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Full Length Research Paper

Vegetation indices as indicators of damage by the sunn pest (Hemiptera: Scutelleridae) to field grown wheat

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The sunn pest, *Eurygaster integriceps* Put. (Hemiptera: Scutelleridae), also known as sting or cereal pest, is one of the most economically important pests of wheat in the world. In this study, a collapsible nylon cloth cage experiments were conducted to determine the feasibility of using remote sensing techniques to detect stress in wheat caused by the density of sunn pests. The results show we can detect the amount of stress in wheat caused by different life stages of sunn pest with a hand-held radiometer. Normalized difference vegetation index (NDVI) based indices; NDVIsg, NDVId, NDVIr, and structure insensitive pigment index (SIPI) were chosen out of 19 indices initially tested. The NDVI based vegetation indices derived from hyperspectral data, recorded by a hand held spectroradiometer, were used to determine the predicted indices using the initial number of Sunn Pest (NOSP). Overall, r^2 values of all predicted indices calculated for 3rd instars were lower than those of 4th and adult stage. When r^2 was considered separately, predicted NDVIr index value (87.4) was the highest and predicted SIPI index value is lowest (80.7) in 3rd instars. The highest r^2 value was obtained in adult stage of sunn pest is NDVIsg (96.9) compare with NDVId (95.5), NDVIr (92.4) and SIPI (94.2). It was also concluded that remote sensing could detect not only the different stages pest damage on wheat, but also the number of sunn pest stages density affect in controlled experiments.

Key words: Remote sensing, ***Eurygaster integriceps***, insect damage, NDVI, spectroradiometre.

INTRODUCTION

The sunn pest, ***Eurygaster integriceps*** Put. (Hemiptera: Scutelleridae), also known as sting or cereal pest, is one of the most economically important pests of wheat in many wheat growing countries including Turkey (Radjabi, 1994; Javahery,1995; Kinaci et al., 1998; Kivan and Kilic, 2004a). Critchely (1998) reported that the sunn pest completes development on wheat, barley, and rye, damaging the leaves, stems, and grains. Feeding of the pest on wheat causes shriveling and lowers grain weight and starch content. It destroys gluten in the seed, causing unfavorable baking properties of the flour (Karababa and Ozan 1998; Hariri et al., 2000; Kinaci and Kinaci, 2004; Ozberk et al., 2005). Every 6 to 8 years, population outbreaks have occurred in Turkey, resulting in losses of tens of millions of dollars in agricultural revenue (Kivan and Kilic, 2004b). An Integrated Pest Management (IPM) system has been developed based on conservation and augmentation of egg parasitoids such as ***Trissolcus semistratus*** (Hymenoptera: Scelionidae) (Kivan and Kilic, 2002; Kivan and Kilic, 2004b). Pesticide application is the conventionally used method for the sunn pest management (Miller and Morse, 1996). Wheat is grown on a large scale, and it is difficult to survey the sunn pest and damage to the wheat with known methods.

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Many developing countries are using global positioning systems, geographic information systems, and remote sensing technology to create new strategies for determination of plant stress due to insect attack. Because chlorophyll content plays a direct role in photosynthesis and it is responsive to a range of stresses, chlorophyll content may be a sound indicator of vegetal health (Gitelson and Merzlyak, 1994). Jensen (2000) stated that remote sensing in the visible and near-infrared (NIR) wavelengths is based on the principle that changes in plant light interception and utilization influence the reflectance properties of vegetation. The use of remote sensing instruments to monitor changes in crop chlorophyll content is well documented (Yang et al., 2005; Steddom et al., 2005; Richardson et al., 2004; Apprico, 2002; Apprico, et al., 2000; Raikes and Burpee, 1998; Serrono et al., 1999; Gitelson and Merzlyak, 1994; Penuelas et al., 1995; Sharp et al., 1985; Blazquez and Edwards, 1986; Tucker, 1979; Rouse et al., 1973). Reflectance data obtained by spectroradiometer over study areas provides information to understand spectral interactions between stress source and crops (Yang et al., 2005; Richardson et al., 2004; Mirik et al., 2006a; Mirik et al., 2007). Studies by Mirik et al. (2006a, 2006b, and 2007) and Yang et al. (2005) demonstrated that remote sensing technology particularly spectroradiometer, which recorded reflectance from plant canopy, has a potential for use as an alternative pest monitoring method for aphid damage in field and greenhouse experiments. The value of using remote sensing to determine damage by aphids on wheat by spectroradiometer has been well demonstrated (Riedell and Blackmer, 1999; Yang et al., 2005; Mirik et al., 2006., Mirik et al., 2007). Spectroradiometer measurements allow collection of data without destroying the study area.

