SEASONAL PATTERNS OF VEGETATIVE INDICES OVER CROPPING SYSTEMS

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ABSTRACT

Remote sensing of reflectance in the visible and near-infrared portions of the spectrum has been used for agronomic applications for a number of years. The combination of different wavelengths into vegetative indices have proven useful for a variety of applications that range from biomass, leaf area, leaf chlorophyll, yield, crop residue, and crop damage. To help refine our understanding of vegetative indices studies were conducted on corn (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.), wheat (*Triticum aestivum* L.), and canola (*Brassica juncea* var. *juncea*) canopies grown under different tillage systems and nitrogen rates to determine the temporal patterns of reflectance and vegetative indices. Additional studies were conducted on eight corn hybrids and eight soybean cultivars to determine if there were detectable differences among genetic material. Reflectance observations were made throughout the year on clear days to determine the reflectance patterns over bare soil and then over the crop canopies through the complete growing season. These observations with made with the four-band Exotech radiometer and the eight-band CropScan radiometer. The same locations were measured in each plot over the period from 2000 through 2007 with five subsamples within each plot. Reflectance over bare soil changed slightly as the soil surface was wet with rainfall and after tillage but the different indices showed little variation within treatments. There was no significant difference among treatments during the offseason. During the season the greatest difference occurred and the visible wavelengths showed little variation within the season with the greatest change in the near-infrared wavelengths. Variation in vegetative indices changed during the season and most showed the largest standard deviation during the vegetative period of development with the least variation during the grain fill period. The patterns changed with the vegetative index being used and this information will guide decisions for precision agriculture.

Keywords: Reflectance, crop canopies, tillage systems, nitrogen management, normalized difference vegetative index, plant senescence reflectance index, reflectance ratios

INTRODUCTION

Remote sensing of agricultural canopies has provided valuable insights into various agronomic parameters. The advantage of remote sensing methods is the ability to provide repeated measures of the same area within field without destructive sampling of the crop. Throughout the past 30 years there have been many advances in the use of remote sensing methods partially because the introduction of narrow band or hyperspectral sensors and increased resolution of aircraft or satellite mounted sensors. One of the remaining challenges is to evaluate the seasonal patterns in the various indices that are typically used for agronomic evaluations.

Vegetative indices (VI's) are developed as combination of various wavebands that have been related to different canopy parameters. These have been summarized in Hatfield et al. (2004) and Hatfield et al. (2008). One of the first VI's was the NIR/Red ratio proposed by Jordan (1969) who related this index to leaf area index (LAI). The purpose of the VI's is to enhance the vegetation signal while minimizing the solar irradiance and soil background effects Jackson and Heute (1991). One of the most used VI's is the normalized vegetative difference index (NDVI) defined as the ratio of $(R_{NIR} - R_{RED})/(R_{NIR} - R_{RED})$ and was first proposed by Deering (1978) as a estimator of LAI in canopies. More recent studies have shown that NDVI is a better estimator of light interception by canopies since the values reach a saturation point during the season (Hatfield et al., 1984, Wiegand et al., 1990, 1992).

One of the major problems encountered in the application of VI's has been the soil background and to adjust for soil background through a soil-adjusted vegetative index (SAVI) described by Huete (1988). The SAVI was defined as $SAVI = (R_{NIR}-R_{red})(1 + L)/(R_{NIR} + R_{red} + L)$, where L is a adjustment parameter and typically 0.5. Huete et al. (2002) further refined this index to derive a Enhanced Vegetative Index (EVI) as $EVI = 2.5(R_{NIR}-R_{red})/(R_{NIR}+6R_{red} - 7.5R_{blue} + 1)$ which added reflectance in the blue region of the spectrum. Both of these indices were developed to help remove soil background problems with reflectance data.

