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Evaluating a crop residue cover index for determining tillage regime in a cotton-corn-peanut rotation

D.G. Sullivan, D. Lee, J. Beasley, S. Brown, and E.J. Williams

Abstract: Conservation tillage is a well known best management practice that improves soil quality, reduces runoff and erosion, and increases infiltration. However, a rapid assessment strategy for quantifying the rate and spatial distribution of conservation tillage practices is lacking. This study was designed to evaluate the sensitivity of a remotely derived crop residue cover index for depicting conventional tillage (CT), strip tillage (ST), and no-tillage (NT) systems in a cotton-corn-peanut rotation in the southeastern Coastal Plain. Treatments consisted of CT (rip and bed operation), NT, NT with subsoiling, and ST. Remotely sensed data were acquired three times prior to canopy closure, using a handheld multispectral radiometer (485 to 1,650 nm) and thermal imager (7,000 to 14,000 nm). Using a combination of visible and near-infrared spectra, a crop residue cover index was calculated and evaluated. Results showed that crop residue cover is greatest in years planted with peanut or cotton—likely due to the later winter cover crop termination date compared to years when corn is planted. The crop residue cover index outperformed the thermal infrared, accurately separating conventional from conservation tillage treatments in four out of six data acquisitions in 2004 and 2006. Differentiation among conservation tillage treatments was inconsistent. Regression analyses showed that a strong linear relationship existed between the crop residue cover index and measured crop residue cover (r^2 = 0.51 to 0.86, alpha = 0.10). These data suggest that remotely sensed data may be used as a rapid, field-scale indicator of conservation tillage adoption. Rapid assessment methodologies are necessary to quantify the impact of conservation practice adoption on water quality/quantity, assess adoption rates, and improve the placement of conservation tillage practices at local, watershed and regional scales.

Key words: conservation tillage—crop residue cover—near-infrared—remote sensing—thermal infrared—visible

Conservation tillage adoption has been attributed with increased infiltration, reduced erosion, and improvements to overall soil quality (McMurtrey et al. 1993; Lal and Kimble 1997; Truman et al. 2003). More recently, some researchers have suggested that conservation tillage also shows promise as a management practice for efficient use of agricultural water resources (Reeves 1997; Truman et al. 2003). This is particularly critical in the southeastern United States where long and sometimes drought-prone growing seasons necessitate supplemental irrigation. Considering the impact that conservation tillage may have on sustainable agricultural resources, a rapid method of monitoring the field-scale distribution of residue cover is necessary to better establish the benefits of conservation tillage to soil and water quality.

Currently crop residue cover estimation is typically achieved by using the line-transect or roadside survey methods (Shelton et al.

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1993; Eck et al. 2001; CTIC 2004). However, obtaining spatially representative estimates of residue cover in a timely and cost-efficient manner is difficult. The only national estimate of conservation tillage adoption has been conducted by the Conservation Technology Information Center (CTIC). CTIC provided national estimates of conservation tillage adoption, via roadside survey (17 states) or best professional judgment, on a bi-annual basis until 2004. While this is currently the only national estimate of conservation tillage adoption, Thoma et al. (2004) found that the roadside survey failed to accurately quantify crop residue cover amounts within the 25% to 35% cover range nearly 58% of the time compared to in-field line transect estimates. By comparison, Landsat (TM) data were more efficient, providing rapid, unbiased estimates of residue cover into two classes (<30% and >30% crop residue cover).

Remote sensing (RS) shows promise as a method to rapidly quantify spatial distributions of crop residue cover at the field, landscape and watershed scales. Yet, recent studies regarding the use of RS data for crop residue estimation have yielded mixed results, and even fewer have evaluated crop residue estimation in the highly weathered soil systems of the southeastern United States. A primary limiting factor in using RS spectra for crop residue estimation lies in the fact that soil and crop residue are spectrally similar (McMurtrey et al. 1993; Streck et al. 2002). Crop and soil spectra increase without inflection throughout the visible (VIS) and near-infrared (NIR), differing only in magnitude of spectral response (Baumgardner et al. 1985; Aase and Tanaka 1991; Daughtry et al. 1995; Sullivan et al. 2004). Thus, variability in surface soil attributes, such as soil water content, particle size distribution, and iron oxide content can cause the soil background to be more or less reflective than crop residue spectra (Chen and Mckyes 1993; Daughtry et al. 1995; Nagler et al. 2000).

The impact of surface soil variability manifests a significant challenge for RS residue cover determinations. In a recent study, Sullivan et al. (2006) demonstrated the impact of soil background on remotely derived estimates of crop residue cover in two different physiographic regions. In the Coastal Plain, where bright sandy surfaces predominate, the addition of rye residue cover in a strip-tillage (ST) system tended to attenuate spectral reflectance compared to conventional tillage (CT) treatments. However, in the Piedmont, where heavier clay surfaces are more common, the addition of rye residues caused no-tillage (NT) treatments to be more reflective compared to CT treatments.

As a result, several RS indices have been established to better quantify crop residue spectral response and reduce the uncertainty in remotely derived estimates of cover. One such index, the cellulose absorption index (CAI) developed by Daughtry et al. (2001), was designed to utilize absorption bands centered on 2,100 nm, which are highly correlated with the presence of cellulose and lignin in organic materials (Elvidge 1990; Daughtry et al. 1996). In a recent study, Daughtry et al. (2005) indicated that Landsat TM vegetation and tillage indices were not well correlated with small changes in crop residue coverage. However, the CAI was linearly related to increasing amounts of crop residue cover having an $r^2 = 0.88$ when the vegetative cover fraction was <0.30. In other studies, the CAI has been shown to be effective even at low levels of crop residue cover (Nagler et al. 2003).