Spectral reflectance differences can be enhanced by using vegetation indices, which are mathematical transformations designed to assess the spectral contribution of vegetation to multispectral observations (Gitelson and Merzlyak, 1996; Barragan et al., 2005; Poss et al., 2006). Maas and Dunlap (1989) stated that a healthy plant can be identified by recording the reflectance of visible and near infrared (NIR) reflectance from its leaves. Jensen (2000) reported that healthy crops are characterized by high absorption in the blue region (400 – 500 nm), relatively high reflection in the green region (500 – 600 nm), very high absorption in the red region (600 – 700 nm), and very high reflectance in the NIR region (700 – 1500 nm). Vegetation indices are determined by contrasting intense chlorophyll pigment absorptions in the red against the high reflectivity of plant materials in the NIR (Tucker, 1979; Elvide and Chen, 1995; Blackburn, 1999; Mirik et al., 2007). Vegetation indices have been used to determine vegetation variables such as concentration of total chlorophyll (Apprico, 2002; Sims and Gamon, 2002; Apprico et al., 2000; Raikes and Burpee, 1998; Serrono et al., 1999; Gitelson and Merzlyak, 1996; Penuelas et al.,1995; Royo et al., 2003; Blazquez and Edwards, 1986; Tucker, 1979; Rouse et al., 1973) and determination of pest damage (Yang et al., 2005; Richardson et al., 2004; Mirik et al., 2006a; Mirik et al., 2007). There is, however, no information as to whether remote measurements of reflected spectra from wheat can be correlated with sunn pest damage and pest density.

The objective of this study was to investigate relationships between spectral vegetation indices and wheat damage by different stages of sunn pest. The experiments were conducted inside the nylon cloth cages in a wheat growing field with a hand-held spectroradiometer and three different instars of the sunn pest.

MATERIAL AND METHODS

Study area and sunn pest experiment design

This study was conducted at Kaanlar Kumkale farm inside the TROIA National Park 20 km west of Canakkale Province, Turkey. The coordinates at the center of the study area are 39° 54`N, 26° 17`E. The study site was an intensively cropped area. The soil in the experimental area is dark brown, fine sandy loam with a pH 8.0. The subsoil extends to a depth of 60 - 90 cm or more. The topography is nearly flat. For this study, winter wheat was sown on October 21, 2006 and harvested in June 27, 2007 (Figure 1).

Eurygaster integriceps was collected from wheat fields in Canakkale province, Turkey. Laboratory progenies of field collected ***E. integriceps*** were used in the experiments. The colony was maintained on potted wheat plants in the screen cages, in an environmental chamber, programmed at 24 ± 1°C, 60% RH, with fluorescent lighting 16:8 h (light : dark) photoperiod. Egg masses were collected daily and put in Petri dishes lined with moist filter paper, and kept in an environmental chamber. The newly emerged first instars were used in experiments.

The experiment was begun on May 3, 2007. The collapsible nylon cloth cages were 80 cm in length and 30 cm in width (Figure 2). Each cage contained 40 wheat plants. Newly emerged 24 and 48 first instars were transferred into each cage along with the control having no individuals as four replications (Figure 1). The number of insects and the instars feeding were observed at the time spectral measurements were made by spectroradiometer.

Remote sensing measurements

Canopy reflectance was detected with a narrow-bandwidth visible-near-infrared Portable FieldSpec Handheld Spectroradiometer (Analytical Spectral Devices, Inc., Boulder, Colorado, USA), fitted with 10° field of view optic. The spectroradiometer detects 512 continuous bands with 3.5 nm spectral resolution of the spectroradiometer for the region 325 - 1075 nm (ASD, 2006).

