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Spectral detection of crop residues for soil conservation from conventional and large biomass soybean

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Abstract – A spectrally derived cellulose absorption index (CAI) was tested to determine its value as a remote sensing method for detecting crop residue ground coverage for soil erosion control in soybean (*Glycine max* (L.) Merr.). Soybean produces inadequate crop residue for soil conservation purposes in many production years. Crop residues left on the soil surface after harvest slow soil erosion rates. The CAI remote sensing technique was tested over field plots of conventional and large biomass soybean (LBS) with known above ground crop residue biomass and surface coverage. New LBS types are being bred and tested at the Beltsville Agricultural Research Center (BARC), Beltsville, Maryland, US, and can grow to heights of 1.8 m and produce increased amounts of crop residue compared to conventional cultivars. The highest performing LBS line for these traits provided 2963 kg/ha more crop residue biomass and provided a maximum increase of 42% more crop residue cover than the poorest performing conventional soybean. The comparison of LBS versus conventional soybean provided a wide range of soybean residue coverage for testing the CAI remote sensing algorithm. Spectrally derived CAI measures of crop residue were significantly associated with physical ground measurements of crop biomass at harvest and % cover after over wintering. Significant correlations were found between, the CAI and at harvest biomass ($r^2 = 0.66$), between, the CAI and the line point transect measurement ($r^2 = 0.74$), and between, CAI and the analysis of red-green-blue digital imagery ($r^2 = 0.74$) for measuring crop residue cover. These findings indicate that LBS can increase crop residue biomass and crop residue soil coverage by soybean litter and these factors can be detected by remote sensing methods in the field.

carbon sequestration / cellulose absorption index (CAI) / remote sensing / soil erosion

1. INTRODUCTION

Soybeans are planted annually on approximately 28 million ha in the United States [24]. Roughly one-third of this land is highly erodible land (HEL). Crop residues left on the soil surface after harvest slow soil erosion rates and provide a cheap and adequate soil conservation practice, especially on HEL. Of the major crops grown in the US, conventional soybeans are notably lower in crop residue biomass production and crop residue ground coverage [13]. Management of crop residues has been suggested as a soil conservation practice for reducing soil erosion and sustaining agricultural production in many parts of the world [1].

An inadequate amount of soybean residue distributed after soybean grain production requires farmers to implement additional soil conservation measures at further cost. Along with farm management practices that increase crop residues, rapid methods to measure the amount and coverage of crop residues are needed. To be an acceptable soil conservation method for most HEL soils, the Conservation Technology Information

Center (CTIC) sponsored by the United States Department of Agriculture (USDA), National Resources Conservation Service (NRCS), in the US recommends a minimum target level for crop residue soil coverage of ~30% at planting [2]. Participation in government (loan) programs usually require growers to develop and implement soil conservation plans on their farms. Crop residue management is often the most cost effective remedy to implementing these soil conservation plans. Large area crop residue assessments are needed to measure residue coverage so that additional soil conservation practices can be implemented as needed and in a timely manner. Spectral remote sensing could provide a method to assess the amount and coverage of crop residues. Natural resource conservation action agencies and crop producers concerned with soil erosion control, increasing soil organic matter composition and carbon sequestration, need a rapid cost effective method of monitoring crop residue management.

Using spectral reflectance information McMurtrey et al. [15] determined that only certain residues could be separated from certain soils in the visible (VIS) – near infrared (NIR), region

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(400–1000 nm) of the spectrum. The lignin-cellulose absorption short wave infrared (SWIR) region at ~2100 nm and the surrounding area (1975–2225 nm) has been suggested as the most promising region for the detection of dry plant litter residues on most soil surfaces [3–6, 8, 17, 18]. Using indoor laboratory experiments, Daughtry et al., [5] proposed a spectrally derived cellulose absorption index (CAI) from the SWIR reflectance area of the spectrum that could be used for the remote sensing of crop residue cover in the field. The spectra of dry crop residues displayed a broad absorption feature near 2100 nm that was absent in the spectra of soils. The relative depth of this cellulose-lignin absorption feature was linearly related to residue cover.

Streck et al. [21] found that CAI was the most successful index for modeling crop residue increases in wheat. Wheat residues in Nebraska, US reached 100% cover at 400 g/m² dry matter (DM). They also determined that the CAI could measure increases in wheat residue dry matter up to 600 g/m². Leblon et al. [14] found that corn could achieve 100% crop residue coverage at 420 g/m² of DM. Nagler et al. [18] found that corn and wheat residues from Japan reached 100% coverage at 501 g/m² of DM, while rice and soybean residues reached 100% coverage at 701 g/m² of DM. All of these studies were conducted by placing predetermined quantities of crop residues within the sampling area. Using field data from several researchers, Gregory [11] derived an equation to predict the fraction of soil covered by crop residue as a function of the mass of the residue. The previous studies, however, do not reflect the true crop residue coverage and distribution that is achieved by the production of biomass from different crop cultivar types under standard field cropping and mechanized harvesting practices.