In contrast, Sullivan et al. 2004 and 2006, showed that VIS and NIR spectra showed promise as a means to depict crop residue coverage in the southeastern Coastal Plain and Piedmont. Sullivan et al. (2004) used the high spatial and spectral resolution Airborne Terrestrial Applications Sensor to differentiate between five wheat residue cover amounts (0%, 10%, 20%, 50%, and 80%) in two physiographic regions of Alabama. Their data showed that a combination of red spectra could be used to differentiate between treatments receiving 20%, 50% and 80% cover. Later, Sullivan et al. (2006) developed a crop residue cover index 1 (CRC1) based on an adaptation of tillage indices used by van Deventeer et al. (1997). Van Deventeer et al. (1997) showed that an index based on TM band 5 (1,550 to 1,750 nm) with TM bands 1 (450 to 520 nm), 3 (630 to 690 nm) or 7 (2,080 to 2,350 nm) could be used to differentiate between CT and conservation tillage practices with 70% to 89% accuracy. Using the CRC1, site-specific threshold values were established for rapid identification of CT and conservation tillage systems in the southeastern Piedmont and Coastal Plain.

Recent field studies are promising and suggest that a rapid, unbiased estimator for depicting tillage regime in the southeastern United States is possible. Moreover, these data suggest that a VIS/NIR-based indicator, which may be calculated using currently available, high spatial resolution satellite and airborne systems, is likely. However, the sensitivity of a VIS/NIR estimator to variability in cover amount is lacking. The objectives of this study are threefold: (1) evaluate the impact of crop rotation on crop residue cover amount, (2) quantify the sensitivity of the CRC1 to variability in cover amount and tillage regime, and (3) evaluate thermal infrared (TIR) spectra as a tool for differentiating among tillage regimes.

Materials and Methods

Study Sites. Study sites were located in the Southeastern Coastal Plain of Georgia at the University of Georgia, Lang Farm (31°31'N, 83°33'W). The soil was a Tifton loamy sand (fine, loamy, siliceous, thermic, Plinthic Kandiudult) cropped to a three year cotton-corn-peanut rotation beginning with cotton in 2004. Tillage treatments consisted of CT in the form of a rip and bed operation (CT), and three conservation tillage treatments: ST, NT, and no-tillage with subsoiling (NT_{ss}). Plots (5.5 × 27m [18.0 ft × 88.6 ft]) were arranged in a completely randomized block design and replicated four times. All plots were planted using a 91 cm (36 in) row spacing. Strip tillage treatments were monitored in 2005 and 2006 only.

A winter rye (*Secale cereale* L.) cover crop was planted in early November of each year on all plots using a no-till drill. In the spring, a contact herbicide was used to kill the winter rye prior to planting. Strip-tillage treatments were prepared using a fluted coulter to cut debris in front of an in-row subsoil shank (depth = 33 cm [13 in]), followed by a set of two wavy coulters, which till a 30 to 46 cm (12 to 18 in) strip for planting (Kelly Manufacturing, Tifton, Georgia). The remainder of the area between beds (row middles) was not tilled. Thus, between rows, the rye residue cover was distributed over 45 to 50 cm (18 to 20 in). No-tillage with subsoiling was conducted using a modified ST rig. The wavy coulters were removed from the ST rig and replaced with pneumatic tires to compress the disturbed soil (5 to 7.5 cm, [2 to 3 in]) surrounding the subsoil shank. No-tillage treatments were not disturbed prior to planting. A Monosem planter (Monosem Inc., Lenexa, Kansas) with fluted coulters and a double disk opener was

Table 1
Dates of site management operations (cover crop planting, cover crop termination, and spring crop establishment) and remotely sensed data acquisitions.

	Winter cover			
Spring crop	**Planting**	**Termination**	**Spring planting**	**Remote sensed data acquisitions**
Cotton	November 7, 2003	April 5, 2004	May 12, 2004	May 18, 2004
				May 28, 2004
				June 2, 2004
Corn	November 9, 2004	February 16, 2005	March 22, 2005	March 30, 2005
				April 13, 2005
				April 25, 2005
Peanut	November 1, 2005	April 6, 2006	May 3, 2006	May 12, 2006
				May 24, 2006
				June 8, 2006

used to plant seed directly into undisturbed residue. The CT plots were ripped and bedded each spring, incorporating most crop residue cover. The rip and bed consisted of a subsoil shank followed by two bed shapers (concave disks), which create a round bed. In 2004, a significant amount of crop residue cover remained on the surface (30% to 33%). A complete listing of planting, harvest and RS data acquisitions can be found in table 1.

Ground Truth. Ground truth and RS data were collected three times at each site as follows: May 18 to June 2, 2004, March 30 to April 25, 2005, and May 12 to June 8, 2006. Sampling times correspond to a four-week period, beginning at planting, and were chosen to minimize the impact of increasing canopy contributions on crop residue cover estimations. Ground truth consisted of digital images and soil water content (0 to 5 cm [0 to 2 in]).

Two digital images were taken at nadir from random locations within each plot to quantify the extent of residue cover. Digital images were acquired without a flash, using a 5-mega pixel Olympus C-505 Zoom (London, UK). Images were acquired from a height of 1.5 m (4.9 ft), centered directly over the row, and represent an area of 1.4 m^2 (4.6 ft^2) on the ground. An unsupervised classification was used to estimate the total percentage of rye residue and canopy cover using ERDAS Imagine 8.4 (Leica Geosystems, Heerbrugg, Switzerland). Percent residue and canopy cover were calculated by dividing pixels classified as residue or canopy cover by the total pixel count in each image (5×10^6). To determine the validity of the classified images, an accuracy assessment was conducted using a random selection of four images (conservation tillage plots only) from each RS acquisition date. Accuracy assessments were conducted using an adaptation of the line-transect on reproduced digital images as described by Sullivan et al. (2006).