The reflectance measurements were made three times during the 2007 growing season. These are on May 12 (when they became 3rd instars), May 18 (4th instars), and June 9 (Adults). The reflectance spectrum was calculated in real time as the ratio between the reflected and the incident spectra of the canopy. The incident spectrum was periodically obtained from the light reflected by a barium sulphate standard panel before and immediately after each measurement (Spectralon Labshere, North Sutton, NH) (ASD, 2006). All corresponding measurements for wheat were carried out on the same days and under sunny conditions between 12:00 and 14:00 as recommended by Salisbury (1999). Cloth cages were opened before the spectroradiometer was placed 50 cm above each nylon

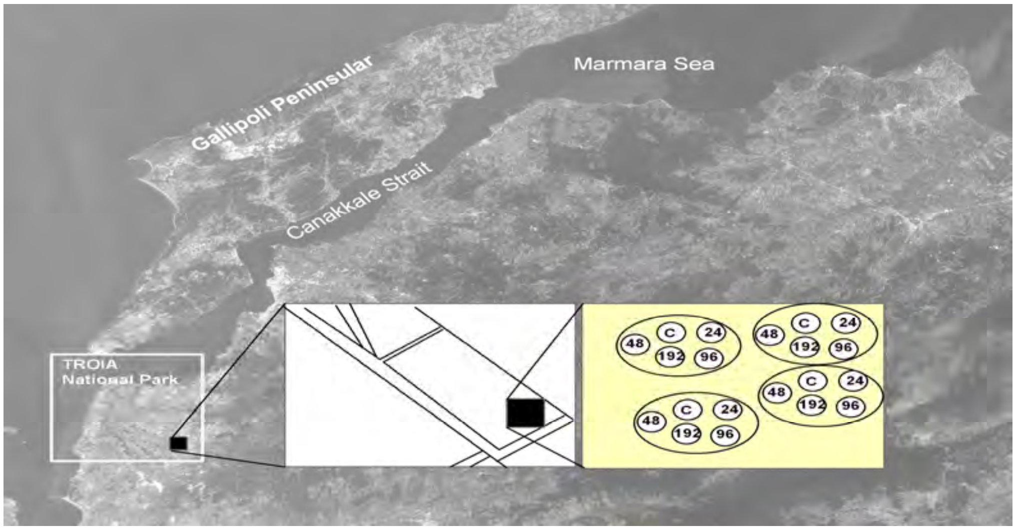

Figure 1. Field experiment located in field experiment.

Figure 2. Nylon cloth cages

cloth cage. The sunn pests in each cloth cage were collected and the number that had survived was recorded. The nylon cloth cages were then removed from the wheat and spectral data were taken. After each measurement, the nylon cloth cages were placed back. Five spectral reflectance measurements were taken for each cage, with each being the average of ten scans. Data collected in the field were analyzed and indices calculated.

Spectral index computations

A total of 19 chlorophyll and plant stress related indices were investigated to determine the best relationship between spectral vegetation indices and sunn pest density on wheat inside the nylon cloth cages (Table 1). Spectral vegetation indices were calculated based on initial number of sunn pests at the beginning of the experiment and number of surviving sunn pests at the end of the experiment. We found that 4 out of 19 vegetation indices showed strong relationships with the initial sunn pest density and marked with asterisks in Table 1. Regression analysis was used to determine the relationship between vegetation indices and initial number of sunn pest. The LSD test at 0.05 level of significance was used to determine separation and significance of means (SAS, 1990).

RESULTS

Reflectance measurements on wheat infested with 3rd, 4th instars and adults of sunn pests inside nylon cloth cages are shown in Figure 3. The number of sunn pests initially transferred to the nylon cloth cage affected the spectral response of wheat. The reflectance of wheat canopies in the NIR region was decreased by 24 individuals of 3rd instars (May 12) and 48 individuals of 4th instars (May 18), as the number of sunn pests inside the nylon cloth

Table 1. Nineteen spectral indices were investigated to determine eight vegetation indices marked with asterisks

