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Original Research Article

Evaluating spectral indices for determining conservation and conventional tillage systems in a vetch-wheat rotation

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ABSTRACT

Conservation tillage (CT) systems, which consist of reduced and no-tillage systems, retain considerable quantities of crop residues on the soil surface. These crop residues perform as a barrier to wind and water to decrease soil erosion and evaporation. The use of remote sensing technology provides fast, objective and effective tool for estimating and measuring any agricultural event. The challenge is to differentiate the tillage systems by the crop residue cover on the soil surface. Spectrally derived normalized difference tillage index (NDTI), Shortwave infrared normalized difference residue index (SINDRI), cellulose absorption index (CAI) and Lignin-cellulose absorption index (LCA) were examined to distinguish their value as remote sensing methods for identifying crop residue cover in conventional and conservation tillage systems. Tillage treatments included conventional tillage (MD: Mouldboard plow+Disk harrow), reduced tillage (CD: Chisel plow+Disk harrow), minimum till (MT: Stubble cultivator), and no-tillage (NT_1 and NT_2: with standing stubble and standing stubble plus threshing residue, respectively).

CAI had a linear relationship with crop residue cover, which the comparative intensity of cellulose and lignin absorption features near 2100 nm can be measure by it. Coefficients of determination (r^2) for crop residue cover as a function of CAI and LCA were 0.89 and 0.79 respectively. Absorption specifications near 2.1 and 2.3 μm in the reflectance spectra of crop residues in minimum and no- tillage systems were related to cellulose and lignin. These specifications were not evident in the spectra of conventional tillage system. In this study the best index to use was CAI, which showed complete separation tillage systems, followed by LCA and NDTI. Four tillage intensity classes, corresponding to intensive (< 6% residue cover), reduced (10–20% cover) minimum (25–40%) and no-tillage (> 60% cover) tillage, were recognized in this study.

1. Introduction

Crop Residue Cover (CRC) after planting is used to determining the classifications of soil tillage intensity. Intensive (conventional) tillage returns less than 15% CRC, while conservation tillage allows to remain at least 30% CRC on the soil surface. No-till (or strip till) system usually disrupts < 25% of row width (USDA-NRCS, 2006).

Retaining crop residue on the soil surface decrease evaporation and soil erosion, increase soil organic matter and improve soil quality (Truman et al., 2003; Jarecki and Lal, 2003; Derpsch, Friedrich, Kassam & Li, 2010). Therefore, crop residue management is the basic part of the various conservation tillage systems. Based on annual roadside surveys of crop residue levels, regional estimates of conservation tillage practices for selected counties has been collected by the Conservation Technology Information Center (CTIC, 2004). These surveys are particular and the methods differ from county to county (Thoma, Satish & Marvin, 2004). Traditional methods of residue cover measurement, i.e. line-point transect or photographic techniques (Laflen, Amemiya & Hintz, 1981) are often error prone due to operator bias, lack of contrast, and spatial variability, and are inefficient for use at the county and state levels (Morrison, Huang, Lightle & Daughtry, 1993).

Discriminating of the spectral signatures of conventional and conservation tillage systems has been acquired mainly using bare soil imagery by effectively applying remote sensing methods (Gowda, Dalzell, Mulla & Kollman, 2001; Bricklemyer, Lawrence & Miller, 2002; Yang, Prasher, Whalen & Goel, 2002; Viña, Peters & Ji, 2003; South, Qi & Lusch, 2004; Yang et al., 2002). The mainly restrictive factor in residue estimation by using remote sensing

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Table 1
Tillage and planting implement specifications.

Equipment	Working width (cm)	Tillage/planting depth (cm)	Number of row/shank	Type of tine/furrow opener
Moldboard plow	108	20	3	General purpose, three bottom regular share cut
Chisel plow	270	25	9	C- Shape, mounted, two row
Stubble cultivator	220	15	5	Split chisel wing share, roller
Tandem disk	250	8–10	7 in each gang	Spherical (53 cm)
Deep-furrow drill	225	5–7	13	Shovel
No-tillage drill	272	5–7	16	Double disc

spectra lies in the fact that soil and crop residue have similar spectral reflectance (McMurtrey, Craig & Thomas, 2005; Streck, Augusto, Rundquist & Connot, 2002). Crop and soil spectra rise without curvature through the visible (VIS) and near-infrared (NIR), differing in scale of spectral response (Aase and Tanaka, 1991; Daughtry et al., 1995; Sullivan et al., 2004). Thus, variation in surface soil properties, such as soil water content, particle size repartition, and iron oxide content can cause the terrain to be more or less reflective than crop residue spectra (Chen and McKyes, 1993; Daughtry et al., 1995; Nagler, Daughtry & Goward, 2000)