Volumetric surface soil water content (θ_v) (0 to 5 cm, [0 to 2 in]) was obtained coincident with each RS acquisition using a Wet Sensor probe (Dynamax Inc., Houston, Texas). The Wet Sensor Probe uses a measure of the dielectric constant of the soil matrix to estimate volumetric water content (Topp et al. 1980; Whalley 1993). The general equation can be solved to estimate volumetric water content:

$$\sqrt{\varepsilon} = a_0 + a_1(\theta_v) , \qquad (1)$$

where $\sqrt{\varepsilon}$ is the square root of the dielectric constant, θ_v is volumetric soil water content, a_0 is the intercept and a_1 is the slope. Using default calibration parameters for a mineral soil, the WetSensor has an accuracy of ± 3% to 5% volumetric water content (cm^3 cm^{-3}). Because the probe was 7.6 cm (3 in) length, it was inserted at a 45° angle to ensure only the upper 5 cm (2 in) of soil water content was measured. Wet Sensor measurements were made at four random locations and composited within each replication of each tillage treatment. Because soil water content can vary quickly over time within 0 to 5 cm (0 to 2 in), precipitation data preceding RS data acquisitions have been provided (figure 1).

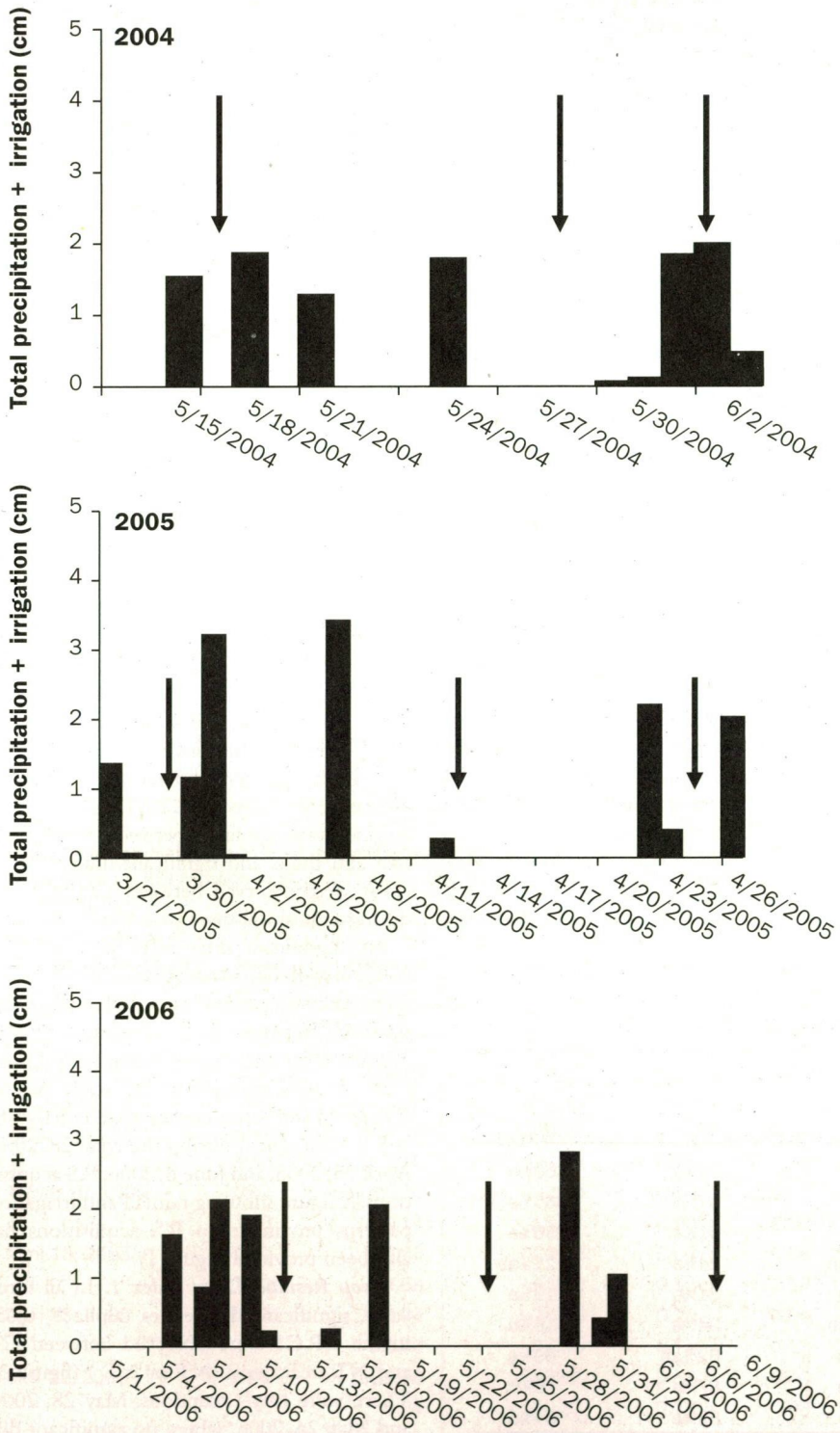
Remote Sensing: CropScan Multispectral Radiometer. Reflectance measurements were collected using a hand-held CropScan Multispectral Radiometer (CropScan Inc., Rochester, Minnesota). The CropScan utilizes narrow band interference filters to select discrete bands in the VIS and NIR regions of the electromagnetic spectrum. Nine bands were measured in this study within the 485 to 1,650 nm range (table 2). The CropScan is equipped with upward and downward looking sensors in each band and simultaneously acquires irradiance as well as radiance over the target. It is assumed that irradiance over the sensor head is equal to irradiance over the target. Radiance and irradiance were measured in millivolts, adjusted for temperature of the Cropscan, and converted to energy. Percent reflectance was determined using the following equation:

$$\text{radiance} / \text{irradiance} \times 100 = \% \text{ reflectance}. \qquad (2)$$

All plot data were collected as close to solar noon as possible, under clear conditions. Data were collected at nadir, over row middles, from a distance of 2 m (6.6 ft) to approximate a 1 m^2 (3.3 ft^2) spatial resolution on the ground. In the ST treatments, where crop residues were not evenly distributed across the plot, CropScan measurements encompassed a 30 to 46 cm (12 to 18 in) tilled strip with 30 cm (12 in) strips of crop residue cover on either side of the row middle. Data collection consisted of a composite of four points within each plot. Sample locations were chosen based on the location of digital images collected for quantification of crop residue cover.

