QUANTIFYING RESIDUE COVERAGE VIA SATELLITE REMOTE SENSING PLATFORMS

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ABSTRACT

Arable lands in conservation tillage may serve as an appreciable sink for soil organic carbon (C) and impact global C pools. Throughout the Southeastern U.S., reduced tillage systems using high residue cover crops are increasingly common. Current methods of estimating residue cover are time and labor intensive, however, remote sensing (RS) may prove a more expedient method of determining residue cover as it relates to soil quality, C dynamics and near-surface soil characteristics. The objective of this study was to use Ikonos satellite imagery to evaluate *in situ* crop residue. In April of 2001, residue plots (15 m x 15 m) were established at the Wiregrass (Coastal Plain) and Sand Mountain (Appalachian Plateau) Experiment Stations in AL. Soils consisted of fine-loamy, kaolinitic, thermic Plinthic Kandiudults at Wiregrass and fine-loamy, siliceous, thermic Typic Hapludults at Sand Mountain. Residue treatments of 0%, 10%, 20%, 50%, and 80% wheat (*Triticum aestivum* L.) were replicated 3 times at each site. Soil moisture, straw moisture, and residue decomposition were monitored, and digital photos were collected during periods of data acquisition. Treatment differences were observed at the Sand Mountain site using a combination of near infrared (NIR) and red spectra. Results indicate reliable estimates of residue cover using Ikonos satellite data were significantly affected by soil type, soil moisture and residue decomposition.

KEYWORDS

Ikonos, wheat, visible, near infrared, conservation tillage

INTRODUCTION

Managing crop residue enhances soil quality primarily through the accumulation of soil organic C (SOC). Keeping in mind more than a third of United States' agricultural lands have been classified as highly erodible, residue management can effectively decrease erosion (USDA, 1991; McMurtrey *et al*., 1993). Residue cover improves infiltration and soil aggregation t,hus reducing off-site transport of nutrients and pesticides (Lal, 1989; USDA, 1995).

Beyond improvements to soil quality, arable lands may be an appreciable C sink and key component in the reduction of CO_2 emissions. Soil C reserves store nearly twice the C in vegetation and 1.5 times the amount of atmospheric C (Rice, 2000). The Intergovernmental Panel on Climate Change (1995) estimates 20% of greenhouse gas emissions come from arable lands (Lal, 1997). Consequently, small changes in SOC reserves may impact the global C budget. Increased levels of SOC associated with conservation tillage systems have been shown to range from as much as 0.5 to 1.0% over a ten-year period (Rice, 2000). However, very small changes can be difficult to detect and vary significantly over short distances.

Residue management and conservation tillage practices necessitate an accurate and time-efficient way to monitor changes in residue cover. Traditional line-transect methods are time-and labor-intensive, but RS may prove to be a valuable new tool in residue cover assessments. Recent field studies show RS has had some success in differentiating among soil and residue spectra. Aase and Tanaka (1991) utilized spectrophotometer and infrared thermometer data to quantify varying degrees of residue cover under wet and dry conditions in the Great Plains. Results showed reflected energy could be used to detect differences among 0, 33, and 66% cover, but no differences were seen between 66 and 100% cover. More importantly, under moist conditions, thermal infrared (TIR) data more accurately quantified residue cover. In a separate study, McNairn and Protz (1993) developed a normalized difference index based on corn residue and thematic mapper bands to evaluate *in situ* residue treatments. Despite some success, little field work exists regarding currently available high resolution RS.

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RATIONALE AND OBJECTIVES

The use of conservation tillage systems in conjunction with efforts to reduce greenhouse gas emissions from America's arable lands necessitates streamlining current residue assessment strategies. Newly available high resolution satellite imagery has not been evaluated with regard to *in situ* residue measurements. The goals of this study were to: 1) evaluate the spectral reflectance of crop residue via the Ikonos multispectral sensor and, 2) determine the threshold for detection of near-surface soil characteristics under variable residue cover.

