conditions, Russian wheat aphid feeding can result in heavy damage to wheat and barley in a short period of time.

A repetitive monitoring strategy that allows for the rapid assessment of aphid infestation and damage over the growing season is critically needed. Tracking the irregular infestation patterns of Russian wheat aphid in order to optimize control efforts is central to the successful management of this aphid. One method that has been shown over a number of years to be useful for monitoring some insect outbreaks is to measure the light reflected by the infested canopy, plant, or leaf. The health of a plant can be readily determined by measuring the relative intensity of visible and near infrared (NIR) light reflected from its leaves and studying changes in plant growth. Optical properties of mature and healthy green leaves or vegetation are characterized by high absorption in the blue (400–500 nm), increased reflection in the green (500–600 nm), high absorption in the red (600–700 nm), and very high reflectance and transmittance in the NIR (700–1500 nm) (Gates, 1970). Spectral responses of vegetation in the visible (400–700 nm) region are primarily governed by the abundance of chlorophylls, carotenoids, and anthocyanins (Broge and Mortensen, 2002; Sims and Gamon, 2002; Gamon and Surfus, 1999; Peñuelas and Filella, 1998). The optical properties of vegetation in the NIR are due to the discontinuities between cell walls and intercellular air spaces in internal leaf structure (Peñuelas and Filella, 1998). Changes in pigment concentrations as well as internal leaf structure are strongly related to the physiological status (Blackburn, 1998a,b), and, consequently, spectral features of vegetation. During the interaction between stressors and their host plants, the physiological state of the invaded tissue is altered, which reflects the changes in photosynthesis, transpiration, metabolism, and temperature (Peñuelas and Filella, 1998). Ultimately, stressors lead to poor growth, loss of vigor, and eventually death of plants or vegetation (Richardson et al., 2004). Therefore, within a given growth condition, reflectance measurement, namely remote sensing, seems to be very effective to differentiate stressed and unstressed plants or vegetation.

Spectral indices combine spectral information contained in two wavebands or more, usually in the visible and NIR or both. Spectral indices aim to increase the extraction of optimal spectral information from the objects of interest. A few spectral indices among many were created to retrieve spectral information on vegetation stress caused by biotic stressors. Peñuelas et al. (1995a) designed the normalized phaeophytinization index (NPQI) to estimate cumulative mite (*Panonychus ulmi* Koch) days on apple trees (*Malus domestica*). Apan et al. (2004) created the Disease-Water Stress Indices ($DWSI_{1-5}$) to evaluate orange rust disease on sugarcane (*Saccharum* spp.). However, these indices have not been largely used or tested for different stressors.