Since most conventional soybean crops provide marginal crop residue cover, new types of large biomass soybean (LBS) that supply increased crop residues are being developed to help retain residue ground cover at acceptable soil conservation levels. LBS were first bred and tested at the Beltsville Agricultural Research Center (BARC), Beltsville, Maryland US, for use as forage soybeans [7, 12]. Later it was determined that the LBS trait would be useful in grain type soybeans for soil conservation purposes [25]. Field testing of LBS has shown these types can provide 40–100% more residue cover than conventional soybeans [16]. Field experiments for testing LBS soybean types for crop residue production started in 1994. The experiments have been used to evaluate and identify superior LBS germplasm lines emerging from a breeding program with enhanced crop residues. Lines have also been identified having grain yields comparable to conventional soybean cultivars. From these studies we found that, depending on year, the increased crop residue from LBS can equate to ~2240 to 7392 kg/ha more dry biomass at harvest than the conventional, shorter, soybean crops [25]. The effectiveness of LBS for soil conservation was evaluated by an estimate of the long-term mean annual rate of soil loss simulated by using the Revised Universal Soil Loss Equation (RUSLE) [22]. RUSLE is a standard model used by the USDA, NRCS as a guide for determining the best methods for soil conservation practices [10]. An estimated 2464 to 28 000 kg/ha annual reduction in soil loss from production fields was projected by RUSLE for Maryland, US soils, if an ideal LBS were used instead of conventional soybeans [25]. Reducing soil erosion not only contributes to

achieving the conservation goal of mitigating the damage to onsite productivity but also contributes to the environmental goal of ameliorating offsite damage due to sedimentation. Since soybean dry biomass is ~40% C, the amount of additional biomass projected by LBS type soybeans [25], would equate to a ~1000 to 3300 kg/ha increase in the immediate sequestration of carbon per year. Increases in soil carbon and organic matter will also improve the tilth and water holding capacity of soils in soybean production areas.

A rapid, large area remote sensing method for quantifying crop residue cover is needed to determine where further soil conservation measures should be taken on soybean production fields. Field plot tests have previously established the advantage for increased biomass at harvest and the increased coverage of soybean residues through spring planting from LBS versus conventional soybeans [16, 25]. With the availability of both LBS lines and conventional cultivars, the testing of remote sensing spectral techniques over a wider range of natural soybean crop residue biomass and soil surface coverage has become possible. Specific measurements of grain yield, above ground biomass and crop residue coverage “ground truth” are recorded. A subset of the data from the 2002–2003 soybean residue test plots at BARC, Beltsville, Maryland, US was used to represent the range of levels of biomass and crop residue cover. Soybean plot production was achieved under natural field growth and harvest conditions. The levels of crop residue from conventional soybean produced in experimental plots are similar to those that are projected during commercial soybean production in Maryland, US. Previous development and tests of the LBS types and their resulting crop residues were conducted at the same location in 1994–1995, 1995–1996 and 1998–1999 residue seasons rendering a history of documented performance for soybean residue production at this location [16, 25]. A prerequisite of any adequate crop residue detection method for soybeans would require separation of different levels of % residue cover at or around the 30% coverage range. Researchers need remotely sensed spectral data (i.e. CAI) collected over a wide range of soybean biomass and soil surface cover in order to predict what different levels of crop residue may be distinguishable in production fields. The comparison of LBS versus conventional soybean at Beltsville, Md., provided a wide range of soybean residue biomass and soil coverage for testing the CAI remote sensing algorithm.

The objectives of the current study were to compare the crop residue production of LBS versus conventional soybean types and to evaluate the spectrally derived CAI remote sensing method proposed by Daughtry and Daughtry et al. [3, 5] for measuring soybean crop residue biomass and crop residue soil surface coverage in the field.