Remote sensing is the way to prepare effective and objective methods for evaluating crops conditions in wide-ranging. However, the many spectral indices that use Landsat TM shortwave infrared bands for evaluating crop residue cover have had indistinct achievement (Daughtry, Hunt, Doraiswamy & McMurtrey, 2005). Sullivan, Lee, Beasley, Brown, and Williams (2008) considered the sensibility of a remotely taken crop residue cover index for illustrating no-tillage, strip tillage and conventional tillage systems in a cotton-corn-peanut rotation in the southeastern coastal plain. Results indicated that emittance spectra represented small, but significant differences between treatments observed.

Optically based remote sensing methods for crop residue identification utilize a number of indices. These remote sensing methods fall into three basic categories: (i) normalized difference indices, (ii) spectral angle methods, and (iii) reflectance-band height indices (Serbin, Daughtry, Hunt, Reeves & Brown, 2009). Of these three methods, reflectance-band height indices usually perform the best, as they are dependent on the distinctive spectral features of soils and crop residues, the former of which vary depending on mineralogy, soil organic carbon (SOC), and particle size (Allen and Hajek, 1989; Clark, 1999; Daughtry et al., 2005; Kokaly, Despain, Clark & Eric Livo, 2003; Serbin et al., 2009). No studies have estimated the potential for remote sensing data to describe residue cover in the Iran, where conservation tillage is becoming to increase in the country recently.

The aims of this study were to (1) assess the spectral reflectance of conservation and conventional tillage systems by the handheld spectroradiometer in dryland vetch-wheat rotation, (2) to evaluate spectral indices for identifying tillage regimes, and (3) to identify relationships of selected indices (NDTI, CAI, LCA, SINDRI) by percent cover and the amount of residue in different tillage systems.

2. Materials and methods

2.1. Site and soil

The field experiment was carried out at Dryland Agricultural Research Station located in a cold semi-arid region of Iran in 2011–2012. The soil (Typic Calcixerept) at the study site had a clay loam texture in the 0–15 cm surface layer (300, 390 and 310 g kg^{-1} respectively sand, silt, and clay) and a clay texture in the 15–60 cm depth (240, 290 and 470 g kg^{-1} respectively sand, silt and clay). The climate of the study area is temperate continental with warm summers based on Koeppen's classification system. The long-term average precipitation, relative humidity and temperature of the study area are 354 mm, 50.2% and 12.5 °C, respectively.

2.2. Tillage treatments

The design of experiment was randomized complete block (RCBD) with 4 replications. The tillage treatments involved of (1) conventional tillage: moldboard plowing followed by one pass of tandem disk (MD); (2) reduced tillage: chisel plow followed by one pass of tandem disk (CD); (3) minimum tillage: stubble cultivator (MT); (4) no-till with standing stubble (NT1) and (5) no-till with total (standing and threshing) previous crop residue (NT2). On NT2 plots, the shredded vetch residue, which was gathered after threshing of the plants from the same plots, was spread evenly before wheat planting. Main tillage depths for MD, CD and MT were 20, 25 and 15 cm, respectively. Tandem disk operations were completed at a depth of 8–10 cm. The explanation of the tillage and planting equipment are given in Table 1.

2.3. Wheat sowing

A winter wheat cultivar (Homa) was planted with a row spacing of 17 cm at the rate of 178 kg per hectare. The planting depth was about 6 cm. Fertilizers were banded the (Triple superphosphate and urea) 3-cm below the seed in one pass. Fertilizer was applied at the rates of 40 kg N per hectare as urea and 10 kg P2O5 per hectare as triple super-phosphate. Supplementary 20 kg N per hectare as urea was used as top dressing on April. The sowing and harvesting date of wheat were on first October and in middle July respectively.

2.4. Vetch sowing

Vetch was planted using the same treatments as used in wheat planting. Forage cultivar Hungarian vetch was planted 6 cm depth at a seeding rate of 80 kg per hectare using deep furrow and Baldan3000 no-till drills for conventional and conservation tillage treatments respectively. Fertilizer consisted of N and P with sources of urea and triple super phosphate banded 3 cm under the seed.