Index	Abb.	Formulas	Reference
Aphid Index	AI	(R761-R908)/ (R712-719)	Mirik (2006a)
Damage Sensitive Spectral Index $_1$	DSSI1	(R719-R873-R509-R537)/ (R719-R873)+(R509-R537)	Mirik (2006b)
Damage Sensitive Spectral Index $_2$	DSSI2	(R719-R873-R509-R537)/ (R719-R873)+(R509-R537)	Mirik (2006b)
Difference Vegetation Index	IR-Red	(R789-R663)	Tucker (1979)
Lichtenthaler Index 2	LIC2	(R440/R690)	Lichtenhaler et al (1996)
*Normalized Difference Vegetation Index $_{sg}$	$NDVI_{sg}$	(R750-R705)/(R750+R705)	Sims and Gamon (2002)
* Normalized Difference Vegetation Index $_d$	$NDVI_d$	(R801-R670)/(R801+R670)	Daughtry et al. (2000)
*Normalized Difference Vegetation Index $_r$	NDVI $_r$	(R789-R649)/(R789+R649)	Rouse et al. (1973)
Photochemical Reflectance Index	PRI	(R531-R570)/(R531+R570)	Gammon et al. (1992)
Pigment Specific Simple ratio Chl a	PSSRa	R800/R680	Blacburn (1998)
Pigment Specific Simple ratio Chl b	PSSRb	R800/R635	Blacburn (1998)
Pigment Specific Simple ratio Cars	PRSSc	R800/R470	Blacburn (1998)
Pigment Specific Normalized Difference a	PSNDa	(R800-R680)/(R800+R680)	Blacburn (1998)
Pigment Specific Normalized Difference b	PSNDb	(R800-R635)/(R800+R635)	Blacburn (1998)
Pigment specific Simple Ratio ($^{775}/_{747}$)	PSSR	(R800-R470)/(R800+R470)	Blackburn and Steele (1999)
Plant Senescence reflectance Index	PSRI	(R680-R500)/(R750)	Merzlyak et al. (1999)
Simple Ratio $_{680}$	SR680	SR680= (R800/R680)	Sims and Gamon (2002)
Simple Ratio$_{705}$	SR705	SR705= (R750/R705)	Sims and Gamon (2002)
*Structure Insensitive Pigment Index	SIPI	SIPI = (***R***800 −***R445***)/(***R***800 −***R***680)	Penuelas et al. (1995)

* Four Indices were used to determine the sunn pest damage on wheat

cages were increased compared to the control (Figure 3). There was a higher reflectance difference in visible region when the number of sunn pests increased in both 3rd and 4th instars. The spectral reflectance from wheat infested with adults also showed a similar pattern of reduced reflectance. The canopy reflectance of wheat from cages was increased in the visible region when the number of sunn pests increased. However, in NIR region, the reflectance from cages having 48 individuals showed lower reflectance values than the control and 24 individuals (Figure 3). This is also reflected in the pattern for all three life stages. When number of sunn pest individuals increased, reflectance of wheat canopy gradually decreased from control to 48 individuals in NIR region. The average numbers of surviving sunn pests on winter wheat inside the nylon cloth cages are presented in Figure 4. Sunn pest damage due to three different life stages varied. Initially, out of 24 and 48 individuals, 20 and 33 survived as 3 rd instars respectively. Similarly, among 4th instars 16 and 23 individuals survived out of the original 20 and 33 individual initially in the cages. In total, 9 and 19 individuals completed their development to the adult stage (Figure 4). The number of individuals, at the beginning of the experiments has an effect on indices values as well as the number surviving. Because we have no information about the exact time of death of individuals, it is impossible to determine the correlation between number of surviving instars and indices values.

In this study, the differences in reflectance values in visible and NIR region indicated a relation with the density of pest individuals at 3rd, 4th instars and adult stage (Figure 3). The regression results of initial sunn pest instars and vegetation indices with the coefficients (***r^2***) corresponding to the three life stages are presented in Table 2. The predicted vegetation and stress indices were calculated by the linear regression models for each of the stages to show relative means of the relationship between the sunn pest densities and index values. Overall, r^2 values of all predicted indices calculated for 3 rd instars were lower than those of 4th and adult stage (Table 2). When r^2 is considered individually, predicted NDVIr index value (87.4) is the highest and predicted SIPI index value is lowest (80.7) in 3 rd instars. The highest r^2 value was obtained with the adult stage of sunn pest when NDVIsg (96.9) compared with NDVId (95.5), NDVIr (92.4) and SIPI (94.2). The predicted indices r^2 values in 4 rd instars was between 3 rd instars and adult stage for all indices (Table 2).