Remote Sensing: Fluke Ti30 Thermal Infrared Imager. Thermal infrared red data were collected using a hand-held Fluke Ti30 Thermal Infrared Imager (Raytek Corporation, Santa Cruz, California). The Fluke Ti30 measures emittance (W m^{-2}) in one broad band (7,000 to 14,000 nm) with a 17° horizontal and 12.8° vertical field of view. Imagery was acquired at nadir from a distance of 2.0 m (6.6 ft). At this height the ground resolution was 0.23 × 0.31 m (0.75 × 1.02 ft). All data were taken coincident with CropScan measurements between 10 am and 12 pm, looking over the center of the same target. Due to spatial resolution constraints of the Ti30, it was assumed that surface features within a 1 m^2 area were similar. To verify this assumption, coefficients of variation were calculated using subsamples (n = 4) of TIR data within each treatment. Based on this analysis, variability in emittance within a plot was typically <10%.

Figure 1
Daily precipitation proximate to each sampling period in 2004 to 2006.



Note: Sampling periods are denoted by arrows for each date.

Statistical Analysis. Using the Statistical Analysis System (SAS Institute, North Carolina), an analysis of variance (alpha = 0.05) was used to evaluate differences among tillage treatments in (1) cover amount using classified digital images, (2) surface soil water content, (3) the CRC1, and (4) TIR emittance. As previously stated, treatments consisted of CT in the form of a rip and bed operation, and three conservation tillage treatments: ST, NT and NT_{ss}. Treatments were arranged in a completely randomized block design and replicated four times. The effect of year, treatment, sampling date, and all possible interactions was evaluated for the CRC1 and TIR, as well as ground measurements of crop residue cover and soil water content. In the case of CRC1, TIR and cover amount, a significant interaction was observed between treatments, sampling date and year, thus data were analyzed separately by sampling date. No significant treatment differences were observed for surface soil water content, however, significant differences in soil water content were observed between sampling events. Thus, soil water content was averaged over treatments during each sampling event, and differences in soil water content between sampling events were evaluated. When significant treatment differences were observed (alpha = 0.05), the least significant difference routine was used as the means separation procedure.

Visible and NIR spectra were used to calculate the CRC1 (Sullivan et al. 2005) as follows:

$$CRC1 = (NIR_{1,650nm} - blue_{485})/(NIR_{1650nm} + blue_{485}), \quad (3)$$

where NIR corresponds to 1,650 ± 100 nm and blue corresponds to 485 ± 45 nm.

A threshold technique was employed to delineate CT from conservation tillage treatments. The assigned threshold was a function of the analysis of variance and means separation procedure. Thus, a threshold was defined as the minimum CRC1 value that differentiates between CT and conservation tillage treatments (alpha = 0.05). Because significant differences in the CRC1 were not consistent with measured ground cover among conservation tillage treatments, no thresholds were established to differentiate between conservation tillage regimes.

Linear regression analyses were used to determine the degree of variability in resi-

Table 2
Spectral specifications for the CropScan Multispectral Radiometer (1.0-m spatial resolution).

Wavelength (nm)	Band	Spectrum region
485 ± 45	B1	Visible-blue
560 ± 40	B2	Visible-green
650 ± 20	B3	Visible-red
660 ± 30	B4	Visible-red
830 ± 70	B5	Near infrared
850 ± 35	B6	Near infrared
1,240 ± 6	B7	Near infrared
1,640 ± 8	B8	Near infrared
1,650 ± 100	B9	Near infrared

due cover (dependent variable) that could be explained via CRC1 or TIR emittance (independent variables). Because significant interactions were observed between sampling dates and years, regression analyses were conducted separately for each sampling date. It should be noted that a significant linear relationship between RS data (VIS, NIR, and TIR) and increasing crop residue cover has been established (Biard and Baret 1997; Nagler et al. 2003; Sullivan et al. 2004). Thus, extreme residue cover conditions (NT or ST vs. CT) were sufficient to establish a relationship between residue cover and RS data.

Results and Discussion

Descriptive Data. When comparing differences in crop residue cover amounts, a significant interaction was observed between tillage treatments and sampling events. Thus, differences in crop residue cover amounts are presented for each tillage treatment and sampling event (table 3).

In 2004, a general decline in crop residue cover amount was observed between the first and last data acquisition (table 3). Cover amounts peaked at 33%, 74%, and 69% for the CT, NT and NT_{ss} treatments, respectively. Significant differences were observed between CT and NT treatments only.

In 2005, when the study area was planted with corn, crop residue cover was significantly lower compared to observed cover in 2004 and 2006 (table 3). To demonstrate the impact of cropping rotation on cover amount, crop residue cover amounts were pooled between treatments and compared across years (data not shown). While no significant differences were observed in the pooled cover estimate between 2004 and 2006 (51% to 53%), significantly less overall cover (22%) was observed in 2005. This is likely due to the fact that corn is planted four to six weeks earlier than cotton or peanuts, and standing rye cover was terminated much earlier in 2005 compared to 2004 and 2006. Because crop residue cover is highly dependent on the amount of above ground biomass, the total amount of residue cover observed in 2005 was low, ranging from 11% to 34%. Only the NT (cover = 24% to 34%) treatments exhibited significantly greater crop residue cover compared to CT treatments, and no significant treatment differences were observed on April 13, 2005.