Two other indices that have been used to assess crop canopies include the normalized pigment chlorophyll ratio index (NPCI) and is defined as $(red_{660} - blue_{460})/(red_{660} + blue_{460})$. This was proposed by Peñuelas et al. (1994) for the use in the detection of leaf chlorophyll content in plants. The form of this index is similar to the NDVI. Other forms of the chlorophyll indices include the $CI_{green} = (R_{NIR}/R_{green})^{-1}$ and $CI_{red\ edge} = (R_{NIR}/R_{red\ edge})^{-1}$ proposed by Gitelson et al. (2003, 2005). Another index that has been introduced by Merzlyak et al. (1999) is the plant senescence reflectance index (PSRI) defined as $(red_{660} - green_{510})/nir_{760}$. This index was proposed as being sensitive to the senescence phase of plant development which often causes problems with other indices.

Remote sensing of plant canopies has utilized these indices to assess various plant parameters, e.g., leaf area, ground cover, biomass, leaf chlorophyll content, residue cover. These relationships have been summarized in Hatfield et al. (2004, 2008) and Zarco-Tejada et al. (2005). Zarco-Tejada et al., (2005) conducted a time series analyses of different VI's in relationship to cotton (*Gossypium hirsutum* L.) yield. They found the modified chlorophyll in reflectance index

(MCARI) provided the most sensitive indicator of cotton yield at the late preharvest stage where other indices, renormalized difference vegetative index (RDVI), modified triangular vegetation index (MTVI), and optimized soil-adjusted vegetation index (OSAVI) showed the best relationship to within field differences and yield at the early growth stages. The MCARI is estimated as the $[(R_{700} - R_{670}) - 0.2 \times (R_{700} - R_{550})] \, X \, (R_{700}/R_{670})$ as defined by Daughtry et al. (2000). The RDVI is computed as $RDVI = (R_{800} - R_{670})/(R_{800} + R_{670})^{1/2}$ as developed by Rougean and Breon (1995). The MTVI was developed by Haboudane et al. (2004) and the OSAVI by Rondeaux et al. (1996). These various indices require wavelengths that may not be available with some of the current sensors because of the need for wavelengths above 0.8 µm, Studies to compare the temporal changes in these indices and their variability with fields is critical to evaluation of field-scale variation.

Understanding the temporal variation in various VI's is important to improving field-scale assessment of different agronomic parameters. This study was designed to evaluate the temporal signature patterns of different VI's observed over multiple crops and to compare the differences among the VI's.

MATERIALS AND METHODS

Observations of various agronomic studies have been collected since 2000 with ground-based radiometers. These have included the Exotech with four wavebands (0.455 – 0.514, 0.528 – 0.597, 0.629 – 0.689, and 0.778 – 0.893 µm) and the CropScan radiometer with eight wavelengths (0.46, 0.51, 0.56, 0.61, 0.66, 0.71, 0.76, and 0.81 µm). These instruments are used in the research program and there is no endorsement by USDA-ARS for exclusive use or preferential treatment of these manufacturers.

Data collection using these instruments followed the same procedure during the course of the different experiments. Observations were made on clear days or when there was a minimal amount of cirrus clouds. Observation times were constrained to sun angles greater than 45º or between 1000 and 1400 CST. The Exotech instrument was mounted on a tractor-mounted boom to obtain a height of 2 m above the canopy. The CropScan unit was mounted a pole that was positioned the instrument at a minimum of 2 m above the surface. This allowed for the pixel size of 1.5 m over each surface. Observations were made in the same location in each treatment by marking an area for the measurements. There were five observation sites within eac treatment that were used to obtain a within treatment variance of the VI's. Prior to and immediately after the observations reflectance readings were collected with the unit in the dark and over a reflectance panel. The dark readings were subtracted from the observations and the reflectance panel was used to evaluate the reflectance values for each waveband.

