FIELD SCALE EVALUATION OF CROP RESIDUE COVER DISTRIBUTION USING AIRBORNE AND SATELLITE REMOTE SENSING

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Abstract. Conservation tillage adoption has been associated with sustainable agricultural practices and linked with increased plant available water content in some regions. However, rapid and spatially accurate field scale assessments in the southeastern U.S. are lacking. A major goal of this study was to evaluate satellite and aerial imagery as a rapid and spatially explicit method for delineating crop residue cover as an estimator of conservation tillage adoption within a watershed. In the spring of 2005 and 2006, crop residue cover variability was measured on five farms located within the Southern Coastal Plain. Remotely sensed data were collected subsequent to planting using the aircraft mounted Airborne Data Multi-Spectral Imaging System (2005) and Quickbird satellite (2006). Coincident with each image acquisition, each site was grid sampled (0.20 ha grid) for soil water content, soil organic carbon content, crop residue carbon and water content, and soil texture. Soil and crop residue were composite sampled within a 1 – m radius of each point. Digital images ($1.4m^2$) were acquired at designated grid points to classify percentages of residue coverage. Ground truth data were used to evaluate the observed error in remotely derived cover estimates. Accurate and rapid estimates of cover at this scale may be used to decrease uncertainties in land use/land cover used to parameterize watershed models that predict water quality and quantity.

INTRODUCTION

Soils in the southeastern Coastal Plain and Piedmont are highly weathered, typically low in carbon and highly susceptible to drought. In an effort to combat these problems, landowners are implementing conservation tillage along with surface residue management as a method to increase infiltration, improve soil water holding capacity and reduce runoff and erosion. Conservation tillage has proven to be an effective best management practice for reducing soil degradation in the Southeastern United States and its use is incorporated within USDA conservation payment programs, such as the Environmental Quality Incentives Program and the Conservation Security Program. Current methods for quantifying the amount of cover at the field scale are time and labor intensive and often do not produce spatially accurate results. Remote sensing is currently being evaluated as an instrument to measure residue cover in a rapid and accurate manner. A major goal of this study is to develop remotely derived crop residue maps and assess the impact that variability in surface soil attributes may have on map accuracy.

METHODS AND PROCEDURES

Site Description

Five fields located in Chula, Georgia were evaluated; however, only one field site will be discussed in detail for this paper. The field was approximately eight hectares in size, having a Tifton loamy sand texture. The cropping system used at this site was a cotton-cotton-peanut rotation with a rye winter cover. The site was mapped to a 0.20 ha grid resulting in 60 grid points for sampling. Remote sensing and ground truth data were acquired in June 2005 and May 2006.

Ground Truth

Ground truth consisted of digital images, soil samples, and crop residue. Digital images were acquired at nadir from the center of each grid point, using a 5-mega pixel Olympus C- 505 Zoom (London, UK). Images were acquired from a height of 1 m with a spatial resolution of $1.4m^2$. Percent cover (residue, vegetation and soil), was obtained via a supervised classification having from 5-15 classes, using ERDAS Imagine 8.4 (Leica Geosystems, Heerbrugg, Switzerland). Residue cover percentage was calculated by dividing the pixels that were classified as residue by the total pixel count within each image.

Crop residue samples were collected from within a $0.09 m^2$ sample ring at each grid point within the field. In the laboratory, samples were weighed, dried at 60˚C and then re-weighed for residue water content. Residue samples were then ground using a Thomas Scientific Model 4 Grinder. Residue carbon and nitrogen content were measured via combustion using a Carlo-Erba NA 1500 C&N analyzer.

Surface soil samples (0-2.5cm) were collected from within a $1 m^2$ radius of each grid point. Five sub-samples were collected and analyzed for the following: particle size distribution as described by Bouyoucos et. al. (1936) and Day et. al. (1965), as well as gravimetric soil water content.

Remote Sensing

Remotely sensed images were acquired using the aircraft mounted- Airborne Data Systems multispectral sensor (2005) and Quickbird satellite (2006). Aircraft images were acquired at an altitude of 1,500m under clear conditions, between 10a.m. and 2p.m. Images had a spatial resolution of 1m and spectral response was measured in four bands: blue (450-490 nm), green (525-585 nm), red (635-685 nm) and near-infrared (NIR) (770-970 nm). Satellite data were acquired at an altitude of 450km on clear days (with less than 10% cloud cover) proximate to noon. Satellite data have a spatial resolution of 2.4m and measure spectral response in four bands including: blue (450-520 nm), green (520-600 nm), red (630-690 nm) and NIR (760-900 nm).

