AIRBORNE MULTI-SPECTRAL REMOTE SENSING FOR RUSSIAN WHEAT APHID INFESTATIONS

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ABSTRACT

The Russian wheat aphid (RWA) is a severe pest of wheat in the High Plains region of the United States. Remote sensing could be effective for detecting RWA infestations for pest management decision-making. We evaluated an airborne multi-spectral remote sensing system for its ability to differentiate varying levels of injury caused by RWA infestation in winter wheat fields. Two study fields were located in southeastern Colorado in spring 2004, and two fields were located in far western Oklahoma in spring 2005. In each field, RWA density and plant damage were determined for 20-24 3x3 m plots with varying levels of RWA damage. Prior to sampling plots, multi-spectral imagery was obtained using an SSTCRIS® multi-spectral imaging system mounted NADIR in a Cessna 172 aircraft. The multi-spectral data were used to compare with RWA infestation level for each plot. Correlations between vegetation indices and the proportion of RWA damaged wheat tillers per plot were negative for all vegetation indices calculated. NDVI and VI were most consistently correlated with the proportion of RWA damaged tillers. Regressions of NDVI versus the proportion of RWA damaged wheat tillers per plot were significant and had negative slopes. However, slopes and intercepts of regressions differed significantly among fields. Any one or a combination of differences in time of day, atmospheric conditions, edaphic factors (e.g. soil type and soil moisture), and possibly unknown factors could have caused the differences observed in regressions among fields.

INTRODUCTION

The Russian wheat aphid (RWA) is a severe pest of wheat in the High Plains region of the United States. The RWA is an introduced invasive species, first detected in the US in 1986 (Stoetzel 1987). The RWA has caused over $1 billion in losses to the wheat industry since its introduction (Webster et al. 2000). The RWA is small (< 1/10 inch) and pale green to grayish in color. Its population explosions cause a rapid progression of crop damage. Severe yield reductions of up to 100% are possible under extremely heavy infestations (Hein et al 1998). Visible damage caused by the RWA includes stunted growth, chlorosis in the form of white to purple longitudinal leaf streaking, and entrapment of seed heads within the leaf sheath (Hein et al. 1998).

The small profit margin associated with winter wheat production dictates accurate pest management decisions in order to maintain acceptable profit. This same constraint makes it impractical for growers to expend scarce resources on costly pest monitoring programs (Holtzer et al. 1996). Still, timely and accurate detection of RWA infestations would facilitate effective use of insecticides to minimize economic losses.

Plants have a characteristic pattern of absorption and reflectance of electromagnetic radiation. Plants under stress often show repeatable changes in absorption and reflectance in particular regions of the electromagnetic spectrum (Shibayama et al. 1993). The resulting plant stress, which may appear similar (or different) spectrally to stress caused by water deficiency, nitrogen deficiency, disease, or other causes, may be detectable using multi-spectral remote sensing. Therefore, differences in absorption and reflectance between stressed and non-stressed plants can potentially be used to assess stress levels, and consequently levels of pest infestation.

When RWAs feed on a plant they injure it by their feeding and by injecting substances that disrupt the wheat plants' physiology and produce visible damage symptoms in the plant. The resulting stress seriously limits the plants' ability to grow and produce an adequate grain yield (Larcher 1995). Laboratory and greenhouse studies have shown that multi-spectral and hyper-spectral remote sensing can detect differences between healthy and RWA infested wheat plants (Riedell and Blackmer 1999;Yang et al. 2005).

Remote sensing on a broad spatial scale could provide an effective method for detecting RWA infestations for the purpose of pest management decision-making. For broad scale detection to work, there are several remaining obstacles to overcome, the first of which is to determine whether the stress caused to wheat by RWA infestation can be detected in wheat fields from an airborne multi-spectral remote sensing platform. The objective of this study was to evaluate an airborne multi-spectral remote sensing system for its ability to differentiate varying levels of injury caused by RWA infestation in production winter wheat fields.

MATERIALS AND METHODS

Two study fields were located in southeastern Colorado in spring 2004, and two fields were located in far western Oklahoma in spring 2005 (Figure 1). The fields studied in 2004 were under moderate drought stress at the time the study was conducted. The fields in 2005 were not affected by drought or any other obvious stress-causing factor other than RWA infestation.