2. MATERIALS AND METHODS

2.1. Field location

Tests of conventional soybean and LBS types with increased crop residues were conducted at the BARC in Beltsville, Maryland, US in the 2002–2003 season using physical ground assessments and remotely sensed spectral measurements. The soil in the test field was a Codorus silt loam. At this field location, soybean grain plots were planted, managed and treated in

a manner that mimicked farm production. Studies conducted in this experiment utilized a model similar to the field testing established by the Uniform Cultivar Testing Program which is followed by USDA researchers and Public University researchers to test comparative cultivar performance for grain yield [23]. Data from Uniform Tests are shared with commercial soybean growers to document the performance that is expected from a specific soybean line if the cultivar is released. The methods are appropriate for studies where seed quantity is limited and the test can not be conducted in a large scale production mode. Uniform cultivar test methods also decrease field variability because variability has been found to be less over small plot test areas. The model is extended in this study to measure the relative differences between cultivar types for dead crop residue coverage through the next spring based on the live growth performance of each cultivar's plot area.

2.2. Experimental test plots

In the 2002–2003 season, a three replication randomized complete block experiment was used to test CAI effectiveness for quantifying soybean crop residue cover with a total of 24 field plots in the test. The test consisted of 4 conventional soybean cultivars and 4 LBS type soybean. The test field was tilled with moldboard turn plowing in early May 2002, followed by disking with a disk-harrow, re-disking, and cultipacking in late May. This produced a planting surface that was free of crop residue, with zero percent residue cover as the baseline soil condition. Soybeans were planted in 4 row plots, 3.08 m long with 0.76 m between rows. Each soybean test plot area was 9.36 m^2 ($3.08 \text{ m} \times 3.04 \text{ m}$). Plot areas were small because only limited amounts of LBS seed for each breeding test line were available. The plots were separated by 2.2 m bare soil alleyways. The soybean crop was planted on 22 May, 2002. Four conventional grain cultivars (Essex, Hutcheson, Spry, Williams-82) adapted to the mid-Atlantic US were used for comparison with the LBS cultivar and experimental lines (Tyron, PA-15, 7P116, 97Va20).

Except for tillage, the typical management practices for conventional soybean crops in the mid-Atlantic region were followed. Fertilizer (P, K) applications were made according to the recommendations from the University of Maryland Agricultural Extension Service, US. Weeds were controlled by Command (Clomazone) and Poast (Sethoxydim) herbicides and hand hoeing to produce a cropping surface that contained only soybean residue materials at harvest.

2.3. Agronomic measurements

Plant height was measured in late September after the LBS lines had reached their maximum height. All the test lines and cultivars were harvested and threshed in the fall (15/11/2002), and grain yields were recorded. Crop residue production by the LBS and conventional soybean types was evaluated by levels of residue cover and amounts of above ground biomass. Total above ground biomass was determined by harvesting and weighing all plants in the plot area. The grain was threshed and weighed and the soybean residue was returned to the respective plot area and spread uniformly. A residue sample of approximately 500 g was weighed on harvest day, dried and re-weighed

after drying to calculate dry biomass. Dry grain weight was subtracted from total dry biomass weight to calculate dry above ground soybean crop residue biomass.

2.4. Ground truth conservation measurements

The level of soybean residue coverage was measured using the line point transect measurement (LPTM) method, and also by analysis of images taken with a digital red-green-blue (RGB) camera. The LPTM method has been adapted by USDA, NRCS, and other soil conservationist in the US as a standard method for counting percent crop residue cover in the field [2]. The approach employs a 15.38 m line with beads every 0.15 m (100 beads per line). For the small plots the line was zig-zagged across each $3.08 \times 3.04 \text{ m}$ 4 row plot, so that the 15.38 m beaded line transversed several times over the plot area [16]. An imaginary point at the side of each bead with crop residue under it was counted as 1%. Measurement of % residue cover level was conducted in the fall of 2002 and in the spring of 2003 with the LPTM method.

Analysis of % residue cover was also accomplished from digital RGB camera images taken with the camera on a pole 3 m above the soybean field plots by overlaying a circle encompassing the field of view of the ASD spectroradiometer from the same acquisition height. The overlay circle contained 100 equally spaced thin lined cross hair points. Each image was assessed for the presence of crop residue, soil, or weed at each cross hair point to calculate % crop residue cover or % weed cover over soil. Figure 1 is a B/W illustration of the range of crop residue cover found within the view of the ASD spectral acquisition when analyzing RGB images. Three over the row and 3 between the row acquisitions were made within each plot area. Camera images, and aligned ASD acquisitions were taken to determine plot means for comparison with other agronomic plot data.

At the time of acquisition of remote sensing spectral data (28/04/2003), 3 samples of soybean crop residue and 3 samples of the parent soil from the top 1 cm of the field surface were weighed, dried, and re-weighed to determine % moisture content of both the soil and crop residue. Spectral measurements were taken on these "predominant" field components and remotely sensed CAI measures and RGB images were made on the same day (28/04/2003). The physical % cover ground truth LPTM counts made in the spring were acquired within a week of the remotely sensed acquisitions. There is great need for soil conservation during this period because of greater spring rainfall and higher soil disturbances associated with planting. This time period is considered the most critical by NRCS for assessing proper levels of crop residue coverage for soil conservation purposes.