Prior to image analysis the field was subset from each image and the map model was adjusted using a 1999 Digital Orthoquad (DOQ) as a reference. Next, each sample point was buffered using ESRI ArcMap 9.1. Buffer distances were chosen based on the spatial resolution of the aircraft (2m) and satellite (4m). Data within the buffered zones were extracted from both the airborne and satellite images, and a database file containing all ground truth and remotely sensed data was generated. In 2005, only the NIR spectra were used due to over exposure in the visible bands. In 2006, all spectral bands were used and remote sensing indices calculated. Remote sensing indices include: the greenness normalized difference vegetation index (GNDVI; Gitelson et. al., 1996), which was calculated as follows:

$$\text{GNDVI} = (\text{NIR} - \text{green}) / (\text{NIR} + \text{green}).$$

The normalized difference vegetation index (NDVI; Rouse et. al., 1974), which was calculated as follows:

$$\text{NDVI} = (\text{NIR} - \text{red})\ (\text{NIR} + \text{red}).$$

The crop residue cover index (CRC1; Sullivan et. al., 2006), which was calculated as follows:

$$\text{CRC1} = (\text{NIR} - \text{blue})\ (\text{NIR} + \text{blue}).$$

Analysis

Twenty percent of the sample points were randomly selected and retained as a check data set so that root mean square errors (RMSE) could be calculated. Using the remaining 80% of the sample points Pearson correlation coefficients were used to evaluate the strength of relationship between remote sensing spectra and crop residue cover. Where a significant correlation existed, a regression between the RS band or index and crop residue cover was used to predict cover at unsampled locations using the check dataset.

RESULTS AND DISCUSSION

Descriptive Data

Crop residue cover varied between years. In 2005, crop residue cover was greatest, ranging from 16 to 67 %. More importantly, crop residue cover was highly variable across the field site. By contrast, in 2006, crop residue cover was much lower, ranging from 0 – 49 %.

Soil water content was also measured, as a variable that can potentially limit our ability to accurately predict crop residue cover remotely (Figure 1). Soil water content was highest and most variable in 2006, ranging from < 5 – 34 % θ_v. In 2005, surface conditions were much drier ranging from < 9 –15 % θ_v. Vegetative cover was generally low averaging 15% in 2005 and 2% in 2006. Sand content ranged from 86-95 % with soil organic carbon levels (SOC) ranging from 0.3 – 1.6%.

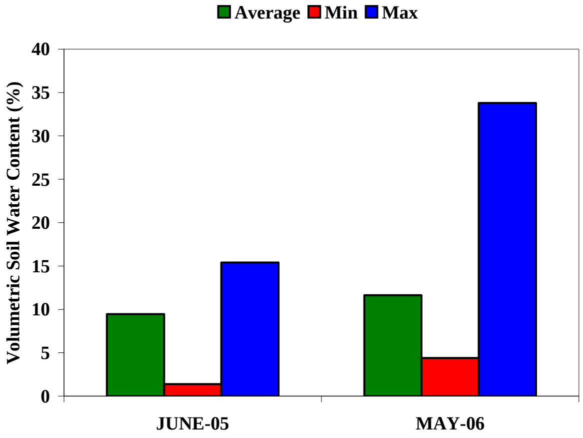

Figure 1. Soil volumetric water content.

Spectral Response

In both years, NIR spectra were highest in areas where there was low residue cover (cover= 16%) and low water content (SWC = 5%). To illustrate the impact of soil water content variability on spectral response, NIR spectra were evaluated at low cover (< 20 %) and high cover (> 45 %) under wet and dry soil conditions using the 2005 dataset (Figure 2). Under low cover conditions, NIR spectral response was fairly consistent, ranging from 80 to 82 digital values under wet and dry conditions, respectively. However, in areas where cover was high, the NIR reflectance ranged from 81 to 87 digital values under wet and dry conditions, respectively. Thus under wet conditions, high cover could easily be misclassified as low cover.