A series of experiments were conducted over the period from 2000 through 2007. These involved different tillage systems, fall-chisel plow or fall strip compared to spring strip tillage on corn and soybean (*Glycine max* (L.) Merr.). These experiments also included multiple corn hybrids and soybean varieties to determine the differences among genetic material in their reflectance values. The hybrids used in the corn experiment were Asgrow RX634YG, Asgrow RX730RR/YG, HSX1120, Pioneer 34B23, Pioneer 35P17, Pioneer 33P67, Pioneer 34M93, and Pioneer 34B24. Soybean varieties included Agrow A2553, Asgrow AG2703, Asgrow A2869, Asgrow AG2905, Asgrow AG2801, Dekalb DK26-52, Midwest G2380, Pioneer 92M70, Stine S2342-4, Stine S2302-4, and Stine S2116-4. These hybrids and varieties were selected based on their use in central Iowa and not to the inclusion of other genetic materials. Each treatment was replicated three times and plot sizes were 27 x 50 m. Row direction was north-south in all years of the experiment.

Within the tillage treatments there was a difference in nitrogen rate applied that ranged from 135 kg N ha^{-1} to 190 kg N ha^{-1}. Nitrogen was applied either in the fall with the fall chisel system or in the spring as a combination of starter and sidedress application in the strip tillage system.

Observations were also collected over canola (*Brassica juncea* var. *juncea*) and this crop was grown with planting in the spring and harvest in mid-summer each year. An additional crop in these observations was wheat (*Triticum aestivum* L.) that was planted in the fall, harvested in the early summer and then replanted to soybean as part of a double crop experiment.

All of the plot areas were located on Clarion loam, Canisteo clay loam, and Storden loam soils. Plot areas were located over the field and covered different soils within the treatment area. All sampling locations were located with GPS equipment to be able to link the reflectance observations with soil types within the field. Additional observations made within each treatment included leaf chlorophyll readings, crop yield, crop phenology, and residue cover after harvest.

RESULTS AND DISCUSSION

Seasonal changes in reflectance over the different crops revealed similar features in terms of the general response with the blue, red, and green wavelengths decreasing during the growing season and the near-infrared increasing. Throughout the complete year from harvest of the proceeding crop until after harvest of the next crop there were changes over the fall and winter period; however, these affected the bare soil reflectance values. An example for corn is shown in Fig. 1. There is a bare soil line that remains fairly constant throughout the non-growing season period and changes in the values are affected more by water content in the crop residue or wetness of the soil surface. These patterns are typical of corn growth with a very sharp change in the near-infrared (nir) reflectance compared to the red and green wavelengths (Fig. 1).

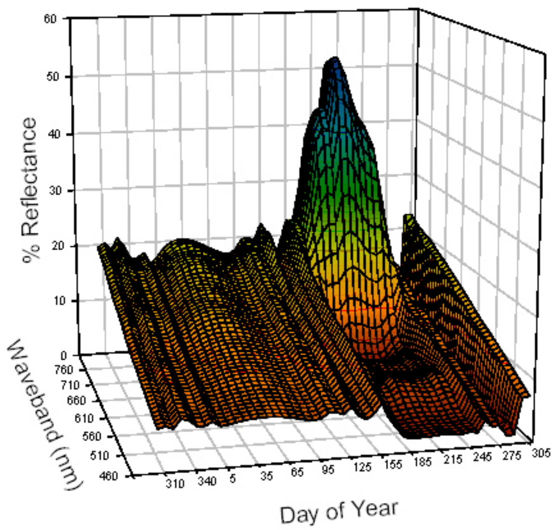

Figure 1. Reflectance over corn obtained throughout the year with a CropScan eight-band radiometer over a spring strip tillage system.