2.5. Remotely sensed measurements

Reflectance spectra ground measurements were acquired on a cloudless day (28/04/2003) within 2 hours of solar noon with a FieldSpec Pro full resolution (FR) spectroradiometer (Analytical Spectral Device (ASD), Inc. of Boulder, Colorado 80301–2344, US). The spectrometer covered the 350–2500 wavelength region at 1 nm intervals. Three over the row and 3 between the row ASD acquisitions and aligned camera RGB

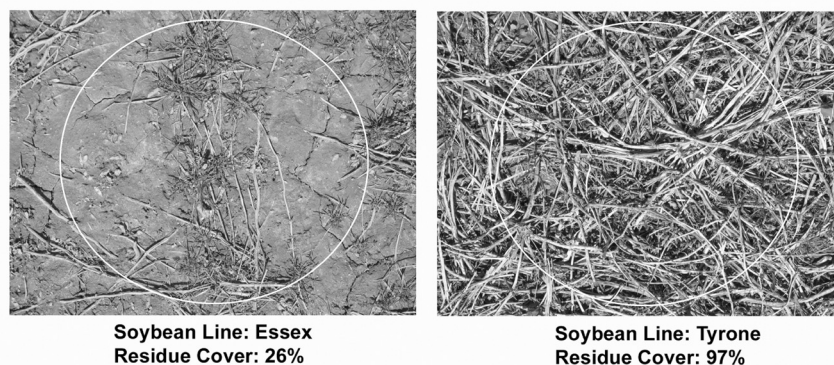


Figure 1. B/W illustration of the range of crop residue cover found when analyzing digital RGB images and ASD field of view area from 2002–2003 field plots at Beltsville, MD.

images were taken to determine each plot mean. Before each replication measurement the following order of procedures were used: (1) ASD dark current correction was made. (2) Spectral gain was optimized for each VIS, NIR and SWIR, ASD detector region while nadir viewing a white panel reference. (3) A white panel reference (Spectralon, Labsphere Inc., North Sutton, NH, US) correction reading was used to set the internal ASD correction data for incident solar radiation for collecting reflectance values. (4) White panel reference readings were acquired before and after each replication of plots to determine if significant decreases or increases in solar radiation had occurred during the measurement period (a total of 48 acquisitions for each replication of plots, within ~15 min time interval).

The FieldSpec Pro FR ASD is a portable, back-pack ready radiometer with a 5 m fiber optic cable and bare fiber optics acquisition port (~22° field of view) that was extended over the target surface. Both the ASD fiber port and the Canon digital camera were mounted on the top of a portable telescoping pole at 3 m above the plot soil surface at 0° viewing zenith to achieve a ~0.79 m² circular ASD field of view free from interference from the pole. The fiber optics was held at a nadir view angle for each plots ground sample (total of 6/plot) by aligning the bubble in a leveling bubble device attached to the pole handle in the operators view. A 0.5 × 0.5 m spectralon panel was mounted on a tripod, placed in the field of view at 0.5 m from the ASD optics and measured at nadir. Data were acquired under clear sky conditions. Reflectance factors were calculated [20]. All radiometric measurements and digital images were taken at the nadir view angle (0° view zenith angle) from the sample surface. Wavebands 1 nm wide were used for radiometric calculations. There was no significant change in solar radiation during the time required to measure each replication (15 min) The CAI proposed by Daughtry [3] was used to discriminate crop residues from soil and was calculated from reflectance as $CAI = 0.5(R_{2000\text{ nm}} + R_{2200\text{ nm}}) - R_{2100\text{ nm}}$.

Three replications of additional reflectance spectra were acquired (28/04/2003) from a solid pile of trashed border soybean crop residue that completely cover the ground. This was used as the target to represent a “predominant” soybean crop

residue spectral component. Likewise, 3 ASD measurements from 350–2500 nm of a bare soil area that was hand-picked free of all vegetative residues were used as a “predominant” soil spectral component. Three replications of measurements from a solidly covered, green weedy area in the field border were used to represent a “predominant” green weed vegetation spectral component found in the agricultural plot area scene.