2.5. Remote sensing of crop residue

A portable FieldSpec3 spectroradiometer (Analytical Spectral Device, Inc. USA) was used for collecting reflectance measurements. The field Spec3 utilize the full spectral range (350–2500 nm) by three detectors enabling automation of data collection and ease of use wide variety of operations. Four ASD acquisitions were taken in each plot. A white panel reference correction reading data was used to set the internal ASD correction data for incident solar radiation for collecting reflectance values before each replications measurement.

2.5.1. Spectral indices

Four spectral indices were used as a tool to discriminate between no-tillage and conventional tillage. Indices included cellulose absorption index (CAI), lignin-cellulose absorption index (LCA), shortwave infrared normalized difference residue index (SINDRI) and normalized difference tillage index (NDTI).

The Landsat TM spectral index used for this research was the NDTI (Daughtry, Serbin, Reeves, Doraiswamy & Hunt, 2010):

$$\mathrm{NDTI} = \left(R_{1650} - R_{2215}\right)/\left(R_{1650} + R_{2215}\right) \tag{1}$$

where R_{1650}, and R_{2215} denote the atmospherically corrected reflectances of TM Bands 5 (1550–1750 nm), and 7 (2080–2350), respectively.

The reflectance-band height indices used for this research were the CAI (Nagler et al., 2000) and the LCA (Daughtry et al., 2005). The CAI is determined by

$$\mathrm{CAI} = 100\left[0.5\left(R_{2.0} + R_{2.2}\right) - R_{2.1}\right] \tag{2}$$

where, R indicates the reflectance and the subscripts 2031, 2101, and 2211 denote 11-nm-wide bands cantered at 2031, 2101, and 2211 nm, respectively.

The LCA is determined as

$$\mathrm{LCA} = 100\left[\left(R_{2210} + R_{2160}\right) + \left(R_{2210} - R_{2330}\right]\right. \tag{3}$$

where $R_{2160,}$ R_{2210}, and R_{2330} indicate reflectance correspond to ASTER Bands 5 (2145–2185 nm), 6 (2185–2225 nm), and 8 (2295–2365 nm), respectively. The ASTER Bands 5 and 6 fall on the slope and shoulder, respectively, of the 2101-nm cellulose absorption; ASTER Band 8 contains the C–H stretching plus CH_2 deformation combination at around 2335 nm seen in cellulose (Daughtry et al., 2005; Workman, Jerry & Weyer, 2007).

The shortwave infrared normalized difference residue index index (SINDRI) is determined as

$$\mathrm{SINDRI} = \left(R_{2210} - R_{2260}\right)/\left(R_{2210} - R_{2260}\right) \tag{4}$$

where R_{2210}, and $R_{22,260}$ indicate reflectance correspond to ASTER Bands 6 (2185–2225 nm) and 7 (2285–2235 nm), respectively.

The narrow-band reflectance values acquired with the ASD spectroradiometer were averaged over the range of the of Landsat Thematic Mapper and Aster bands in order to simulate these broad bands (Streck et al., 2002)

2.6. Amounts and cover of crop residue

The previous crop residue was collected using traditional agronomic methods by 4 replications on each plot, and then was dried at 65 °C for 48 h. A reference heap was sited in each measurement plot for gathering residue, to avoid maladjustment between the field of view for ASD measurements and $1 \times 1\ m^2$ quadrat of biomass measurements

Crop residue was determined by dividing the weight of the dried residue by the surface area of the plot ($g\ m^{-2}$).

Line point transect measurement method applied to measure the levels of wheat and vetch residue cover (Thoma et al., 2004). The method utilizes a 15.38 m line with beads every 0.15 m. The line was zigzagged across each plot due to small plots, thus the 15.38 m beaded line was traversed several times at the each plot (McMurtrey et al., 2005) Percent cover was calculated by dividing the counted number of beads by total beads beside the transect and multiplying by 100.

2.7. Statistical analysis

The SAS statistical software package (Institute, Sas, 1990) was used for analysis of data. When the F-test specified statistical significance at the 1% level, means were classified by the Duncan's new multiple range test. The Xlstal 2011 software used for Regression analyses of data.