In 2006, crop residue cover ranged from 4% to 6%, 46% to 60%, 62% to 87%, and 64% to 76% for CT, ST, NT, and NT_{ss}, respectively (table 3). Significant differences between treatments varied between sampling dates. During the first sampling event, significant treatment differences were observed between CT, ST and NT_{ss}, no significant differences were observed between NT and either NT_{ss} or ST. During the second data acquisition, cover estimates were generally higher compared to the first data acquisition of 2006. Because residues decompose relatively quickly in the southeastern United States and these results mistakenly suggest an increase in cover, data illustrate the limitations of using point-based measurements to depict residue distributions at the field scale. Significant treatment differences at this time were observed between CT, ST, and NT. Crop residue cover declined between acquisitions two and three, and significant differences in cover were observed between all treatments during acquisition three.

No significant differences in soil water content were observed between tillage treatments; however, significant differences were observed between data acquisitions (figure 2). Volumetric soil water content ranged from <5% to 10% throughout the study period (figure 2). Soil water contents were driest (θ_v = 5 - 7 cm^3 cm^{-3}) during the May 28, 2004, April 25, 2005, and June 8, 2006, RS acquisitions. A figure showing rainfall and irrigation patterns proximate to RS acquisitions has also been provided (figure 1).

Crop Residue Cover Index 1. In all three years, significant differences (alpha = 0.05) in the CRC1 were observed between CT and NT treatments (NT or NT_{ss}) (figure 3). There were two exceptions, May 28, 2004, and May 24, 2006, where no significant differences were observed between treatments. The lack of significant differences is unclear, considering that canopy contributions were minimal and surface soil conditions were

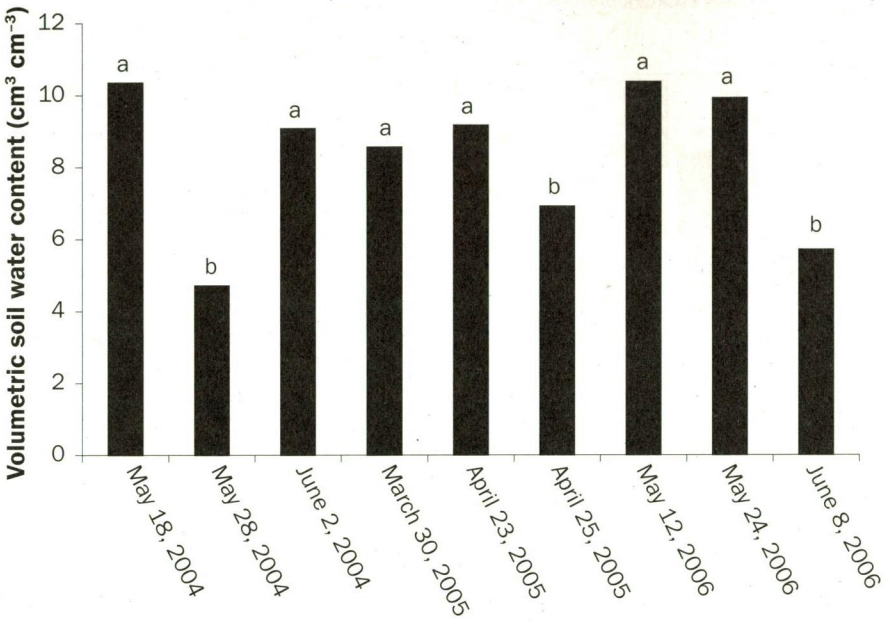
Table 3
Crop residue cover determined via digital image classification.

Remote sensing data acquisitions	Tillage treatments*			
	CT	ST	NT	NT_{ss}
May 18 , 2004	33%b		74%a	69%a
May 28, 2004	33%b		67%a	65%a
June 2, 2004	30%b		51%a	56%a
March 30, 2005	11%b	21%ab	24%a	21%ab
April 13, 2005	16%a	23%a	31%a	19%a
April 25, 2005	16%b	27%ab	34%a	16%b
May 12, 2006	4%c	52%b	62%ab	69%a
May 24, 2006	6%c	60%b	87%a	76%b
June 8, 2006	6%d	46%c	82%a	64%b

* Tillage treatments are defined as follows: CT = conventional tillage (rip and bed operation), ST = strip tillage, NT = no-tillage, and NT_{ss} = no-tillage with subsoiling.

Note: Means followed by the same letter (across rows) are not statistically different (alpha = 0.05).

Figure 2
Surface soil water content measured during each remotely sensed data acquisition.



Note: Within each year, means followed by the same letter are not significantly different (alpha = 0.05).

relatively dry during the May 28, 2004, sampling event, and no differences in soil water content were observed between the May 12 and May 24, 2006, sampling events (figures 1 and 2). More importantly, ground truth data suggest significant differences in cover between CT and NT systems during both data acquisitions.

The CRC1 also discriminated between CT and ST treatments. This was best demonstrated on April 25, 2005, May 12, 2006, and June 8, 2006 (figure 3). These data correspond well with ground truth assessments of cover, which showed significantly higher cover on ST treatments on May 12, 2006, and June 8, 2006. Although a significant difference in measured cover was not observed between CT and ST on April 25, 2005, ST treatments were numerically higher. These data suggest that RS data may be more sensitive to differences in cover amount compared to ground truth assessments, which are subject to observer bias.

In a similar study, Sullivan et al. (2006) demonstrated the utility of the CRC1 to differentiate between CT and conservation systems in the Coastal Plain and Piedmont of Georgia. Results indicated that under low canopy conditions, the CRC1 more accurately differentiated between CT and conservation tillage systems compared to standard vegetation indices.