2.6. Statistical analysis

A mixed model analysis of variance (SAS Inc., Cary NC, US) was used to assess the separability of crop parameters and spectral features with respect to soybean lines. The fixed effects for the mixed model were the soybean lines while the heterogeneity associated with the blocked field plots was designated as a random source of variation. Least significant difference (LSD) mean separations were deemed significant at $P < 0.05$. Correlation analysis was used to identify linear relationships among spectral indices and crop parameters. Regression analysis was used with the assumption that the variability of remotely sensed measurements was solely dependent on the variability of independent physical ground truth measurements.

3. RESULTS

3.1. Spectral attributes

Analysis of soybean plot areas included the spectral assessment of a “predominant” green weed vegetation, a “predominant” bare parent soil, and a “predominant” soybean crop residue spectral components, respectively, (Fig. 2), found in the in situ agricultural scene of the field plot test area. These spectral components delineated differences in several parts of the VIS, NIR and SWIR reflectance spectrum between green vegetation, soil and crop residues. Green vegetation present at this time consisted of spring weeds scattered throughout the field. Where the green vegetation predominated the scene the

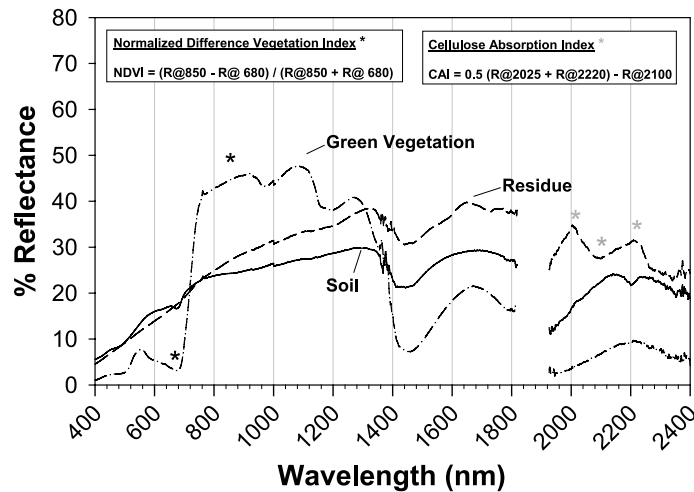


Figure 2. Spectral characteristics of the “predominate” components ($n = 3$) found in the agricultural scene after harvest through planting to detect crop residue productivity.

spectra displayed a characteristic low reflectance (3–5%) in the blue (400–500 nm) and red (650–690 nm) regions of the spectrum due to absorption of the chlorophylls. As expected, green vegetation reflectance around 550 nm approached 10%. Where soil and soybean crop residues predominated the spectra from the scene showed a continuing asymptotic increase starting with about 5% reflectance at 400 nm and gradually rising to about 20% reflectance at 800 nm. The parent soil test area, however, did display a slight dip in the chlorophyll absorption region at 675 nm, presumably due to chlorophylls in algae in the soil surface. The 660 to 900 nm region of the spectrum is a region where the normalized difference vegetation index (NDVI) is known to distinguish differences between green vegetation and, the crop residue / soil complex. However NDVI can not discriminate crop residue from soil.

The spectra from soil and soybean residue began to separate at 850 nm and continued through 2400 nm NIR and SWIR regions. The Codorus silt loam soil type in the field remained lower in reflectance than soybean crop residue. The soil and residue spectra in this region maintained the same general shape with a pronounced dip in the 1425 nm region, which is known to vary with water content [5]. Samples for the % moisture of the soil and crop residue were determined by gravimetric weight differences before and after drying. The soil on the day of the spectral measurements was retaining 16% moisture whereas the soybean crop residues were retaining 8% moisture. These differences in moisture are evident in the spectral signatures of both soil and soybean residues at 1425 nm. The soil had ~22% reflectance whereas soybean residues had ~34% reflectance indicating more absorption because of more water in the soil. We postulate that absorption features that are influenced by moisture content will tend to enhance the spectral differences between soils and crop residues in most field situations because crop residues on the soil surface have a tendency to dry out faster than the underlying soil surface.

Spectral data from 1800–1925 nm was excluded from analysis due to extreme variability of the signal caused by major water absorption, of the sun’s incoming radiation by the earth’s atmosphere. Separation of crop residues, soils, and green vegetation was most pronounced in the 1975–2250 nm regions. Soybean crop residues showed a pronounced dip in the spectra at ~2100 nm (Fig. 2). This area of the spectrum is the region where differences in CAI values can be determined, which is the primary subject of this investigation.