MATERIALS AND METHODS

Two distinct physiographic provinces within Alabama were assessed to determine the utility of satellite imagery to evaluate residue cover. In April of 2001, several residue plots (15 m x 15 m) were established at the Wiregrass and Sand Mountain Experiment Stations of AL. Soils classified as fine-loamy, kaolinitic, thermic Plinthic Kandiudults at Wiregrass and fine-loamy, siliceous, thermic Typic Hapludults at Sand Mountain. Treatments consisted of five residue cover rates (0%, 10%, 20%, 50%, and 80%) and plots were arranged in a completely randomized design. Total mass per treatment was calculated based on the amount of residue necessary for complete ground coverage. Fistula bags were used to monitor residue decomposition. Bags were filled with straw to reflect treatment, staked within each plot, and collected on a bimonthly basis. Straw was dried and ground to pass a 1-mm sieve and total C was measured via a Leco CHN-600 analyzer (Leco Corp., St. Joseph, MI).

Soil samples were collected prior to residue applications to determine near surface soil properties. Soils were air-dried and sieved to pass a 2-mm sieve. Analyses included total C, dithionite-citrate extractable iron (Jackson et al., 1986), and particle size distribution (Kilmer and Alexander, 1949). Total C samples were further ground to pass a 1-mm sieve prior to combustion. During satellite data acquisition, soil surface samples were collected for gravimetric soil moisture content. Digital photographs were taken along with satellite imagery to estimate residue cover. Cover estimates were made using a supervised classification routine in ERDAS Imagine 8.4.

Remotely sensed images were acquired via the Ikonos satellite. Ikonos orbits the earth in a sun synchronous orbit at an altitude of 681 km, with a revisit time of two to three days. The sensor on board Ikonos possesses a multispectral scanner equipped with three visible (VIS) (0.45-0.52, 0.52 – 0.60, 0.63 – 0.69 µm), one NIR (0.76 – 0.90 µm), and one panchromatic (PAN) band (0.45 – 0.90 µm). Spatial resolution ranges from 1 m for the PAN band to 4 m for the VIS and NIR bands. Multispectral satellite data were acquired at the Sand Mountain site on 18 May 2001, 7 July 2001, and 14 February 2002. Acquisitions were made at the Wiregrass location on 13 May 2001 and 19 February 2002. Data was collected on days having less than 10% cloud cover, as close to solar noon as possible. These results reflect analyses based on raw digital values (DV).

Individual bands were stacked by site using ERDAS Imagine 8.4 prior to analysis. Plots were extracted using a subset function and pixels exported in ASCII format. Each plot consisted of 9 pixels. Average and coefficient of variation (% CV) were calculated within each plot. Outliers within plots having greater than 10% CV were excluded.

RESULTS AND DISCUSSION

Soil analysis confirmed uniformity of near surface soil properties by site. Soils contained 0.53% SOC, 0.25% iron, 79.6% sand, 12.6% silt, and 7.9% clay at Wiregrass and 0.57% SOC, 0.21% iron, 55.5% sand, 37.8% silt, and 6.7% clay at Sand Mountain. These values are generally representative of surface horizon properties for soils in these regions.

Literature suggests residue spectral response increases without inflection throughout the VIS and NIR, differing from soil spectral response only in magnitude of reflected energy (Baumgardner *et al*., 1985; Aase and Tanaka, 1991; Daughtry *et al.*, 1995). However, spectral analyses of Ikonos data showed residue spectra peaked at approximately 0.76 µm with inflection points at 0.45, 0.52, and 0.63 µm. Comparing inflection points, the greatest difference in the amount of reflected energy was observed between 0.76 and 0.63 µm, suggesting a band ratio comprised of these wavelengths may be useful in differentiating among residue treatments.