Differences among conservation tillage treatments were observed in 2005 and 2006 (figure 3). In 2004, only NT and NT_{ss} treatments were evaluated, with no significant differences in the CRC1 observed between them. Because measured residue cover was generally low during the 2005 growing season, ranging from 11% to 34% (table 3), it is difficult to discern whether observed treatment differences accurately reflect small changes in crop residue cover. For example, no significant differences in measured cover were observed on April 13; however, CRC1 data suggest significant differences in CRC1 between ST, NT, and NT_{ss}. Moreover on both April 13 and April 25, 2005, CRC1 data suggest that cover decreases as follows: NT > NT_{ss} > ST. However, measured cover indicates cover decreasing as follows: NT > ST ≥ NT_{ss}.

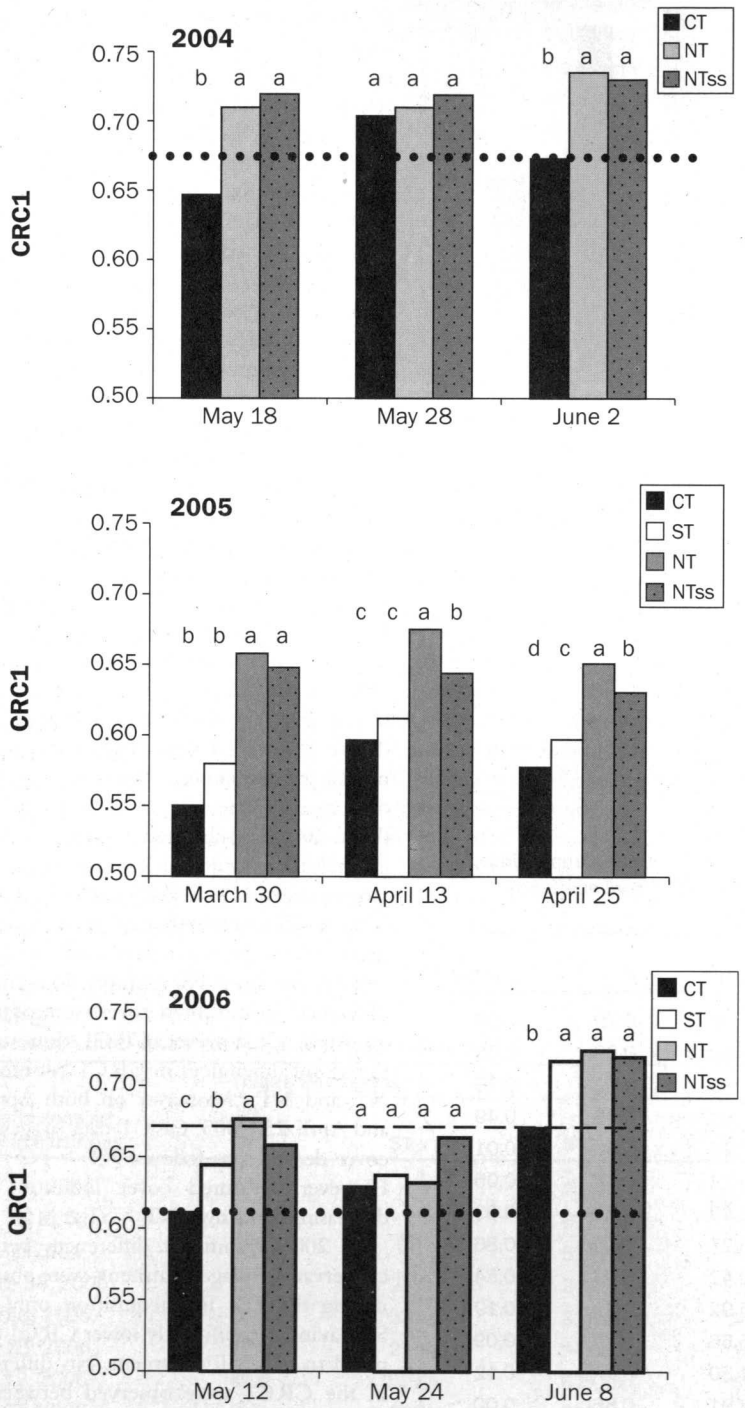
In 2006, significant differences between conservation tillage treatments were observed during the first RS acquisition only, with ST having a significantly lower CRC1 compared to the NT treatment. No differences in the CRC1 were observed between ST and NT_{ss}. While it appears that the CRC1 is sensitive to differences between CT and ST treatments, the CRC1 did not consistently differentiate between conservation tillage treatments, when crop residue cover amount ranged from 46% to 87%.

Table 4
Regression parameters describing the relationship between crop residue cover, crop residue cover index 1 (CRC1 = [1,650 - 485 nm]/[1,650 + 485 nm]), and thermal infrared emittance (W m⁻²).

Remote sensing data acquisitions	Index	Slope	Intercept	r^2	*p* value
May 18, 2004	CRC	553.64	-324.08	0.79	0.00
	Ti30	8.62	-207.60	0.68	0.00
May 28, 2004	CRC	26.70	35.85	0.02	0.70
	Ti30	3.53	-67.98	0.05	0.49
June 2, 2004	CRC	352.96	-206.26	0.51	0.01
	Ti30	7.75	-178.72	0.33	0.05
March 30, 2005	CRC	85.70	-32.80	0.30	0.03
	Ti30	0.14	15.27	0.00	0.86
April 13, 2005	CRC	67.73	-20.42	0.03	0.54
	Ti30	2.68	-35.92	0.12	0.19
April 25, 2005	CRC	162.34	-76.66	0.20	0.09
	Ti30	2.70	-34.30	0.17	0.12
May 12, 2006	CRC	1091.40	-658.91	0.86	0.00
	Ti30	6.24	-130.31	0.73	0.00
May 24, 2006	CRC	257.15	-108.35	0.07	0.34
	Ti30	8.86	-208.32	0.32	0.02
June 8, 2006	CRC	1159.09	-771.71	0.82	0.00
	Ti30	12.80	-334.30	0.85	0.00

Figure 3

Differentiation between tillage treatments (conventional [CT], strip tillage [ST], no-tillage [NT], and no-tillage with subsoiling [NT_{ss}]) using the crop residue cover index 1 (CRC1).