Reflectance values obtained over a double-crop wheat soybean within the same year show the dynamics of the vegetation development of these two crops (Fig. 2). There was a unique feature in these patterns with a increase in reflectance observed in the seasonal trends from Day of Year (DOY) 180 until 200 when there was a presence of weeds within the soybean crop that was removed through herbicide application. The shapes of these curves throughout the year are similar to corn with very stable red and green reflectance compared to the change in the nir wavelengths. There was a noticeable and significant

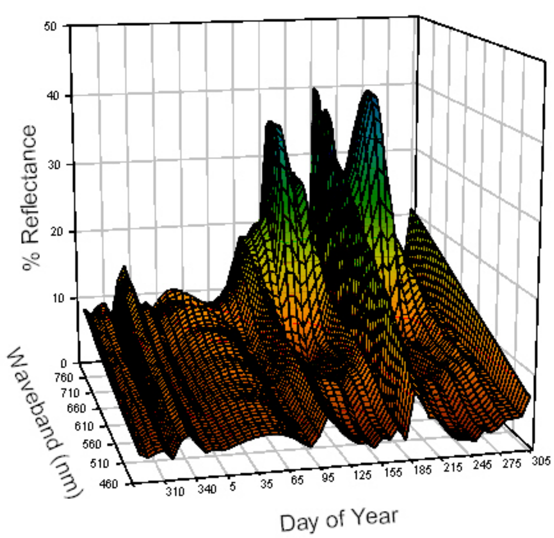

Figure 2. Reflectance over wheat (until DOY 180) and soybean (DOY 180 and greater) obtained throughout the 2006- 2007 year with a CropScan eight-band radiometer.

decline in the nir reflectance over the wheat canopy following the presence of the panicles at the top of the canopy. In wheat these morphological structures reduce the nir reflectance values compared to the leaves of the canopy (Fig.2). As the soybean crop began to develop the same pattern in reflectance change appeared with reflectances in the visible wavelengths decreasing and the nir increasing (Fig. 2). Observations over the canola canopy had a different temporal pattern because of the early season development and maturity and harvest in mid-summer (Fig. 3).

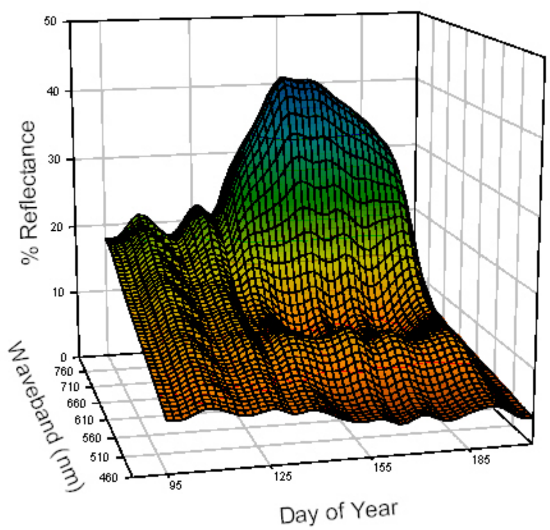

Figure 3. Reflectance over canola during the 2007 growing season obtained with a CropScan eight-band radiometer.

The patterns of reflectance are similar to the other crops observed in the study with the largest temporal change in the nir wavelengths (Fig. 3). Reflectance values in the red region were often less than 0.05 during the growing season while nir values ranged from 0.2 to 0.4 (Fig. 3). In these four canopies the changes in the reflectances across the wavelengths show the dynamic nature of the reflectance values observed over agronomic crops and indicate that for accurate development of VI's there is a need for frequent observations during the growing season while during the off-season there is little change.

Seasonal changes in the VI's showed patterns that were indicative of the seasonal patterns in the wavebands as shown in Fig. 1, 2, and 3. Values for NDVI showed a bare soil value of near 0.15 and increased to 0.9 during the period of maximum vegetative growth (Fig. 4). An interesting pattern in the NDVI values was the changes in the standard deviation during the year. The greatest variation was present during the period from DOY 175 through 210 which covered early season development through early grain-fill (Fig. 4). Once the tassels on the canopy matured there was little variation until after harvest. However, during the period from DOY 190 through 240 there was no significant change in leaf area of the crop. The increased variation after harvest was significantly different in the