Correlations were evaluated to determine the extent to which a relationship existed between VIS/NIR energy and decomposing residue. Results were highly variable between sites, indicating differences in soil type strongly affect this relationship. Sandy epipedons characteristic of the Wiregrass site were similar in spectra to residue. Thus, spectral response patterns associated with cover rates were not easily separable from bare soil spectral response (Figure 1). By contrast, results from Sand Mountain showed significant correlations with residue were observed in the red and NIR regions of the spectrµm. A NIR to red band ratio analysis produced a significant correlation (r = -0.49, *P* = 0.10) with residue cover in May and a strong relationship (r = -0.65, *P* = 0.01) existed between reflected red energy and cover rate during the February acquisition. Concurrent with February data acquisition, moist surface soils (gravimetric water content = 13.6%) may have contributed to the highly significant correlation observed in the red region of

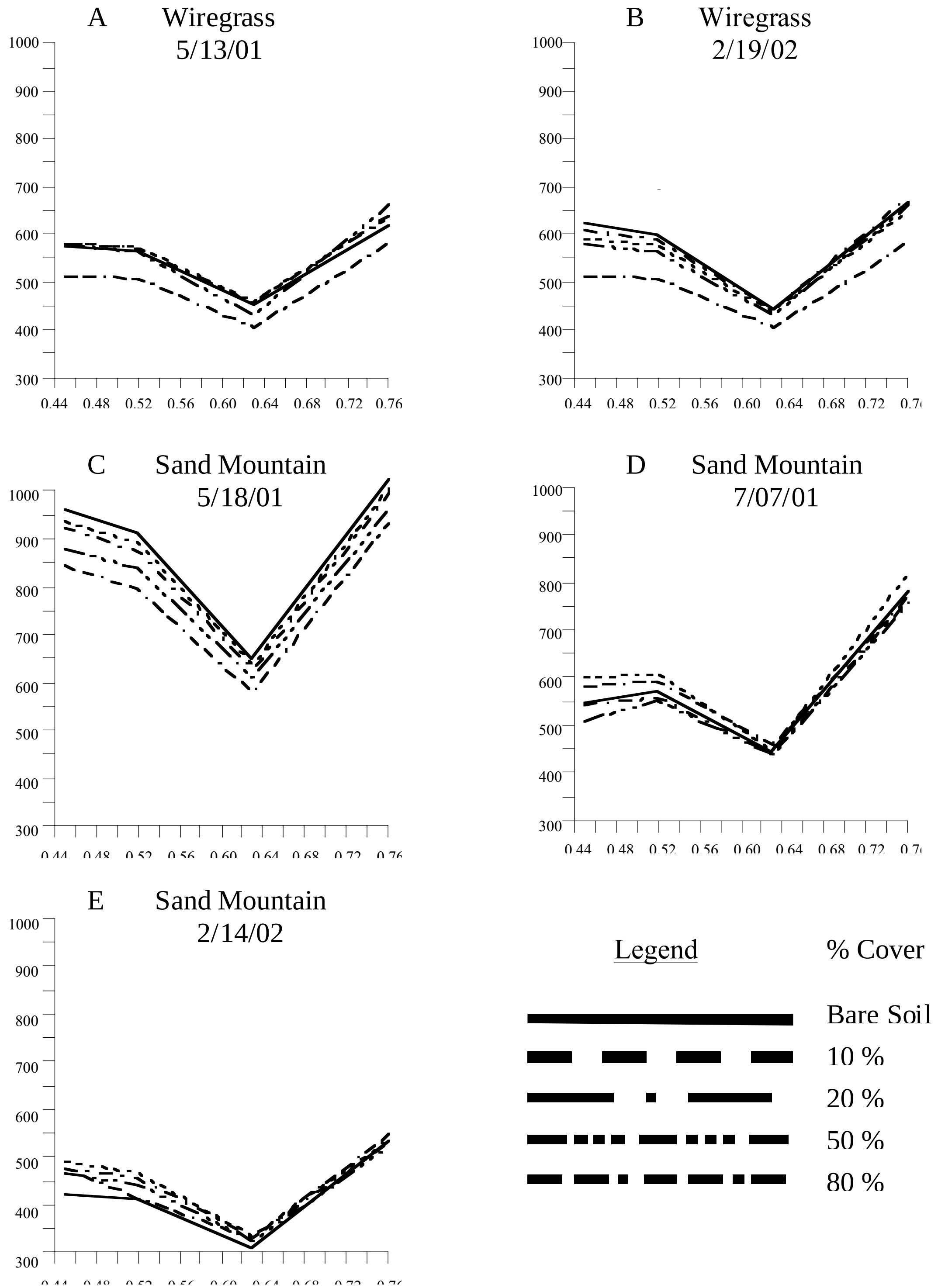

Fig.1. Spectral response curves for each treatment based on percent cover and digital value. (A) Wiregrass study site 5/13/01, (B) Wiregrass study site 2/19/02, (C) Sand Mountain study site 5/18/01, (D) Sand Mountain study site 7/07/01, and (E) Sand Mountain study site 2/14/02.

the spectrum. Results agree with previous studies that report mixed results due to differences in soil type, soil moisture, and residue decomposition. Daughtry *et al.* (1995) was unable to differentiate among residue cover using VIS/NIR data. In their case, Daughtry *et al.* (1995) utilized a variety of crop residues, which had been air-dried and ground, against soils representing 14 suborders. However, an earlier report by McMurtrey (1993) showed red and NIR energy simulated to match thematic mapper bands successfully estimated residue cover. Later reports from Daughtry

Table 1. Regression parameters for digital values versus % residue cover for the Wiregrass and Sand Mountain study sites.