Notes: Means within the same measurement period followed by the same letter are not significantly different (alpha = 0.05). Broken lines indicate threshold CRC1 levels separating CT from ST on May 12, 2006 (dotted line), and June 8, 2006 (dashed line).

To better determine the relationship between the CRC1 and crop residue cover amount, a regression approach was used. Regression analyses confirmed that a highly significant linear relationship ($p < 0.01$) existed between the CRC1 and crop residue cover in six out of nine sampling events (table 4). In all cases, the slope was positive suggesting that the CRC1 increases with increasing amounts of cover. Results were best in 2004 and 2006, when crop residue cover was greatest (table 3), having coefficients of determination from 0.51 to 0.82. Not surprisingly, under low cover conditions (2005), the relationship between cover and CRC1 was poor, explaining only 20% to 30% of the variability.

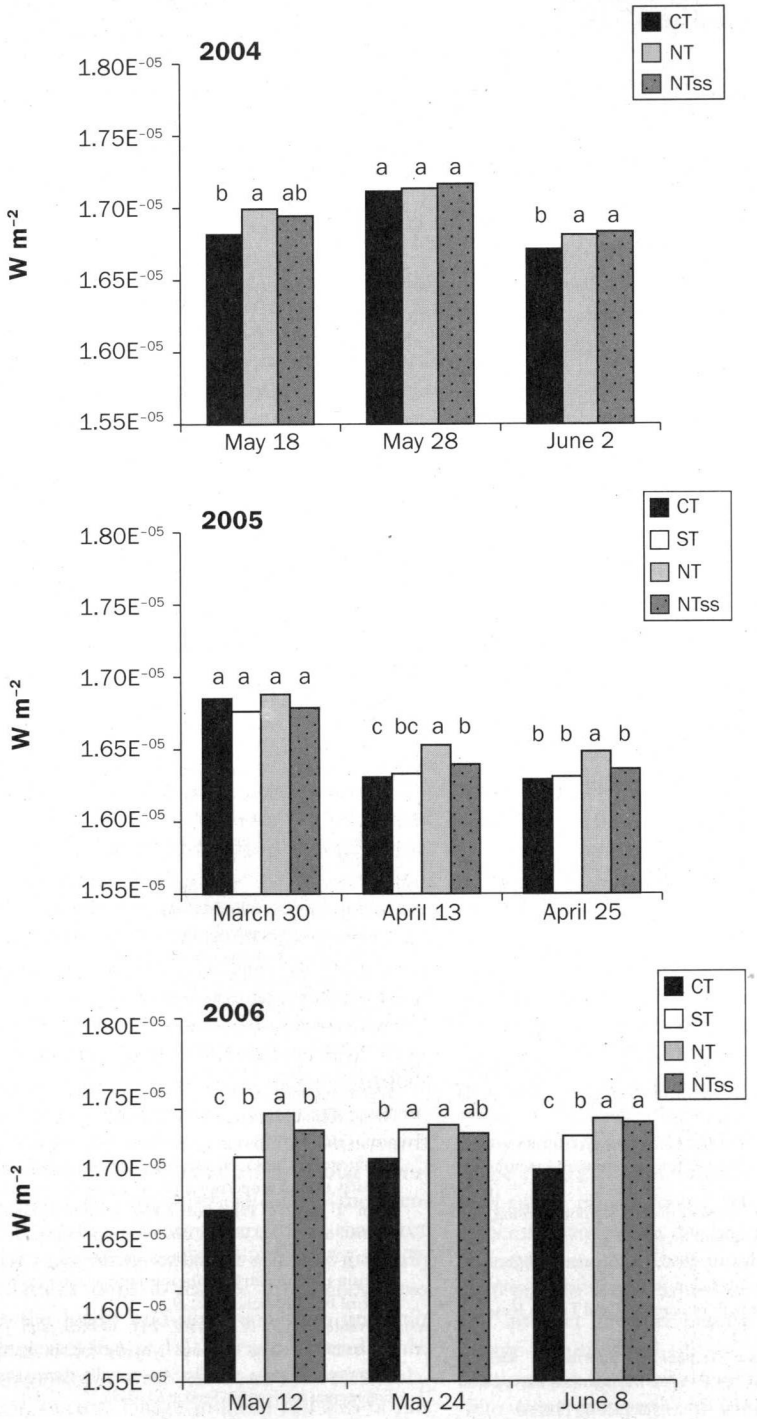
Despite the linear response observed, variability in slope and intercept values were noted between RS acquisitions (table 4). For instance, in 2004 the slope ranged from 554 to 353, with a corresponding range in the y-intercept of –324 to –206. Data suggest that using the CRC1 as a quantitative measure of crop residue cover distribution would necessitate ground truth measurements proximate to RS data acquisition. Instead, a CRC1 threshold approach has been proposed (Sullivan et al. 2006) to differentiate between CT and conservation tillage regimes without the need for extensive ground truthing.

The utility of the CRC1 threshold was best exemplified in 2004 and 2006, when the range in observed crop residue cover was greatest (table 3, figure 3). In 2004, the maximum observed CRC1 value separating CT from NT and NT_{ss} was 0.67. This is substantially higher than the threshold reported by Sullivan et al. (2006) of 0.58. Considering that the CRC1 is positively linearly related with cover, the higher CRC1 reported in this study is likely a result of some residue remaining on the surface following the rip and bed operation (30% to 33%) on the CT treatment.