A rectangular study area of 100 to 150 m in length and 50 to 75 m in width was established in each field. The study area was marked on its four corners by white plastic tarps. Study areas were chosen to encompass a wide range of intra-field variation in the intensity of RWA infestation. In 2004, 24 3x3 m plots were established within

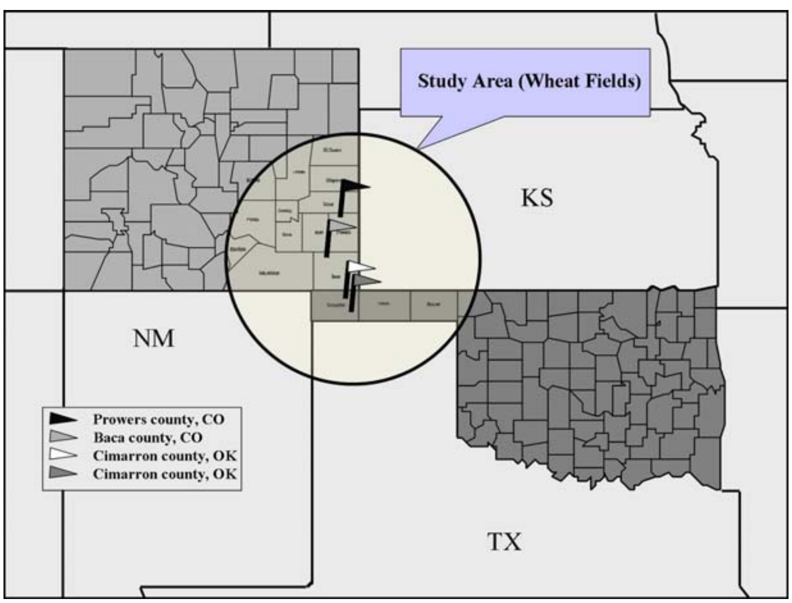

Figure 1. Locations of study fields in SE Colorado and the Oklahoma Panhandle.

the boundary of the study area in each field, and in 2005 each study area had 20 such plots established in it. White towels were laid down in the field to aide in locating the plots in the image. They appeared as small white dots in the image. Plots were located in areas in each field representing a range of damage levels, from virtually no RWA damage to wheat plants, to almost 100% of plants damaged.

Damage caused by the RWA was estimated for each 3x3 m plot by sampling 60 tillers (stems of wheat) from random locations within the plot and scoring each tiller for the presence or absence of damage caused by the RWA. Immediately prior sampling the plots for damage, multi-spectral imagery was obtained using an SSTCRIS® (SST Development Group, Inc., Stillwater, Oklahoma) multi-spectral imaging system mounted NADIR in a Cessna 172 aircraft. The towel point layer was used to identify the correct locations of plot corners in imagery acquired using the SSTCRIS. At the laboratory, we used ERDAS Imagine 7.0© to create AOIs (areas of interest) of 2x2 m plot area one meter SW of the towels used to mark the NE plot corner. This was done for all plot locations in each study field. We converted all pixels within each AOI to a spreadsheet format from which we could calculate mean reflectance for each plot as well as various indices that might be useful for detecting plant stress caused by the RWA.

The SSTCRIS images in three bands. The wavelengths in the green, red and near infrared bands used in the SST CRIS are centered at 550, 650, and 800 nanometers with bandwidths of 70, 40, and 65 nanometers, respectively. With the SSTCRIS multi-spectral data, we could compare the level of RWA damage to wheat plants for each plot with reflectance intensity in remotely sensed imagery. The vegetation index (VI) and normalized differenced vegetation index (NDVI), which are calculated from red and near-infrared bands of multi-spectral data, are well known for their utility in differentiating levels of biomass and plant health in remotely sensed imagery (Lillesand and Kiefer 1987). The mean of VI and NDVI over all pixels in the AOI were calculated for each plot. Green VI and NDVI, which are similar to NDVI in mathematical structure, but are calculated from green and near-infrared bands, have also shown utility for detecting levels of plant health (Gitelson and Merzlyak 1997). The mean of green VI and green NDVI were calculated for each plot. Finally, we statistically analyzed the relationship between vegetation indices and the level of RWA damage to wheat in plots using correlation and linear regression analyses.

RESULTS AND DISCUSSION

All fields studied showed lower values for vegetation indices for highly damaged plots than for less damaged plots. Most correlations were significantly different from zero (Table 1). Among the vegetation indices investigated, NDVI and VI were most consistently correlated with the proportion of RWA damaged tillers in plots (Table 1). Green NDVI and Green VI were usually significantly correlated with the proportion of damaged tillers, but the correlations were not consistent for all fields. Correlations between vegetation indices and the proportion of RWA damaged tillers per plot were negative for all vegetation indices (Table 1).

The relationship between NDVI and damage rating per plot for each field is illustrated in Figure 2. NDVI was lower for plots with high RWA damage compared to plots with lower levels of damage. Despite the fact that the two Colorado fields studied in 2004 were drought stressed, RWA damage was easily distinguished using NDVI. This indicated that the additional stress caused by the RWA in the drought stressed fields was detected in the imagery and may influence NDVI additively or even be positively associated with the stress caused by the RWA. Such an association is suggested by the observation that the NDVI and damage rating relationship was more negative for the 2004 fields than for the 2005 fields, which were not drought stressed.