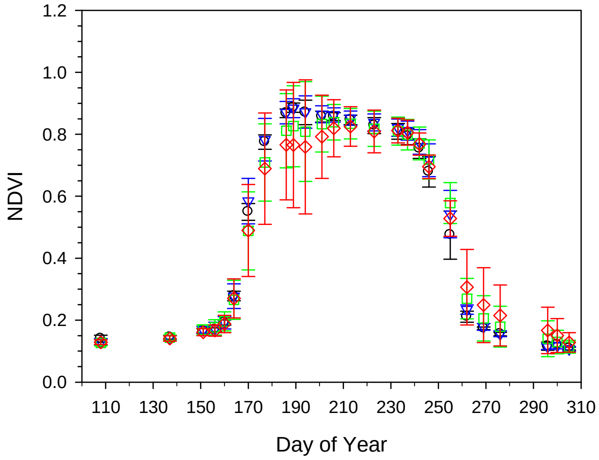

Figure 4. Values for NDVI and the standard deviation over the treatment means throughout the growing season for corn in 2007. Fall strip with 135 kg ha^{-1} (○), fall strip with 135 kg ha^{-1} with N-serve (Δ), spring strip with 135 kg ha^{-1} (□), and spring strip with 191 kg ha^{-1} (◊).

spring strip tillage plots due to the presence of the crop residue that was not disturbed by tillage after harvest. Early in the season; however, there was no difference among treatments. The other time with a significant difference was in the early growth period prior to the reproductive stage and the spring strip treatments had lower NDVI values (Fig. 4).

Other VI's showed a different temporal pattern than NDVI. The patterns for the NPCI index showed a slight but significant change in the early season and then an increase as the crop matured (Fig. 5). These patterns show the spring strip system at both N rates to have less chlorophyll in the canopy compared to the fall strip system. In this index the variation remained large throughout the growing

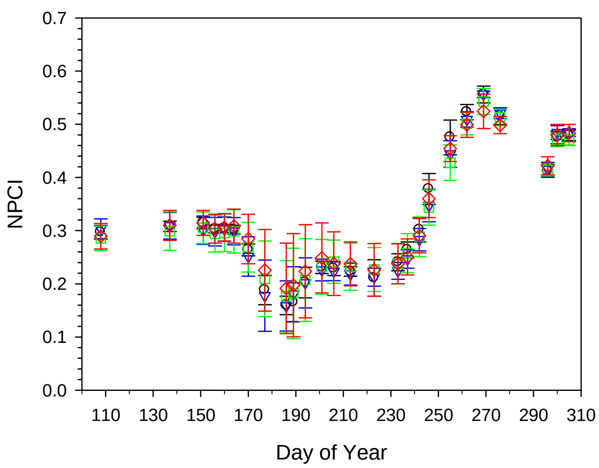

Figure 5. Values for NPCI and the standard deviation over the treatment means throughout the growing season for corn in 2007. Fall strip with 135 kg ha^{-1} (○), fall strip with 135 kg ha^{-1} with N-serve (Δ), spring strip with 135 kg ha^{-1} (□), and spring strip with 191 kg ha^{-1} (◊).

season when there was a crop present but relatively low variation during the remainder of the year (Fig. 5). The pattern of variation for the PSRI index had a similar pattern of variation throughout the year with a large deviation until the reproductive stage began and then very little deviation until maturity (Fig. 6).

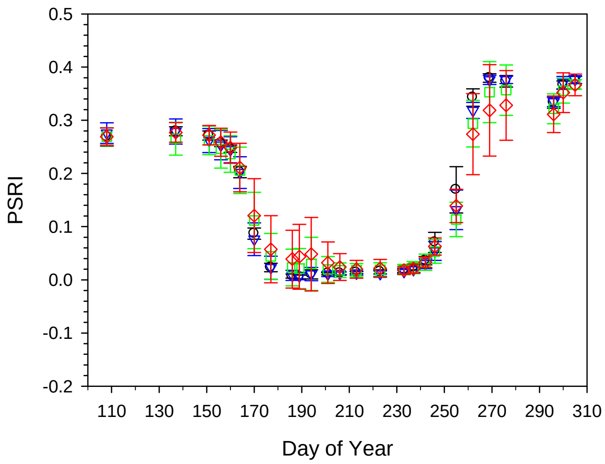

Figure 6. Values for PSRI and the standard deviation over the treatment means throughout the growing season for corn in 2007. Fall strip with 135 kg ha^{-1} (○), fall strip with 135 kg ha^{-1} with N-serve (Δ), spring strip with 135 kg ha^{-1} (□), and spring strip with 191 kg ha^{-1} (◊).