Site Date	Wavelength From	 To	Slope	Intercept	r^2	*P* = 0.10
	-------- µm	-------				
Sand Mountain						
5/14/05	0.45	0.52	0.216	902	0.01	0.69
	0.52	0.60	0.305	853	0.03	0.58
	0.63	0.69	0.209	614	0.03	0.52
	0.76	0.90	0.104	980	0.01	0.80
	0.45	0.90	0.110	871	0.01	0.76
	0.76	0.63	-0.0004	1.60	0.24	0.07
7/8/05	0.45	0.52	0.226	548	0.02	0.64
	0.52	0.60	0.260	567	0.16	0.47
	0.63	0.69	0.248	437	0.16	0.14
	0.76	0.90	0.052	774	0.00	0.93
	0.45	0.90	-0.009	588	0.00	0.98
	0.76	0.63	-0.0009	1.78	0.03	0.53
2/15/06	0.45	0.52	0.001	465	0.00	0.99
	0.52	0.60	0.007	446	0.00	0.99
	0.63	0.69	0.024	326	0.00	0.93
	0.76	0.90	-0.523	539	0.54	0.00
	0.45	0.90	-0.442	451	0.12	0.23
	0.76	0.63	-0.002	1.67	0.09	0.31
Wirgrass						
5/14/05	0.45	0.52	0.166	593	0.01	0.76
	0.52	0.60	0.010	579	0.00	0.98
	0.63	0.69	-0.045	462	0.01	0.78
	0.76	0.90	0.215	646	0.01	0.68
	0.45	0.90	-0.180	567	0.01	0.69
	0.76	0.63	0.0006	1.40	0.06	0.38
2/20/06	0.45	0.52	0.070	581	0.00	0.91
	0.52	0.60	0.007	567	0.00	0.99
	0.63	0.69	0.013	431	0.00	0.96
	0.76	0.90	0.035	646	0.00	0.95
	0.45	0.90	-0.056	560	0.00	0.92
	0.76	0.63	0.000	1.50	0.00	0.98

(2001) also found NIR and red spectra effectively distinguished among cover rates. As stated earlier, differences in results between data acquisitions may be due to variable decomposition rates of straw. During the decomposition process spectral response patterns necessarily change with changes in straw composition. During tissue chlorophyll loss, spectral response is greatest between 0.4 to 0.8 µm, as residues absorb incoming blue light and reflect green and red. Presence of water at this stage masks absorbance features in the NIR associated with lignin and cellulose features (Elvidge, 1990) As decay progresses, spectral response patterns shift to longer wavelengths due to the increasing percentage of lignin and cellulose present (Elvidge, 1990). Relative comparisons of spectral response curves between data acquisitions generally agree with this observation (Figure 1).