Table 1. Correlations between vegetation indices and the proportion of RWA damaged tillers per plot for winter wheat fields imaged in Colorado in May, 2004 and Oklahoma in May, 2005

Vegetation Index	Colorado 1	Colorado 2	Oklahoma 1	Oklahoma 2
NDVI	-0.83*	-0.69*	-0.50*	-0.37*
VI	-0.84*	-0.73*	-0.47*	-0.39*
Green NDVI	-0.83*	-0.65*	-0.18	-0.40*
Green VI	-0.83*	-0.67*	-0.20	-0.40*

Regressions of NDVI versus the proportion of infested tillers were significant ($F = 34.7$; df = 7, 80; $P < 0.0001$). However, intercepts ($F = 23.3$; df = 3, 80; $P < 0.0001$) and slopes ($F = 6.2$; df = 3, 80; $P < 0.0008$) differed significantly among fields. Regression slopes were steeper for the fields studied in 2004 than for the 2005 fields. In addition, the relationship between NDVI and the proportion of damaged tillers was less variable in 2004 than in 2005 (Figure 2).

We have shown that multi-spectral remotely sensed data acquired using the SSTCRIS multi-spectral imaging system was sensitive to variation in the damage caused by the RWA in production winter wheat fields. Since the damage caused by the aphid is highly correlated with its population density, both attributes can be measured in production winter wheat fields using multi-spectral remote sensing. The inconsistent relationship in linear regressions between NDVI and plant damage could have resulted from one or more of several factors. The time of day when imaging was done, which differed among the two years, could have influenced the results, as could atmospheric differences, and within field differences in edaphic factors, such as soil type and soil moisture. It was not feasible to control for all these factors in our study, and in fact it would be infeasible to control for them in an operational pest monitoring system. Results of this study indicate that further research is warranted to develop ways to use multi-spectral (or hyper-spectral) remote sensing for detecting and monitoring RWA infested fields in operational pest management programs.

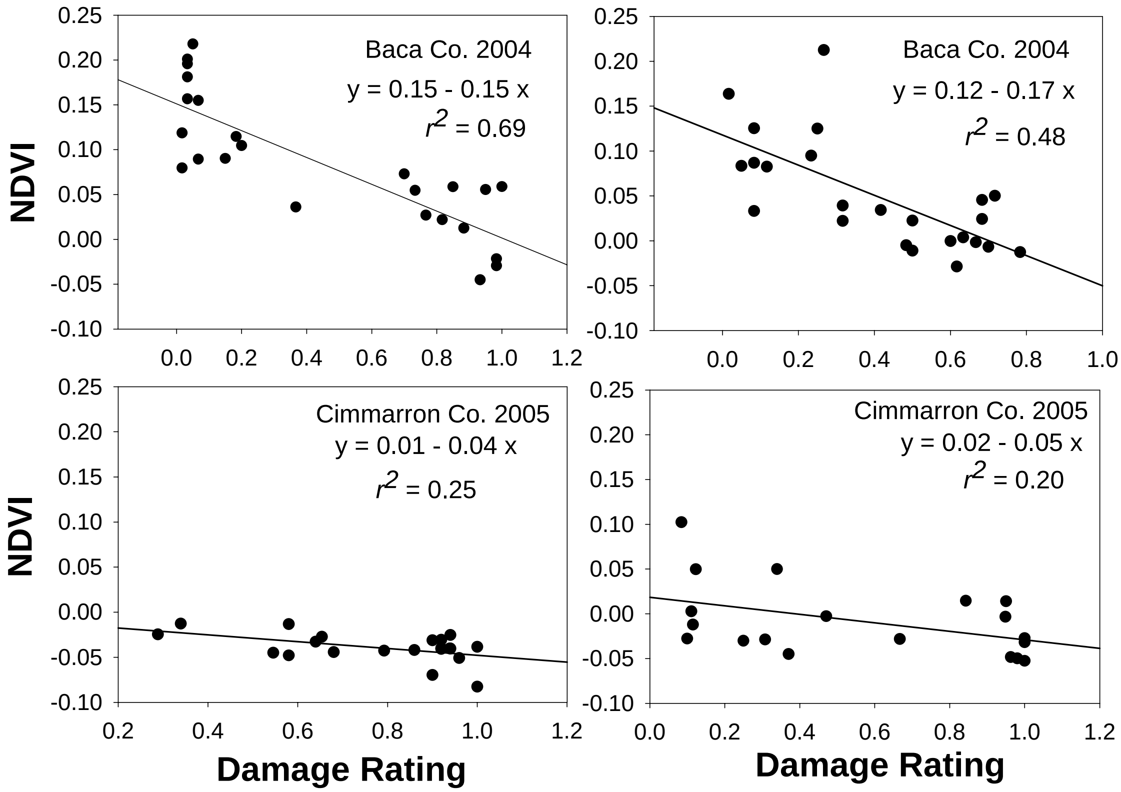

Figure 2. Relationship between NDVI and damage rating per plot for each field.

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