These results present a significant challenge to mapping field scale variability of crop residue cover.

A similar pattern was observed using all 4 bands in 2006. In 2006, three remotely sensed indices were also evaluated as tools to depict crop residue cover amount. Under low cover and low SWC, index values were 0.04, 0.11 and 0.16 for the NDVI, GNDVI and CRC1, respectively. As SWC increased our index values increased by 0.02 for all indices. At high residue cover and high SWC, index values ranged from 0.08 – 0.20. The greatest difference between low residue cover and high cover was observed using the GNDVI.

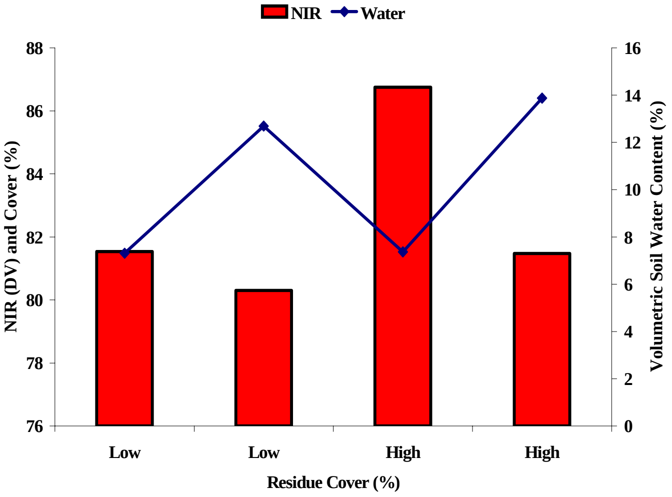

Figure 2. Near-infrared spectral response under low cover (< 20 %), high cover (>45%) and variable soil water content.

Correlation

In 2005 and 2006, a linear relationship was established between NIR spectra or RS indices and crop residue cover. Correlations were best using the NIR band alone, having coefficients of –0.43 to –0.50. Remotely sensed indices were also evaluated as a means to reduce the impact of atmospheric attenuation, illumination and shadow. In 2006, the correlation between RS indices and crop residue cover ranged from 0.38 to 0.48, peaking with the GNDVI. Although the GNDVI was designed to detect living vegetation, the index is also sensitive to increasing ground cover. In our study vegetative cover was minimal at the time of RS data acquisition.

Regression

Remotely sensed spectra explained from 14 – 28 % of the variability in crop residue cover. Results were best using NIR spectra in both years. The low coefficients of determination are not surprising, considering that no RS indices were available to test in 2005 and crop residue cover was relatively low in 2006.

Perhaps, it is more useful then to evaluate the magnitude and source of the error. Despite the relatively higher coefficients of determination observed for the NIR, the RMSE was lowest for remotely sensed indices (RMSE = 4 – 6%) compared to estimates derived based on the NIR band (RMSE = 6 – 8 %). More importantly, an analysis of residual distributions in both years, demonstrates that increasing soil water resulted in increasing errors in estimated cover amount. Additionally, under low cover conditions, our models tended to overestimate crop residue cover amount.

CONCLUSION

Conservation tillage has proven to be an effective best management practice for reducing soil degradation and conserving water resources in the Southeastern United States. However, quantifying the level of adoption at the field scale is difficult. The objective of this study was to evaluate remote sensing as an instrument to measure residue cover in a rapid and accurate manner.

Results indicate that spectral reflectance using NIR or RS indices is linearly related (r = -0.43 to –0.50) to field scale distributions of crop residue cover. Using regression analyses to model cover amount, an uncertainty analysis was conducted using a check data set, containing sample locations not included in the model. Analysis of residual distributions indicates that our current model has a tendency to overestimate cover at low cover conditions. More importantly, as soil water content increases the likelihood of over or underestimating cover amount increases.

In the future we anticipate the evaluation of a threshold technique for distinguishing between conventional and conservation tillage fields using satellite imagery. High-resolution ground truth data (soil water content, particle size distribution, and crop residue cover amount) will be used to evaluate the uncertainty in our estimates and determine the most appropriate spatial resolution by which to develop remotely derived crop residue cover maps.

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