3. Results and discussion

3.1. Spectral response curves

Spectral reflectance of different tillage systems in wheat and vetch residue are shown in Figs. 1 and 2. Spectral response curves were smoothen by SAMS software given a Savitzky-Golay filter (Press, William, Teukolsky, Vetterling & Flannery, 1988). For the tillage systems evaluated in this study, Minimum tillage and No-till treatments are spectrally similar with reflectance increasing without inflection throughout 400–1400 nm. The No-till with total residue (NT_2) spectrum shows major differences from other treatments in reflectance values and spectral shape across all wavelengths. In general reflectance of conservation tillage treatments was higher than conventional tillage (Chisel and mold board plow) treatments (Fig. 1). Daughtry et al., (2005) stated that the spectra of soil and crop residue had similar shapes and difference was only in amplitude over the 400–1200 nm wavelength region. The major water absorptions near 1446 and 1930 nm made breaks in the spectra where the atmosphere absorbs almost all of the received radiation. The absorption property at 2200 nm in conventional and reduced tillage is relevant to clay minerals of soils (Ben-Dor and Banin, 1995), but is invisible in the conservation tillage systems spectra which covered with plant residue.

Broad absorption features near 2100 and 2300 nm are related with cellulose and lignin in the crop residues in conservation tillage systems (Curran, 1989; Elvidge, 1990; Nagler et al., 2003; Daughtry et al. 2005) As the coverage of residue increased (NT_2 against NT_1), the prominence of 2100 nm absorption feature also increased. These absorption specifications are not obvious in the conventional tillage reflectance spectra (Fig. 1).

Spectral reflactance of the tillage treatment in vetch residue were somewhat different from that's of wheat residue. It may be because of the little residue of conservation tillage at vetch field, the nevertheless response of treatments, especially conservation treatments including min and no-tillage were similar to wheat residue field (Fig. 2). Moreover, wheat field separation of no-tillage treatments and conventional tillage in vetch field was the most visible in the 2000–2250 nm areas. No- tillage treatments (NT_1 and NT_2) displayed a noticeable dip in the spectra at near 2100 nm (Fig. 2). According to previous studies, differences of CAI values

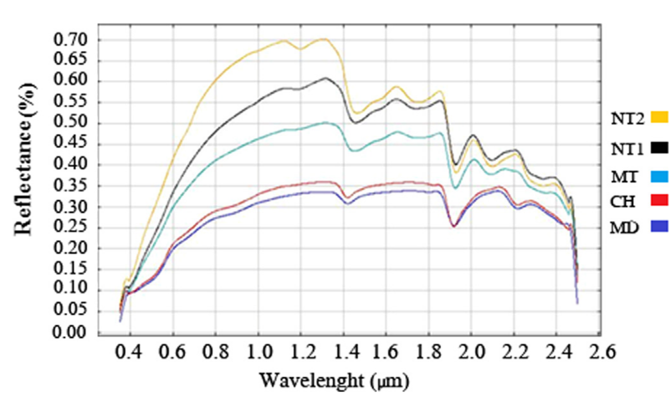

Fig. 1. Spectral reflectance of different tillage systems in wheat residue.

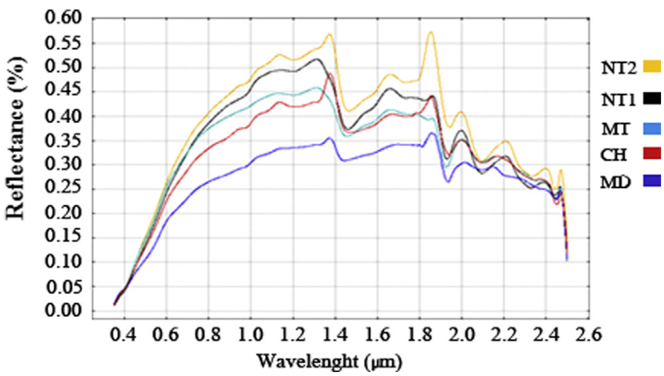

Fig. 2. Spectral reflectance of different tillage systems in vetch residue.

can be determined in this region (Daughtry et al., 2005)

3.2. Effects of tillage systems on spectral indices

Means values of spectral indices were significantly different. All of the indices were able to separate No-till treatments from conventional tillage. However, two of the indices, CAI and LCA, were able to separate significantly No-till treatments and stubble cultivator (Minimum Tillage) from chisel plow and mold board plow treatments (Table 2). Among all of the spectral indices the NDTI had lower performance to differentiate tillage treatments from each other. In general, it appears that NDTI may be usable to distinguish no-tillage treatment from conventional tillage system, but SINDRI is capable to separate the conservation tillage systems from conventional tillage, where CAI and LCA both had the highest performance. In this study, the CAI and LCA values of conventional tillage (Moldboard plowing + disking) were negative. Nagler et al. (2003) also demonstrated that CAI values of bare soils are negative. Conservation tillage systems including minimum tillage (Stubble Cultivator) and no-tillage treatments had positive CAI and LCA values. Differences between CAI and LCA values of reduced (Chisel plowing + disking) and conventional tillage were significant. (Table 2). In NT_2 (No-till in total previous crop residue) treatment, CAI value (7.2) was significantly highest.