Daughtry et al. [5] indicated that different % moisture and weed levels in the scene can affect the performance of the cellulose absorption feature. In general, in our study, weed cover increased as crop residue cover decreased ($r^2 = -0.71$). The % cover of green weed vegetation in the scene was determined from RGB digital images and was positively correlated to the NDVI ($r^2 = 0.77$) (Data not presented). Even though green vegetation contains cellulose, the CAI of green vegetation is similar to the CAI of soil. The greater water content of green vegetation tends to completely mask the cellulose absorption band of the CAI. Heavy weed growth covering crop residues would tend to under-estimate residue cover by CAI. Mean weed cover in the plot area was 18% and the highest weed cover in the experiment did not exceed 37%. Since weed cover was relatively low no further analysis of this spectral attribute was made in this study. It is apparent however that a remotely sensed NDVI value would be of benefit in identifying areas within the field for selective weed spraying of broad based non-selective herbicides and warrants further investigation.

3.2. Agronomic conservation measurements

Plant heights of the lines in the test at the end of the 2002 growing season showed significant differences between LBS lines and conventional type soybeans (Tab. I). However, increased plant height did not necessarily translate into higher

Table I. Comparison of LBS and conventional soybean types with agronomic conservation measurements and cellulose absorption index (CAI) remotely sensed data from 2002–2003 field plots at Beltsville, MD.

Soybean line	Type	Plant Ht.‡ (cm)	Biomass‡ (kg/ha)	% Cover† (LPTM)	% Cover† RGB image	CAI† (100x)
Tyrone	Forage LBS	189 a	11925 a	82 ab	84 a	2.03 a
PA-15	Forage LBS	137 c	9908 ab	83 a	83 a	2.16 a
7P116	Forage LBS	156 b	7931 bcde	69 abc	76 a	1.77 ab
97VA20	Multi-use LBS	164 b	8289 bcd	67 bc	66 b	1.49 bc
Hutcheson	Conventional	81 de	8764 bc	59 cd	65 b	1.20 c
Williams	Conventional	96 d	5170 e	58 cd	45 d	.44 d
Essex	Conventional	74 e	6930 cde	46 de	55 c	.18 d
Spry	Conventional	82 de	5338 de	41 e	49 cd	.18 d
LSD _(0.05)	–	19.3	2951	16.7	9.3	0.537

Within column means with the same letter are not significantly different by Mixed Model ANOVA, LSD_(0.05) pair-wise means comparisons procedure.

† Means are based on 3 replicates each with 6 sub-samples.

‡ Means are based on 3 replicates.

biomass. For example, LBS-type PA-15 was significantly taller (56.3 cm, $P < 0.0001$) than the conventional-type Hutcheson but the biomass increase of 1144 kg/ha for the PA-15 LBS-type was non significant. At harvest, the best LBS residue producing types (Tyrone and PA-15) produced significantly higher levels (>2951 kg/ha; $P < 0.05$) of dry crop biomass than three (Essex, Spry, and Williams) out of the four conventional soybean types in the test. Since above ground soybean dry biomass is ~40% carbon, the data also indicate that the best LBS producer (Tyrone) can contribute ~1200 kg/ha more carbon residue input to the soil surface complex than the best conventional type (Hutcheson) soybean cultivar.

In the spring of 2003, physical ground truth measurement counts taken by both the NRCS, LPTM method and the digital RGB image analysis method showed significantly higher crop residue coverage for several LBS lines versus several conventional soybean types (Tab. I). When mean data among LBS and among conventional type soybeans were pooled, both methods indicated a significant 24% increase ($P < 0.0001$) in residue cover for LBS types. The greatest mean separation by the LPTM method occurred between the LBS, PA-15 type (83%) and the conventional cultivar type Spry (41%). The greatest mean separation by digital RGB image analysis occurred between the LBS, Tyrone type (84%) and the conventional cultivar type Williams (45%). Digital RGB image analyses were conducted on the exact ASD, 0.79 m² spectral field of view, “footprint”. Figure 1 illustrates the broad range of crop residue coverage between soybean types and plot areas found in the experiment.

3.3. Remotely sensed cellulose absorption

Daughtry [3] determined in the laboratory that a spectrally derived CAI composed of three narrow bands in the SWIR was related to the coverage of crop residue on a soil surface. In the present test, CAI calculated from reflectance data taken over field plots of soybean residue had a LSD_(0.05) value of 0.537 for closest pair-wise t test comparison of soybean lines (Tab. I). When mean data among LBS and among conventional type

