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Evaluating the relationship between biomass, percent groundcover and remote sensing indices across six winter cover crop fields in Maryland, United States

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ABSTRACT

Winter cover crops are an essential part of managing nutrient and sediment losses from agricultural lands. Cover crops lessen sedimentation by reducing erosion, and the accumulation of nitrogen in aboveground biomass results in reduced nutrient runoff. Winter cover crops are planted in the fall and are usually terminated in early spring, making them susceptible to senescence, frost burn, and leaf yellowing due to wintertime conditions. This study sought to determine to what extent remote sensing indices are capable of accurately estimating the percent groundcover and biomass of winter cover crops, and to analyze under what critical ranges these relationships are strong and under which conditions they break down. Cover crop growth on six fields planted to barley, rye, ryegrass, triticale or wheat was measured over the 2012–2013 winter growing season. Data collection included spectral reflectance measurements, aboveground biomass, and percent groundcover. Ten vegetation indices were evaluated using surface reflectance data from a 16-band CROPSCAN sensor. Restricting analysis to sampling dates before the onset of prolonged freezing temperatures and leaf yellowing resulted in increased estimation accuracy. There was a strong relationship between the normalized difference vegetation index (NDVI) and percent groundcover ($r^2 = 0.93$) suggesting that date restrictions effectively eliminate yellowing vegetation from analysis. The triangular vegetation index (TVI) was most accurate in estimating high ranges of biomass ($r^2 = 0.86$), while NDVI did not experience a clustering of values in the low and medium biomass ranges but saturated in the higher range (>1500 kg/ha). The results of this study show that accounting for index saturation, senescence, and frost burn on leaves can greatly increase the accuracy of estimates of percent groundcover and biomass for winter cover crops.

1. Introduction

The Chesapeake Bay watershed is located in the mid-Atlantic on the East Coast of the United States. The Chesapeake Bay is the largest estuary in the United States, with the watershed comprising portions of six states and the District of Columbia (Goetz et al., 2004). Nutrient runoff from farmland has negative effects on water quality in the Chesapeake Bay. Residual nitrate in the soil profile after crop harvest is subject to leaching from agricultural areas into groundwater and adjacent tributaries. Pollution from nutrients and sediment has negative consequences for waterways, including eutrophication, reduced stocks of fish, and declining habitats through destruction of submerged aquatic vegetation (Dauer et al., 2000). These conditions have worsened in the Chesapeake Bay over time, in part due to fertilizer and manure application on agricultural lands (Jordan et al., 1997).

1.1. Cover crops

Planting cover crops is an effective method to reduce both nitrogen leaching and sedimentation from agricultural lands (Meisinger et al., 1991). Winter cover crops are planted post-harvest on corn and soybean fields to scavenge residual nitrogen that remains in the soil, and to meet soil groundcover conservation guidelines, providing substantial water quality benefits (Dabney, 1998; Delgado et al., 2007). Cover crops accumulate biomass during the fall, with

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Table 1
Extent of winter cover crops enrolled in the Maryland agricultural cost share program during the winter of 2012–2013. Data were provided by the Maryland agricultural cost share program.

Species	Hectares (% of total)	Hectares	Fields (% of total)	Number of fields
Wheat	67	112061	62	7981
Barley	15	24491	14	1795
Rye	12	20182	17	2246
Forage radish	3	5369	2	320
Triticale	2	3201	2	288
Spring oats	1	2117	2	228
Ryegrass	<1	468	<1	29
Canola/rapeseed	<1	196	<1	14
Clover/wheat	<1	152	<1	5

growth slowing through the winter, and typically green up again in the spring. Earlier planted cover crops are able to accumulate more biomass prior to the onset of cold weather (Hively et al., 2009), leading to increased water quality benefits. In addition to planting date, a variety of factors, including species, planting method, and the amount of residual nitrogen available in soils, can lead to a large range of biomass and groundcover outcomes on cover cropped fields. Because increased biomass is related to increased groundcover and nutrient uptake, it is important to be able to accurately estimate cover crop biomass.

A majority of the Chesapeake Bay estuary is located in Maryland. The Maryland Department of Agriculture (MDA) offers cover crop subsidies to farmers with the Maryland agricultural water quality cost-share (MACS) program, through which farmers can either plant traditional non-harvested cover crops or commodity cover crops for harvest. Table 1 shows the breakdown of Maryland subsidized cover crops that were planted during the 2012–2013 cover cropping season.