Analysis of means shows that at 3rd instars stage NDVI indices (NDVIsg, NDVI d, NDVI r) for wheat damage in each experimental cages having control, 24, and 48 individual pests is significantly different from each other at the 0.05 level. However the SIPI index for all treatments is not significantly different at 3 rd instars stage (Table 3). Similarly, all indices for cages with control, 24 and 48 initial individuals showed significant difference at 4th instars. At adult stage, NDVIsg index is significantly different for 48 initial pests and control and 24 initial bugs

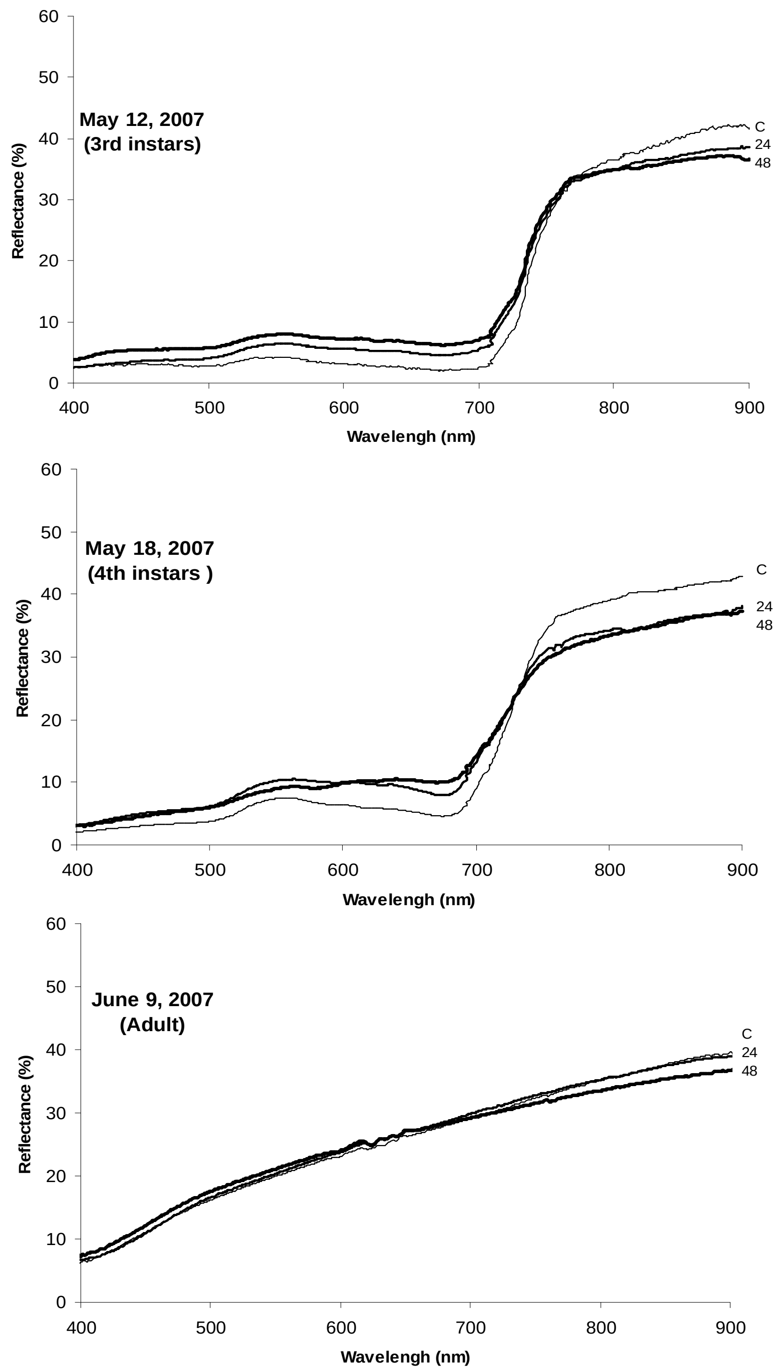

Figure 3. Spectral reflectance of wheat affected by sunn pests damage on May 12 (3rd instar), May 18(4th instars), June 9 (Adult). C= control, 24 and 48 are the number of sunn pests in each experimental cages.

as shown in Table 3.