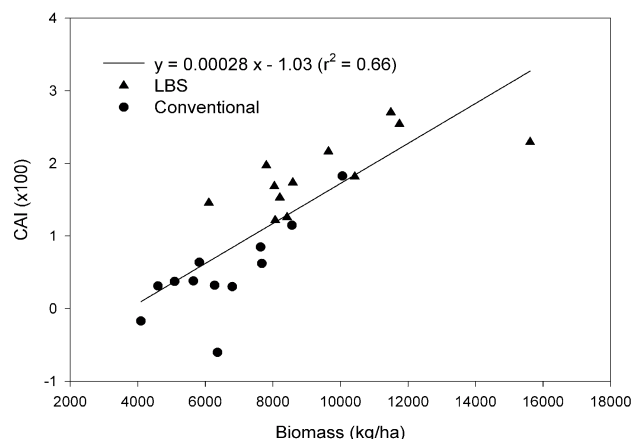


Figure 3. Relationship of the remotely sensed cellulose absorption index (CAI) to the crop residue biomass at harvest on soybean field plots.

soybeans were pooled, a mean higher CAI (1.36 index value, $P < 0.0001$) indicated a significantly higher residue cover for LBS types. The CAI was also able to separate significant differences between the highest LBS crop residue biomass producing types, the medium LBS/conventional crop residue biomass producing conventional soybean types. For instance, the CAI was able to significantly separate soybean line types Tyrone and 97VA20 that had as little as a 3636 kg/ha difference in crop residue biomass at harvest (Tab. I). Likewise the medium biomass producing lines (97VA20 and Hutcheson) were statistically distinguishable by CAI from the lower at harvest biomass producing lines (Williams and Spry). A significant positive relationship between CAI and the crop residue dry biomass levels at harvest, $r^2 = 0.66$ (Fig. 3) was found. Correlation analysis indicated significant positive relationships ($r^2 = 0.74$) between CAI and LPTM % residue coverage (Fig. 4). The LSD_(0.05)

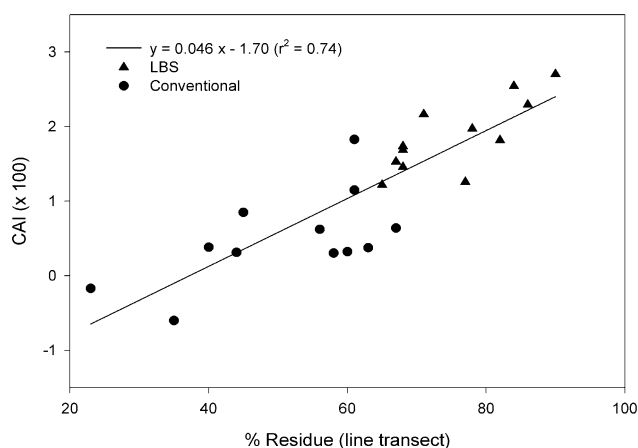


Figure 4. Relationship of the remotely sensed cellulose absorption index (CAI) to crop residue percent cover as determined by the line point transect method (LPTM) on soybean field plots.

value of 0.537 for CAI indicates that the 15% cover difference by LPTM of Tyrone versus 97VA20 could be tracked with CAI (Tab. I). The same coefficient of determination ($r^2 = 0.74$) was found between CAI and the digital RGB image % residue coverage (Fig. 5). The RGB image monitored the exact same “footprint” as the CAI remotely sensed data for each sample. The digital RGB images determined there was an 18% crop residue cover difference between Tyrone and 97VA20 (Tab. I). Note also the co-lateral significant CAI value (> 0.537) differences between high % residue cover of Tyrone and PA-15, medium % residue cover of 97VA20 and Hutcheson and low % residue cover Essex and Spry soybean line types as measured by both LPTM and digital RGB image % residue cover methods. Significant differences in CAI values were found by linear regression analysis. If we assume that the (independent) digital RGB image % residue cover values are the absolute “true” % residue cover values, we find that the (dependent) CAI values produced a root mean square error of 0.47 (RMSE = 0.47) in the regression analysis. Points along the regression line were significantly different at CAI values of greater than ($>$) 0.47 allowing discrimination between high, medium, and low soybean crop residue coverage.

4. DISCUSSION

Murray and Williams [19] suggested that the strong absorption at 2100 nm appears in all compounds containing $-OH$ groups, such as sugars, starch, and cellulose. The 2100 nm dip that is used in the CAI has been reported to be clearly evident in the reflectance spectra of dry crop residues [3, 21] and in dry, intact plant materials [9] by various laboratory methods. Crop residue coverage levels from soybean crops can be appreciably lower than other major crop species such as corn and wheat, and are of concern in the management of crop residues for soil conservation purposes.