In 2006, the CRC1 threshold was established using the May 12 and June 8 acquisition dates (figure 3). These acquisitions were selected based on the lack of significant treatment differences observed on May 24. Comparing the two acquisition dates, no single threshold consistently differentiated between CT and conservation tillage treatments. However, the May 12 acquisition resulted in a threshold value (0.61) that more closely approximates the CRC1 threshold identified by Sullivan et al.

Figure 4

Differentiation between tillage treatments (conventional [CT], strip tillage [ST], no-tillage [NT] and no-tillage with subsoiling [NT_{ss}]) using thermal infrared emittance (7,000 to 14,000 nm, W m^{-2}).



Note: Means within the same measurement period followed by the same letter are not significantly different (alpha = 0.05).

2006. The lower observed threshold, relative to 2004, is attributable to cleaned tilled surfaces on CT treatments (cover = 4% to 6%).

Thermal Infrared. Emittance spectra exhibited small, but significant differences between treatments. Emittance followed the expected response of increasing emittance with increasing cover (figure 4). Differences between tillage treatments were observed in all three years showing lower emittance from CT treatments in most cases. This was likely a function of heat capacity, where the lower heat capacities of organic materials (crop residue) resulted in higher emittance compared to a mineral surface with a greater affinity to absorb incoming radiation (Campbell 1996).

In 2004, treatment differentiation was similar to the CRC1 (figure 4). One exception was noted during the first data acquisition, where emittance spectra failed to differentiate between CT and NT_{ss} treatments. In 2005, when cover from conservation tillage plots was low, emittance spectra failed to consistently differentiate between tillage treatments. During the first data acquisition, no differences in tillage treatments were observed when ground truth indicates a significant difference in crop residue cover between CT and NT treatments (table 3). Thermal infrared also indicated treatment differences during the second acquisition, when no differences in measured cover were noted. The only case in 2005 when TIR emittance accurately depicted variability in ground cover was observed during acquisition three.

In 2006, treatment separation using TIR emittance improved (figure 4). During all three data acquisitions, treatment separation using TIR spectra more accurately differentiated among tillage treatments compared to the CRC1. Thermal infrared was particularly sensitive to differences between CT, ST, and NT, during acquisitions one and three.

Using TIR emittance, variability in treatment separation was observed between and within years. This is likely due to sensitivity of these measurements to time of day, surface conditions (soil water content, crusting, bare soil contributions), and small fluctuations in air temperature during data acquisition. Future research is necessary to evaluate the effects of the aforementioned parameters on the utility of emittance spectra for delineating crop residue cover.

Results from the regression analysis showed that emittance is linearly related to residue,

explaining from 32% to 85% of the variability in five of nine data acquisitions (table 4). As previously observed for the CRC1, no significant relationship existed during the 2005 growing season when residue cover was low. Additionally, the slope and intercept observed were highly variable between RS acquisitions. Thus, the utility of using emittance as an indicator of tillage regime will require some ground truth observations of crop residue proximate to RS acquisition.

Summary and Conclusions

Results showed that crop residue cover was variable between years and was primarily a function of the termination date of the winter cover. Spring residue cover was greatest in years planted to cotton and peanut, compared to corn when winter covers were typically terminated one month earlier.

Two different RS approaches were evaluated in this study for differentiating between tillage regimes: (1) VIS and NIR reflectance and (2) TIR emittance. Each approach accurately differentiated between CT and conservation tillage systems; however neither approach consistently and accurately differentiated between tillage systems when the cover amount ranged from 4% to 87%.

The relationship observed between either reflectance (r^2 = 0.51 to 0.86, alpha = 0.10) or emittance (r^2 = 0.32 to 0.85, alpha = 0.10) with crop residue cover was linear and positive in nine of twelve data acquisitions during 2004 and 2006. In only a few instances, a significant relationship between cover and RS data was observed in 2005. Lack of a stronger relationship in 2005 was likely an artifact of low crop residue cover conditions. Using the 2004 and 2006 dataset, variability in the slope and intercept over time indicate the need for ground truthing proximate to the time of remotely sensed data acquisition.

An alternative thresholding approach was proposed in this study, using the CRC1 index to identify tillage regime, rather than quantify cover amount. The CRC1 consistently differentiated CT from conservation tillage treatments in four out of six acquisitions in 2004 and 2006. Differentiation among conservation tillage treatments was more variable. Thus, a CRC1 threshold ranging from 0.67 to 0.61 was defined to separate CT from conservation tillage treatments in 2004 and 2006, respectively. The high CRC1 threshold selected in 2004 is a result of high residue remaining on the surface following the rip and bed operation that spring. In 2006, the CRC1 threshold more closely approximated previously reported values (Sullivan et al. 2006).

Results indicate that in sandy soils of the southeastern Coastal Plain, the CRC1 can be used as a rapid, unbiased indicator of conservation tillage adoption. However, variability in the CRC1 threshold suggests some ground truth may be necessary. In our study, variability in surface soil water content in these sandy soils was not a limiting factor in using the CRC1. Moreover, the CRC1 was effective within one month of planting date, suggesting a relatively large window for RS data acquisition and necessary ground truth. These data provide evidence that VIS and NIR data can be used to differentiate between CT and conservation tillage. More importantly, results reported here may provide the foundation necessary to develop a satellite-based conservation tillage mapping algorithm for delineation of conservation tillage adoption within the southeastern Coastal Plain. Satellite derived maps of conservation tillage adoption could facilitate yearly inventories of adoption, strategic placement, and assessments of conservation tillage impacts at the local, watershed, and regional scales.

Endnote

Use and/or mention of a particular product does not indicate the endorsement of the USDA Agricultural Research Service.

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