During 2012–2013, wheat was the most common cover crop in terms of both acreage and percent of enrolled fields. Together, barley, rye and wheat contributed 96% of the cover crop acreage in Maryland. Triticale and ryegrass covered over 3500 ha combined.

Following winter dormancy, cover crops typically experience a spring green-up when warm temperatures return, allowing for additional nitrogen uptake before kill-down, if residual nitrogen is left in the soil (Dabney et al., 2001). Availability of soil nitrogen also plays a role in the accumulation of biomass, with some cover crops growing poorly due to nitrogen limitation. The amount of fall residual soil nitrogen found in different fields can vary based on the previous crop's performance relative to fertilization, temperature, and rainfall.

In addition to reducing nutrient runoff, cover crop groundcover provides protection from raindrop impact and increases soil aggregate stability, decreasing erosion by wind and water (Dabney et al., 2001). If plants can reach their tiller stage (formation of side shoots) before winter dormancy, they are able to cover a greater amount of soil, resulting in better erosion control and environmental outcomes (De Baets et al., 2011; Fisher et al., 2011). Along with high residue tillage practices, cover crops are often used to meet groundcover requirements on highly erodible lands (Mirsky et al., 2009).

1.2. Phenology and spectral indices

Remote sensing indices that measure plant greenness based on reflectance in the near-infrared and visible wavelengths are often used to estimate aboveground biomass (Gitelson, 2004), and can also be used for measuring percent vegetative groundcover (Purevdorj et al., 1998 Wiegand et al., 1991). Such data can be gathered through remote sensing instruments such as Earth-orbiting satellites, aerial photos, proximal sensors, or other means. The atmosphere can create differences in the relationship between surface reflectance and radiance detected at the sensor, and ground-based proximal sensors can be utilized to minimize atmospheric effects. A majority of solar radiation in the visible spectrum is absorbed by pigments in the leaves, resulting in low transmittance and reflectance, and the chlorophyll adsorption feature maximally reduces reflectance in the red portion of the spectrum (around 660 nm) with slightly less adsorption in the green wavelengths (around 550 nm). Low reflectance in the red is coupled with increased brightness in the near-infrared region of the spectrum, where there is low absorption and high transmittance and reflectance (Tucker and Sellers, 1986). Ratios of low-reflecting red and high-reflecting infrared measurements allow for unit-less measures of the chlorophyll absorption peak in green vegetation. A myriad of vegetation indices have been developed and researched over the years, 10 of which are shown in Table 2.

Testing multiple indices is useful, because at low fractional vegetated groundcover factors such as soil reflectance may interfere with the vegetation signal, and different indices are more sensitive in different ranges of biomass and groundcover. In cover crop fields there may be little growth by the beginning of the winter season due to low temperatures and late planting dates, leading to limited horizontal layering of plants and a reduced impact on reflectance from canopy structure. On one hand, this limited hori-

Table 2
Definition of spectral indices. Bands are designated in the formulas as R (red), B (blue), G (green), RE (red-edge), NIR (near-infrared), and L (soil line).

Index	Name	Citation	Formula
NDVI	Normalized difference vegetation index	Tucker (1979)	(NIR − R)/(NIR + R)
GNDVI	Green normalized difference vegetation index	Moges et al. (2004)	(NIR − G)/(NIR + G)
SR	Simple ratio	Tucker and Sellers (1986)	NIR/R
SAVI	Soil-adjusted vegetation index (L = 0.5)	Huete (1988)	[(NIR − R)/(NIR + R + L)](1 + L)
G − R	Green minus red		G − R
EVI	Enhanced vegetation index	Huete et al. (2002)	2.5(NIR − R)/(NIR + 6 × R − 7.5 × B + 1)
TVI	Triangular vegetation index	Broge and Leblanc (2000)	0.5[120(NIR − G) − 200(R − G)]
NGRDI	Normalized green red difference index	Tucker (1979)	(G − R)/(G + R)
VARI	Visible atmospherically resistant index	Gitelson et al. (2002)	(G − R)(G + R − B)
NDREI	Normalized difference red edge index	Gitelson and Merzlyak (1994)	(RE − R)/(RE + R)