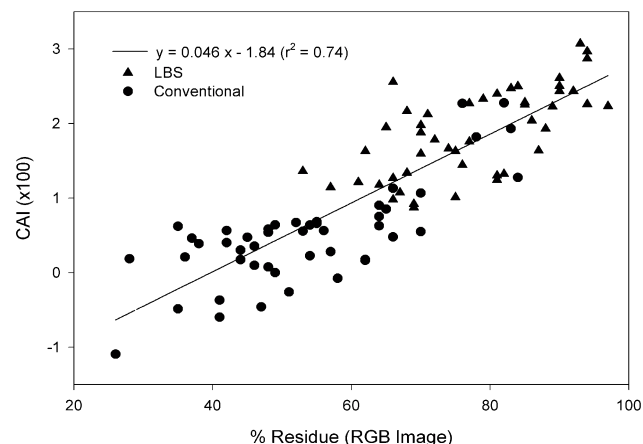


Figure 5. Relationship of the remotely sensed cellulose absorption index (CAI) to crop residue percentage as determined by the digital red, green, blue (RGB) photographic analysis method on soybeans from 2002–2003 field plots at Beltsville, MD.

Results from this study conducted under field plot conditions confirm the CAI is a valid method to separate the coverage of crop residues with remote spectrally derived data. This study documents the detection of differences in % cover and CAI remotely sensed spectral data from soybean field plot residues which at harvest produced dry biomass levels in the 5 000 to 11 000 kg/ha range. Previous studies have shown that ~40% of the above ground soybean biomass is carbon. The mean dry above ground soybean biomass for LBS types was 9513 kg/ha versus 6551 kg/ha for the conventional soybean type of cultivars, indicating that LBS types can provide ~31% increase in crop residue carbon inputs to the soil.

In this study the biomass levels resulted in a range of soybean crop residue coverage in the spring before planting that was as low as 26% cover and as high as 97% cover. Analysis of variance statistical procedures produced LSD t test comparisons within LPTM % cover, digital RGB image % cover and CAI values, which were significantly different. Pair-wise mean comparisons, of soybean line types in this test, indicated that a LSD of + or -0.537 in CAI value will separate classes of residue coverage. The same soybean line type pairs were able to distinguish a comparable 18% difference in soybean crop residue ground cover by digital RGB image and a 15% difference in soybean crop residue ground cover by LPTM. Factors, such as differing moisture conditions, residue age and degradation, and different soil types may cause additional variability in the data but were not addressed by this study.

The study indicated significant positive increases in crop residue coverage by planting LBS types, which will benefit soil conservation programs and increase carbon inputs to the soil. Planting of LBS on soybean lands along with successful implementation of the CAI crop residue monitoring technique over large areas will fully document the increased soil conservation practice benefits of LBS for conserving soil on HEL lands. Interpolation of a cultivar’s crop residue biomass and resulting % crop residue ground cover forward from harvest through spring planting will be needed in order to predict an average

year's biomass retention and % coverage on the soil surface under different tillage scenarios and climates. This will assist achievement of future goals in determining regional soil conservation effectiveness for soil erosion control and provide inputs to carbon sequestration models. The soybean breeding evaluation trial for LBS lines versus conventional soybean cultivars was an ideal test to determine the detection capability of CAI for the variability found in soybean crop residues under field plot conditions. The study demonstrated that increases in crop residues from LBS and other soybean types can be detected in the field by remote sensing. Currently the AVIRIS aircraft sensor and the Hyperion EO-1 satellite sensor have the appropriate spectral and spatial resolution for monitoring crop residue coverage.

The long-term goal of the research is to integrate the remote monitoring of crop residues with agronomic management alternatives that can increase residue production and coverage on soybean lands. Using these crop residue monitoring and managing approaches Natural Resource Conservationist will have the potential to monitor the status of crop residue coverage for soil conservation with CAI, and also demonstrate a potential remedy for increasing crop residue on soybean lands by switching to higher residue performing LBS or conventional type of soybean cultivars.

ACRONYM KEY

7P116	= large biomass soybean experimental germplasm line
97VA20	= large biomass soybean experimental germplasm line
ASD	= analytical spectral device
BARC	= Beltsville Agricultural Research Center
CAI	= Cellulose absorption index
CTIC	= Conservation Technology Information Center
DM	= dry matter
FR	= full resolution
HEL	= highly erodible land
IR	= infrared wavelengths
K	= potassium
LBS	= large biomass soybean
LPTM	= line point transect measurement
LSD	= least significant difference
NDVI	= normalized difference vegetation index
NRCS	= National Resources Conservation Service
P	= phosphorus
PA-15	= large biomass soybean experimental germplasm line
RGB	= red, green, blue
RMSE	= root mean square error
RUSLE	= revised universal soil loss equation
SWIR	= short wave infrared
US	= United States
USDA	= United States Department of Agriculture
VIS	= visible wavelengths

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