Airborne Multi-Spectral Remote Sensing of Russian Wheat Aphid Injury to Wheat

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Abstract. The Russian wheat aphid (RWA), Diuraphis noxia (Mordvilko), is a severe pest of wheat in the High Plains region of the United States. Remote sensing may be an effective way to detect RWA infestations in fields for pest management decision-making purposes. 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 fields located in southeastern Colorado were studied in spring 2004 and two fields located in far western Oklahoma were studied in spring 2005. The proportion of wheat stems damaged by RWA in each field was measured in 20 to 24 3x3-m plots with varying levels of RWA infestation. 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 compared with the intensity of RWA damage to wheat plants within the plots. Correlations between vegetation indices calculated from the multi-spectral data with the proportion of RWA damaged wheat tillers per plot were negative for all vegetation indices. Regressions of vegetation indices versus the proportion of RWA damaged wheat tillers per plot were usually 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), wheat variety, and possibly other factors could have caused the differences observed in regressions.

Introduction

The Russian wheat aphid (RWA), Diuraphis noxia (Mordvilko), an introduced invasive species first detected in the United States in 1986 (Stoetzel 1987), has

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caused over $1 billion in losses to the wheat industry of the Great Plains region (Webster et al. 2000). Population explosions cause a rapid progression of crop damage. Severe yield reductions of up to 100% are possible under extremely heavy infestations. Visible damage to wheat 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. 2004).

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, Larcher 1995). RWA injure plants by their feeding and by injecting substances that disrupt the plants' physiology, producing damage symptoms which are detectable as altered patterns of reflectance of electromagnetic radiation. Laboratory and greenhouse studies have shown that differences in reflectance occur between healthy and RWA infested wheat plants. Differences in reflectance were evident in several wavelength bands, including a band at approximately 450-500 nm (green visible light), a chlorophyll absorption band at approximately 625-675 nm, and a near-infrared (NIR) band at approximately 750-850 nm (Riedell and Blackmer 1999, Yang 2005). Bands roughly encompassing these wavelengths are commonly included in satellite based multi-spectral sensors, such as Landsat TM and SPOT, and in a variety of airborne multi-spectral sensors (Richards 1993).

The small profit margin associated with winter wheat production dictates that accurate pest management decisions be made 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. Differences in absorption and reflectance between stressed and non-stressed wheat plants can potentially be used to assess stress levels and, consequently, levels of infestation by RWA.

Remote sensing has potential as a method for detecting RWA infestations for the purpose of pest management decision-making. If conducted on a broad spatial scale, remote sensing could be a cost effective method for monitoring wheat fields for the presence of potentially damaging RWA infestations. For broad scale detection to work, there are several obstacles to overcome, the most obvious of which is to determine whether results from laboratory and greenhouse studies, which showed that RWA induced stress could be detected using multi-spectral remote sensing, still hold true when the analysis is taken to the scale of wheat plant canopies in production wheat fields.

The SSTCRIS® (SST Development Group, Inc., Stillwater, Oklahoma) is typical of multi-spectral imaging systems used for airborne remote sensing of natural resources. The system records imagery in three spectral bands, which are similar to those previously identified in laboratory and greenhouse studies as sensitive to RWA induced stress (Riedell and Blackmer 1999, Yang 2005). The objective of this study was to evaluate SSTCRIS remotely sensed data 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 (Fig. 1). The fields selected were planted to wheat varieties that were susceptible to RWA injury. Total precipitation recorded at a meteorological station located near the sampled fields was calculated for the period from October-March of each of the two wheat growing
seasons. For the Colorado fields in 2004, we used meteorological data from a recording station in Walsh, CO, which is within 40 km of both study fields. For the Oklahoma fields in 2005, we used data from a recording station near Boise City, OK, which is within 10 km of both fields.

A rectangular study area 100–150m in length and 50–75m in width was established in each field. The study area was marked on its four corners by silver 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 the boundary of the study area in each field, and in 2005 each study area had 20 such plots established. Plots were located within the study area to encompass a broad range of damage levels, from virtually no damage to wheat by RWA to nearly 100% of plants damaged. The intensity of damage caused by 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 damage caused by RWA. No attempt was made to rate the intensity of damage to each tiller because we found that difficult to do objectively in the field. Thus, our measure of damage intensity for each plot was the ratio of the number of damaged tillers to the total of 60 tillers sampled.

**FIG. 1.** Locations of four study fields in SE Colorado and the Oklahoma Panhandle.

Immediately prior to sampling, multi-spectral imagery was obtained using an SSTCRIS multi-spectral imaging system mounted NADIR in a Cessna 172 aircraft. Imaging was accomplished from approximately 610m above ground level. At that altitude an individual pixel in an image covered an area approximately 0.3x0.3-m at ground level. Thus, approximately 100 pixels in an image covered the 3x3-m area of each plot.

The center wavelengths for the three bands (green, red and NIR) recorded by the SST CRIS are 550, 650, and 800 nm with bandwidths of 70, 40, and 65 nm, respectively. Each pixel in an image contains a digital number for each of the three bands recorded by the SSTCRIS. The digital number measures the amount of light in
each band reflected from within the pixel and recorded by the SSTCRIS mounted in
the airplane.