The treatment differences were significant in the early season and at maturity with the greatest separation during the maturity stage. This index is most sensitive to the senescence phase in being able to differentiate among treatments. This index pattern can be used to determine the rate of senescence in different crops by comparing the rate of change from a green canopy to a senesced canopy. Combination of the different indices throughout the growing season can be used to define the points at which the indices can be most useful in their comparison.

One of the most variable indices was the EVI in the early season (Fig. 7). The variability persisted until the late grain fill period. However, when there was no crop growing and only residue covered soil the variability was minimal. The EVI was able to separate differences among tillage treatments in this study. The combination of the blue, red, and nir wavebands in this index provided a VI that was most sensitive to differences in the growth patterns of the corn crop. Simple ratio indices exhibited the most variation during the growing season and the green/red index is an example of large variation (Fig. 8). The variation was large through the season until the canopy matured and then there was little variation among the treatments.

The patterns shown in the different indices for the corn canopy were typical of those observed in the different crops in this study. The patterns of variation for an index provide insights into the ability of the index to detect differences among treatments or plant growth patterns. Utilization of these indices to define agronomic parameters for precision agriculture applications will require understanding about the causes of the variation since these patterns are induced by

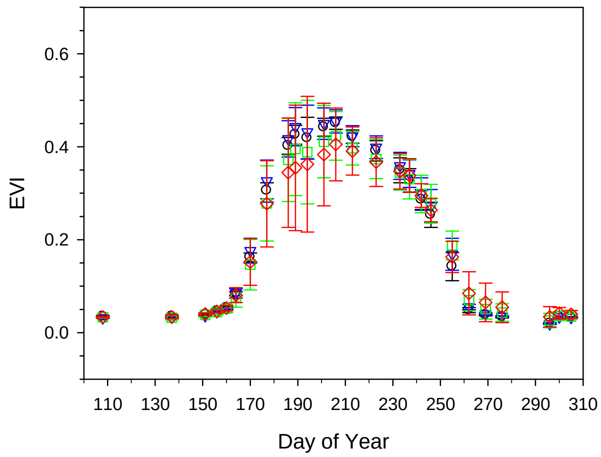

Figure 7. Values for EVI and the standard deviation over the treatment means throughout the growing season for corn in 2007. Fall strip with 135 kg ha^{-1} (○), fall strip with 135 kg ha^{-1} with N-serve (Δ), spring strip with 135 kg ha^{-1} (□), and spring strip with 191 kg ha^{-1} (◊).

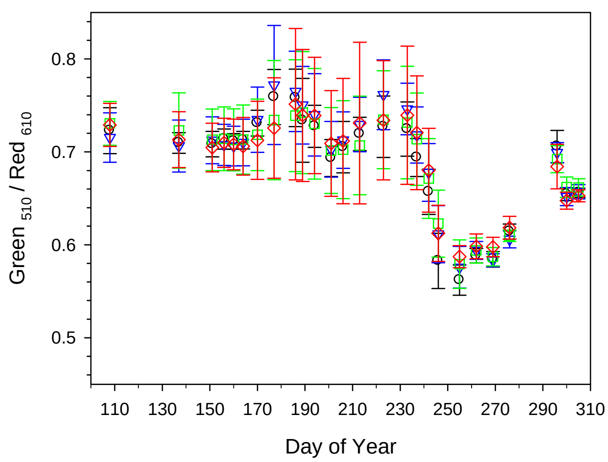

Figure 8. Values for green$_{510}$/red$_{610}$ ratio and the standard deviation over the treatment means throughout the growing season for corn in 2007. Fall strip with 135 kg ha^{-1} (○), fall strip with 135 kg ha^{-1} with N-serve (Δ), spring strip with 135 kg ha^{-1} (□), and spring strip with 191 kg ha^{-1} (◊).

subtle growth differences and not large soil differences that could be encountered in a field.