3.3. Correlation between spectral indices and crop residue cover

There was observed a relationship between the percent coverage of residue retained on the soil and CAI, LCA, SINDRI and NDTI (Figs. 3–6). Of the indices determined, CAI showed the highest R^2 value with percent of residue cover (Fig. 3.) followed by

Table 2
Mean comparisons of spectral indices in different tillage systems.

Tillage systems	Spectral Indices			
	NDTI[a]	CAI	LCA	SINDRI
Moldboard plowing + disking (MD)	0.0777b	−1.345c	−0.0150c	−0.0104d
Chisel plowing + disking (CH)	0.1245ab	0.598c	0.0063c	0.0273c
Stubble Cultivator (MT)	0.1147ab	3.364b	0.0347b	0.0473bc
No-till with standing crop residue (NT_1)	0.1640a	7.161a	0.0823a	0.0665ab
No-till with total crop residue (NT_2)	0.1573a	7.250a	0.0891a	0.0794a
LSD 1%	0.0683	3.403	0.0216	0.0205

In each column, values followed by the same letters are not significantly different according to Duncan's new multiple range test at the 1% level of probability.

[a] NDTI: Normalized difference tillage index, CAI: Cellulose absorption index, LCA: Lignin-cellulose absorption index, SINDRI: Shortwave infrared normalized difference residue index.

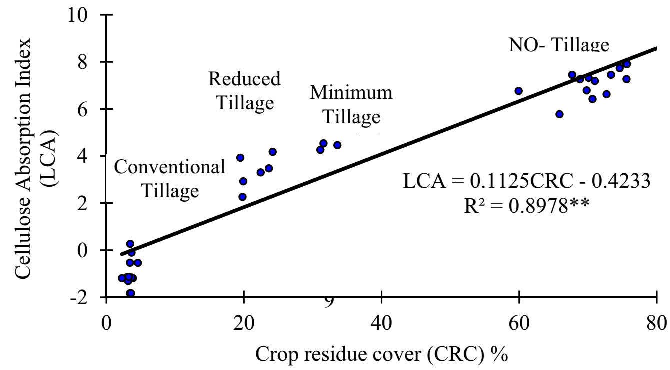

Fig. 3. Relationships of cellulose absorption index (CAI) and crop residue cover in different tillage systems.

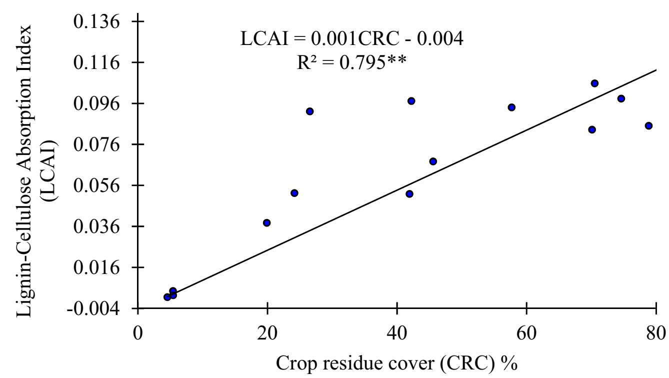

Fig. 4. Relationship between lignin-cellulose absorption index and crop residue cover (LCA).

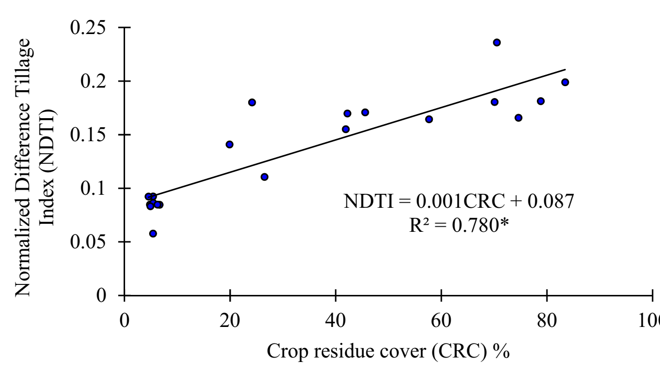

Fig. 5. Relationship between crop residue cover and normalized difference tillage index (NDTI).