White towels (ca. 50x75-cm) were laid down in the field to aide in locating the
plots in the image. The towels appeared as small white dots in the imagery acquired
using the SSTCRIS. The towels were used to identify the correct locations of plot
corners in imagery. We used ERDAS Imagine 7.0© to create AOIs (areas of interest)
of 2x2-m starting 0.7-m SW of the towels used to mark the NE corner of each plot.
Thus, each plot was given an approximately 0.5-m wide buffer around its periphery.
Buffering was done to avoid including mixed pixels from the edge of the 3x3-m plot in
the spectral data to be analyzed. We converted data for all pixels within each AOI to
a spreadsheet format from which we calculated the mean reflectance value for each
band for each plot as well as various indices that might be useful for detecting plant
stress caused by the RWA.

We compared the proportion of infested tillers per plot to reflectance intensity in
imagery. The vegetation index (VI) and normalized differenced vegetation index
(NDVI), which are calculated from red and NIR 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). Mean VI and NDVI were calculated for
all pixels in each AOI. Green VI and green NDVI, which are similar to NDVI in
mathematical structure, but are calculated from green and NIR 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 AOI.

We statistically assessed the relationship between vegetation indices and the
level of RWA damage to wheat in plots by correlation and linear regression using
appropriate SAS procedures (SAS Institute 2004). The regression model used was a
homogeneity of slopes model. The full model incorporated regression coefficients for
the slope and intercept for each of the four fields (a total of eight coefficients). The
regression coefficients were tested for significance using appropriate F-tests for full
and reduced models (Neter and Wasserman 1974).

Results and Discussion

All fields studied showed lower values of vegetation indices for highly damaged
plots than for less damaged plots. Correlations between vegetation indices and the
proportion of RWA damaged tillers per plot were negative for all vegetation indices in
all four fields (Table 1). Most correlations were significantly different from zero.
Among the vegetation indices investigated, NDVI and VI were significantly correlated
with the proportion of RWA damaged tillers in plots in all four fields. Green NDVI and
green VI were significantly correlated with the proportion of damaged tillers in three of

<table>
<thead>
<tr>
<th>Vegetation Index</th>
<th>Prowers Co.</th>
<th>Baca Co.</th>
<th>Cimmarron Co. 1</th>
<th>Cimmarron Co. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDVI</td>
<td>-0.83a</td>
<td>-0.69a</td>
<td>-0.50a</td>
<td>-0.37a</td>
</tr>
<tr>
<td>VI</td>
<td>-0.84a</td>
<td>-0.73a</td>
<td>-0.47a</td>
<td>-0.39a</td>
</tr>
<tr>
<td>Green NDVI</td>
<td>-0.83a</td>
<td>-0.65a</td>
<td>-0.18</td>
<td>-0.40a</td>
</tr>
<tr>
<td>Green VI</td>
<td>-0.83a</td>
<td>-0.67a</td>
<td>-0.20</td>
<td>-0.40a</td>
</tr>
</tbody>
</table>

*Correlation coefficient significant at P = 0.05
the four fields. Overall, VI and NDVI had the strongest relationship to the proportion of damaged tillers per plot. Based on the correlations, we chose the index NDVI to model the relationship between reflectance and intensity of RWA damage to wheat.

The homogeneity of slopes linear regression of NDVI versus the proportion of infested tillers was 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 fields studied in 2004 than for 2005 fields (Fig. 2).

**FIG. 2.** Linear regressions for NDVI versus RWA damage rating for four wheat fields.

NDVI was lower for plots with high RWA damage than for plots with lower levels of damage (Fig. 2). The total precipitation from October-March, 2003-2004, at Walsh, CO, was 5.7-cm, which is roughly one-half of the 30-year average for those months of 10.7-cm. The low total precipitation indicates that drought stress was a high possibility for the fields studied in 2004. Total precipitation for Boise City from October-March, 2004-2005, was 13.7-cm, which was close to the normal total for that period of 11.2-cm. Thus the fields studied in 2005 were probably not seriously affected by drought.

Despite the fact that the two Colorado fields studied in 2004 were probably drought stressed, RWA damage was easily distinguished using NDVI. This suggests that the additional stress caused by the RWA was detected in the imagery and may have influenced NDVI additively or even been positively associated with the stress caused by drought. 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. The result would be expected if RWA infestation reduced the ability of the wheat to tolerate drought, thereby causing the two stresses, drought and RWA, to act synergistically in affecting plant response to drought. Riedell (1989) found that RWA infestation reduced the ability of wheat to tolerate drought, which indicates that such a relationship is possible.

We have shown that multi-spectral remotely sensed data acquired from production winter wheat fields using the SSTCRIS multi-spectral imaging system is sensitive to damage caused by RWA. Since the damage caused by the aphid is highly correlated with its population density, at least during the increasing phase of RWA population growth (Archer and Bynum 1993), 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 influence reflectance, as could atmospheric differences, and differences among fields in edaphic factors, such as soil type and soil moisture (Lillesand and Kiefer 1987). We did not measure these variables and cannot determine which, if any, of them affected our imaging results. Obviously it is not feasible to control for these factors in field studies. In fact, it would be infeasible to control for them in an operational pest monitoring system, and it would generally be impractical to measure them in an operational system so that corrections to data could be accomplished. Many factors, which are impossible to control and difficult to correct for in analyzing remotely sensed imagery can affect reflectance. We think that the most important contribution of this study is demonstrating that multi-spectral remotely sensed data acquired by a relatively inexpensive and easily used multi-spectral imaging system was able to detect RWA induced stress in production winter wheat fields in the presence of other stress inducing variables. The result suggests that the presence of other stress factors will not impede the utility of multi-spectral imaging for monitoring RWA infestations in winter wheat fields; however, more research is needed to verify this assertion.

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**References Cited**