Patterns of VI's over the course of multiple seasons demonstrate the utility of the indices to track agronomic parameters. Over the course of these experiments we have been able to collect data over experiments that show the seasonal changes. An example of this is the seasonal patterns in NDVI across a fall strip system (Fig. 9). There were eight corn hybrids in this study and there were no significant differences among the hybrids. Both the broad-band Exotech and narrow waveband CropScan units were used in this sequence and there was no difference in the NDVI calculated with either unit. When the NDVI values were

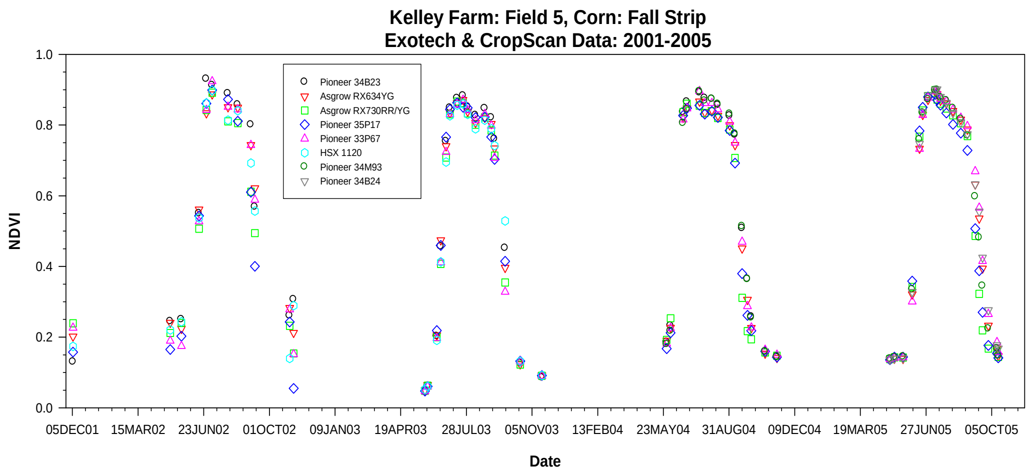

Figure 9. Seasonal patterns in NDVI over eight corn hybrids from 2002 to 2005 with a fall strip tillage treatment and a 135 kg ha^{-1} N rate.

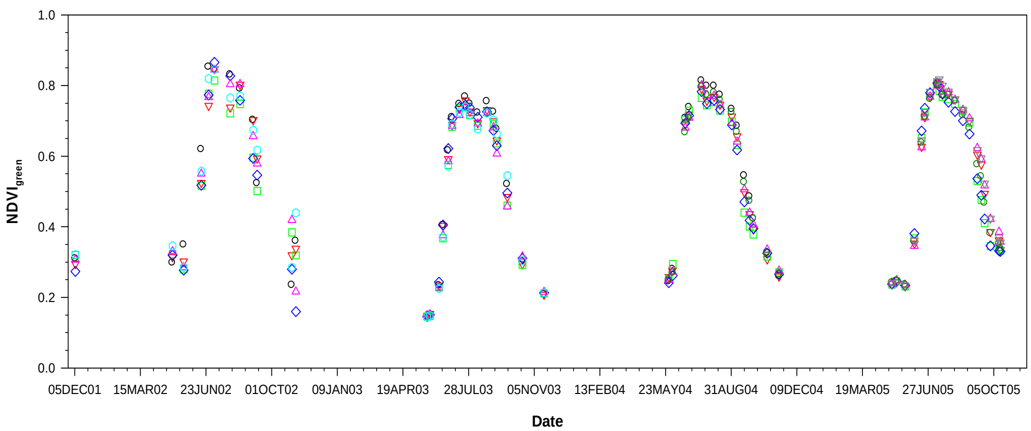

Figure 10. Seasonal patterns in NDVI over eight corn hybrids from 2002 to 2005 with a spring strip tillage treatment and a 135 kg ha^{-1} N rate.