A linear relationship was observed between reflected energy in the NIR and red portions of the light spectrum at the Sand Mountain study site (Table 1). During the May acquisition, a weak relationship ($r^2 = 0.24$ at $p = 0.10$) existed using the NIR to red ratio, and significant treatment differences were limited to bare soil and 20% cover rates (Table 2). February data revealed an $r^2 = 0.54$ at $p = 0.10$ with significant differences among treatments occurring primarily between bare soil and 80% cover. No treatment differences were observed between 10, 20, 50 or 80% cover rates ($p = 0.05$) (Table 2). It appears soil water content during the February acquisition was a key factor in differentiating between bare soil and 80% cover rates.

Based on the spectral response curve for bare soil, estimates were made to determine where soil spectral features attenuate with increasing residue cover. Threshold

Table 2. Least significant differences ($P = 0.05$) observed between residue treatments within a wavelength at Sand Mountain.

	Wavelength (um)		Residue cover, % of area				
Date	From	To	0	10	20	50	80
	----- µm ------		-------------------------------- D.V. ----------------------------				
Sand Mountain							
5/14/05	0.45	0.52	607 A	608 A	568 A	577 A	627 A
	0.52	0.60	587 A	589 A	561 A	569 A	592 A
	0.63	0.69	465 A	467 A	452 A	456 A	464 A
	0.76	0.90	655 A	668 A	619 A	641 A	678 A
	0.45	0.90	577 A	582 A	537 A	540 A	574 A
	0.76 /	0.63	1.405 A	1.427 AB	1.368 B	1.406 AB	1.461 AB
7/8/05	0.45	0.52	575 AB	574 AB	494 C	537 CB	596 A
	0.52	0.60	588 A	581 AB	533 B	571 AB	604 A
	0.63	0.69	448 AB	441 AB	428 B	445 AB	464 A
	0.76	0.90	802 A	782 A	729 A	773 A	797 A
	0.45	0.90	605 A	597 A	556 A	575 A	606 A
	0.76 /	0.63	1.793 A	1.775 A	1.704 A	1.738 A	1.718 A
2/15/06	0.45	0.52	465 A	438 A	326 A	533 A	439 A
	0.52	0.60	422 A	419 A	431 A	448 A	441 A
	0.63	0.69	313 A	333 A	222 A	326 A	325 A
	0.76	0.90	546 A	549 B	532 AB	524 AB	513 B
	0.45	0.90	446 A	442 A	442 A	436 A	428 A
	0.76 /	0.63	1.775 A	1.651 A	1.596 A	1.607 A	1.581 A

residue cover rate at which soil spectral features were no longer detectable occurred between 20 and 50% coverage. Furthermore, soil spectral response consistently declined with increasing cover at both locations and all data acquisitions (Figure 1). Differences in soil and residue spectral response patterns are slight, and differ primarily in the magnitude of reflected energy.

CONCLUSION

Multispectral Ikonos imagery did not reliably evaluate% residue cover at either site. Perhaps results were limited by spatial resolution, since studies using ATLAS airborne imagery under the same conditions indicated RS could differentiate among residue treatments (Sullivan *et al*., 2002). Although differences were observed throughout the spectrum, differences in residue cover were most consistent using Atlas TIR bands. Furthermore, Atlas data were adjusted for atmospheric conditions whereas Ikonos results were limited to raw digital values.

Ikonos data was able to differentiate among residue cover rates at the Sand Mountain site alone, suggesting soil type and other edaphic factors may be an overriding factor in the ability of RS to detect residue cover. Data indicate freshly applied residue can best be observed using a NIR to red ratio, but it appears the red region of the light spectrum was more sensitive to decomposing straw under wet conditions associated with the February acquisition. In this case, treatment differences were greatest between bare soil and 80% cover rates.

As residue cover increases, the ability to detect soil spectral response patterns greatly diminishes. Losing soil spectral response may be an important consideration with respect to soil survey and natural resource inventory applications of remotely sensed data. Threshold residue cover at which soil spectral response weakened occurred between 20% and 50% residue cover. Data show this relationship held as residue decomposed over the course of one year.

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