Plant damage symptoms caused by sunn pest individuals were found to be closely related to the growth stage of wheat. When we examined the effect of different instars of the sunn pest, we found that the coefficients (r^2) for determination of indices showed an increasing pattern from 3rd instars to the adult stage. Regression coefficients were higher for 3rd instars than for 4th instars for all indices, and regression coefficient were highest at the adult stage. Results revealed that wheat damage also depends on the initial number of sunn pests put in the cages. Because time of death of pests could not be determined, we did not use the surviving sunn pest numbers as a factor in wheat damage. Wheat canopy

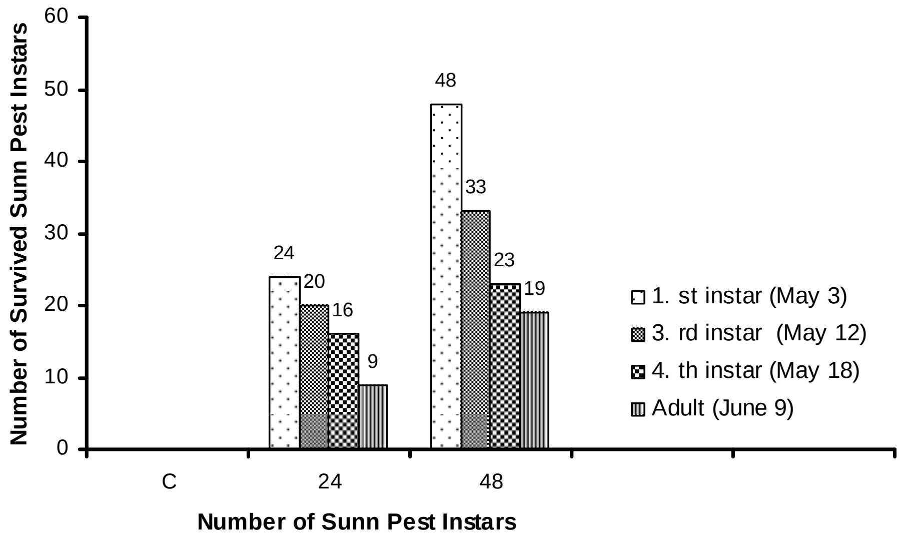

Figure 4. The number of survived sunn pest individuals on winter wheat at different life stages.

Table 2. The regression results of different instars of the sunn pest and vegetation indices.

3 rd instars (May 12, 2007)		4 th instars (May 18, 2007)		Adult (June 9, 2007)	
Formula	**r^2**	**Formula**	**r^2**	**Formula**	**r^2**
$NDVI_{sg}$ =0.526 - 0.0020NOSP	87.4	$NDVI_{sg}$ =0.417 - 0.0023NOSP	87.6	$NDVI_{sg}$ =0.046 - 0.00024NOSP	96.9
$NDVI_d$ =0.730 - 0.0023NOSP	87.2	$NDVI_d$ =0.677 – 0.0025NOSP	94.6	$NDVI_d$ =0.125 - 0.00061NOSP	95.5
$NDVI_r$ =0.686 - 0.0019NOSP	89.9	$NDVI_r$ =0.639 – 0.0023NOSP	92.2	$NDVI_r$ =0.135 - 0.00071NOSP	92.4
SIPI =1.043 - 0.0010NOSP	80.7	SIPI =1.040 + 0.0036NOSP	93.5	SIPI =3.427 + 0.00140NOSP	94.2

Table 3. Means of vegetation indices for initial sunn pests at three different densities.