calculated for the spring strip tillage system and compared to the fall strip system there were differences during the growing season with the spring strip having lower NDVI values during each season (Fig. 10). Maximum values of NDVI in the fall strip system were near 0.9 compared to 0.8 for the spring strip system. There were no significant differences among hybrids in this study for either of the tillage systems. Since the NDVI is related to interception of solar radiation this index can be used to estimate cumulative intercepted solar radiation as shown in Fig. 11. The differences in the growth translate into different cumulative solar radiation totals for the growing season. These can be up to 10-15% different among treatments.

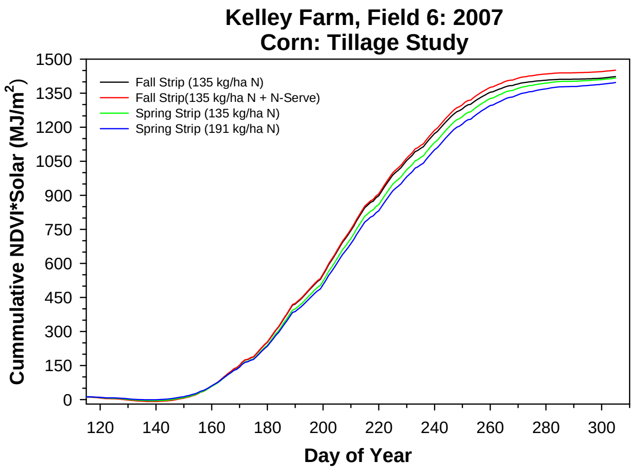

Figure 11. Cumulative intercepted solar radiation for two tillage systems, fall strip and spring strip with different N treatments.

CONCLUSIONS

Seasonal patterns of reflectance reveal many of the attributes related to canopy development in terms of biomass and leaf area accumulation. Reflectance across the visible and near-infrared spectrum shows that there is little difference when the soil is covered only with residue or tilled. The greatest differences occur when the crop is developing and during this time the visible portion of the spectrum has a decreased reflectance compared to the bare soil and throughout the growing season these values remain relatively constant compared to the nir which increases rapidly as the canopy develops. The peak nir reflectance values occur when there is maximum leaf area or biomass in the canopy. The presence of tassels in corn or panicles in wheat cause the nir reflectance values to decrease even though the leaves have not changed because these morphological structures have a different color and morphology compared to the leaves. The changes in the reflectance patterns during the season help identify when the intensity of reflectance measurements should be increased to detect changes in the crop.

Variation about the mean for different indices also helps to refine our understanding of the temporal dynamics of VI's. The NDVI values are most variable early in the season on corn, soybean, wheat, and canola and then the variation decreases during the grain-filling period. The reason for this pattern is not entirely clear because when other indices, e.g., NPCI, EVI, or PSRI are evaluated they show a similar seasonal response in terms of variation. However, these indices are more sensitive to differences in crop development than NDVI and separate out agronomic practices, e.g., tillage, nutrient status, or crop residue cover, with greater reliability. The PSRI is most sensitive to changes in crop maturity and in the different crops provides the greatest separation during the senescence phase of development. The NDVI does detect differences in crop conditions that are related to light interception and provides a good method of being able to assess cumulative light interception by different canopies.

Remote sensing methods provide valuable tools for crop canopy assessment and further refinement of these tools will help to provide improved information for precision agriculture applications. Understanding the temporal dynamics of VI's will help enhance the information content required for improved management decisions.

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