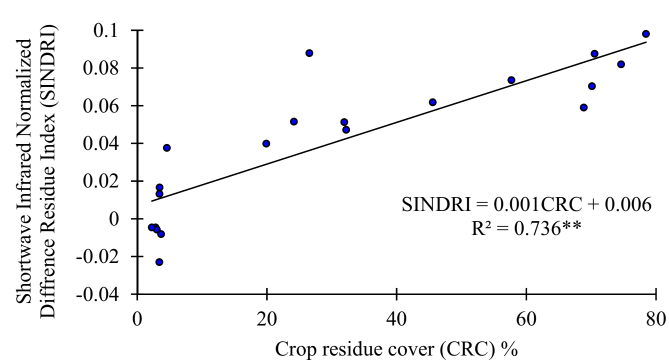

Fig. 6. Relationship between crop residue cover and shortwave infrared normalized difference residue index (SINDRI).

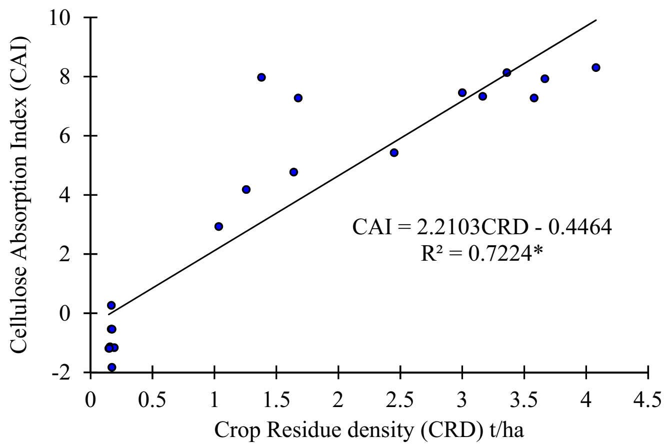

Fig. 7. Relationships of CAI and crop residue density in different tillage systems.

LCA, NDTI and SINDRI respectively. The higher R^2 values suggest that CAI and LCA mostly carry out better than NDTI and SINDRI.

It is important to note, only the residue weights and percent of residue cover against the reflectance were evaluated, other factors such as soil moisture and color could have influenced the reflectance values (Daughtry et al., 2006; Pacheco and McNairn, 2010; Thoma et al., 2004).

In less than 6% residue cover in conventional tillage (Moldboard plowing+disking), CAI value was negative which shows that little amounts of residue cover in conventional tillage could not be distinguished from bare soil. CAI values also increased as the amount of crop residue on the soil surface increased, (Fig. 3). As the cover of crop residue on the soil surface increased, CAI values also increased. Chisel plow plus disk harrow by 10–20% crop residue had CAI values between 2 to 4 and subsequently stubble cultivator by 25–44% crop residue cover had 4.5–5.7 CAI values. Finally, in no-tillage systems CAI values increased up to 8 as crop residue increased to 75%.

The relationship between the amounts of residue in ton per hectare with CAI is shown in Fig. 7. In this study the crop residue densities less than 200 kg per ha had negative CAI values, by increasing crop density of 1000–2000 kg per ha the CAI index increased from 1.76 to 4. The R^2 value of CAI with residue density was 0.72, where this value in percent of crop residue cover with CAI was 0.90. These results offer that surface measurements of reflectance could be better at forecasting the crop residue cover than residue quantity. Obade et al. (2011) also reported similar results.

4. Conclusions

In this study the best index to use was CAI, which showed complete separation tillage systems, followed by LCA and NDTI.

Results showed that, in vetch–wheat rotation system, No-tillage and Minimum tillage systems are spectrally similar with reflectance increasing without inflection throughout 400–1400 nm. Both in wheat and vetch fields, separation of no-tillage treatments and conventional tillage were most noticeable in the 2000–2250 nm areas. A marked dip in the spectra at ~2100 nm was observed in no- tillage treatments (NT_1 and NT_2).

All of the spectral indices were able to separate No-till treatments from conventional tillage. However two of the indices, CAI and LCA, were able to separate significantly No-till treatments and stubble cultivator (Minimum Tillage) from chisel plow and mold board plow treatments.

In this study spectral indices such as CAI derived from spectrometry by hand held spectroradiometer was used for separating tillage systems. The data of satellites equipped with sensors which produce favorite wavelengths are needed to develop this way for future studies.

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