	Instars	NDVIsg	NDVId	NDVIr	SIPI
3 rd instars MAY 12	C	0.516^{a*}	0.717^{a}	0.678^{a}	0.988^{b}
	24	0.499^{b}	0.699^{b}	0.658^{b}	1.032^{ab}
	48	0.418^{c}	0.607^{c}	0.585^{c}	1.036^{ab}
4. th instars MAY 18	C	0.429^{a}	0.676^{a}	0.644^{a}	1.052^{c}
	24	0.339^{b}	0.621^{b}	0.574^{b}	1.122^{b}
	48	0.314^{c}	0.554^{c}	0.534^{c}	1.229^{a}
Adult JUNE 9	C	0.046^{a}	0.124^{a}	0.133^{a}	3.411^{c}
	24	0.040^{ab}	0.113^{b}	0.124^{a}	3.799^{b}
	48	0.035^{c}	0.095^{c}	0.099^{b}	4.091^{a}

*Means with the same letter are not significantly different at 0.05 significance

complexity increases and the characteristics of the spectral responses to sunn pest effect as outlined above may change due to other factors such as meteorological conditions.

DISCUSSION

Several indices have been used to detect crop health and stress by scientists for different purposes, including concentration of total chlorophyll (Apprico, 2002; Sims and Gamon 2002; Apprico et al., 2000, Raikes and Burpee, 1998; Serrono et al., 1999; Gitelson and Merzlyak, 1996; Penuelas et al., 1995; Blazquez and Edwards, 1986; Tucker, 1979; Rouse et al., 1973) and pest damage (Yang et al., 2005; Richardson et al., 2004; Mirik et al., 2006a., Mirik et al., 2007). In this study, four vegetation indices out of 19 were sensitive to sunn pest densities. These indices were derived from blue, red, and NIR bands are NDVI (Sims and Gamon, 2002), NDVI (Daughtry et al., 2000), NDVI (Rouse et al., 1973), and SIPI (Penuelas et al., 1995). The insect pest damage causes the loss of chlorophyll in the plants. Mirik (2006 and 2007) were also showed that the red band is active chlorophyll absorption bands and NIR bands are active chlorophyll reflectance bands. Our results also indicate that the density of sunn pest is closely related to chlorophyll loss in wheat plants.

According the Jensen (1996), healthy green vegetation reflects 40 to 50% of the incident near infrared energy (0.7 to 1.1 µm) and incident energy is absorbed 80 to 90% of visible part of spectrum. He also mentioned that dead vegetation reflects a greater amount of energy than healthy green vegetation throughout the visible part of spectrum. NDVI (ranges between -1 to 1) is used to determine the vegetation health for different studies. The NDVI value for unhealthy vegetations is close to 0 and healthy vegetation NDVI value is close to 1. The values of NDVI for healthy vegetation range generally between 0.5 and 0.7 in field conditions (Jensen, 2000).

This study is the first to determine effect of sunn pests on wheat with remote sensing instruments. Reflectance from wheat canopy in the visible region (400 - 700 nm) was higher in the experiments with 3rd and 4th instars. In the adult stage, reflectance values for control and 24 initial pests were close but higher for 48 initial pests. Increasing the number of sunn pests increased damage levels on plants. Increasing the number of sunn pests caused lower reflectance in the NIR region (710 - 900). Higher reflectance value in visible region and lower reflectance value in NIR region indicated that lower photosynthetic pigment concentrations in particular chlorophylls, which leads to lowered photosynthetic rate of wheat. Similar result was found in relation of crop damage to reflectance values by aphid infestation on wheat (Mirik et al., 2006, 2007; Riedell and Blackmer, 1999).

The results suggest that it may be possible to determine the affect of sunn pest density on wheat with remote sensing instruments by use of a spectroradiometer under field conditions. Determination of predicted indices provides relative information about sunn pest damage on wheat. One could determine the index values without remote sensing measurements by determining the number of sunn pest collected from a field. This must be studied over a large area before it can be adapted into practice.

Initial number of sunn pest instars significantly increased the visible reflectance and decreased the NIR reflectance at the canopy level when compared with control experiment. The relationships between sunn pest individuals and spectral vegetation indices showed that spectral indices derived from remotely sensed data provide a method for discriminating sunn pest damage to wheat in controlled experiment in field conditions. In this study, we tested pest density and stage of the sunn pests, but have not controlled the other stress related factors such as disease, nutrient deficiency, or drought stress, that result in leaf chlorosis, mottling, necrosis, may also have similar effects on canopy reflectance. The next steps must be tested the other stress related factors under laboratories and field conditions.

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