Remote sensing of wintertime ground cover on agricultural fields: cover crop performance for Chesapeake Bay

W. Dean Hively
U.S. Geological Survey
Eastern Geographic Science Center

With: Greg McCarty, USDA Agricultural Research Service
    Jason Keppler, Maryland Department of Agriculture
    Shawn Smith, Talbot County Soil Conservation District
Research Approach

• The research investigates the linkage between agricultural land use, conservation practices, and water quality

• Effective implementation of agricultural conservation practices is critical to the reduction of nutrient and sediment loading to the Chesapeake Bay

• We are developing geospatial tool kits to measure the effects of conservation practice implementation, with a focus on winter cover crops

• Data integration approach matches satellite measurements of winter biomass (Landsat, SPOT) with site-specific knowledge of agricultural conservation practices

• Collaborative approach, working within the context of the USGS Chesapeake Bay Science Plan and the Executive Order for Chesapeake Bay protection and Restoration
Collaborators:

- United States Department of Agriculture (USDA) Agricultural Research Service - Hydrology and Remote Sensing Laboratory
- University of Maryland Geography Department
- Maryland Department of Agriculture
- Soil Conservation Districts, Farmers
Chesapeake Bay
Remote sensing of winter cover crop performance

Winter cover crops for water quality

• Improve soil aggregate stability, biological activity
• Alleviate compaction, increase trafficability
• Provide groundcover and reduce soil erosion
• Help to manage weeds
• Produce useful products (grain silage, emergency forage, straw harvest, bioenergy)
• Improve nutrient management

* REDUCE NITROGEN AND SEDIMENT LOSS *
On-farm performance is variable
Nitrogen capture by winter cover crops can reduce nutrient and sediment loss to the Chesapeake Bay. But performance is variable. How much is captured? And how do agronomic practices compare? These questions can be answered by combining farm-program data records with satellite remote sensing and on-farm sampling.
• Satellite-based remote sensing of wintertime ground cover
• Mapping farmland, crop rotations, and conservation practices
• Associating topography, soils, hydrology, and nutrient transport
• Linking changes in agricultural management to water quality monitoring data

2014 study areas

- Showcase Watersheds
- Landsat footprints
- USGS Reston
- SPOT imagery
- Beltsville Agricultural Research Center
- Choptank River CEAP
- Conservation Effects Assessment Project
Remote sensing of winter cover crop performance

• Combining spatially accurate satellite imagery analysis with site-specific knowledge of agricultural land use management
• Estimating biomass and nutrient uptake on fields enrolled in the Maryland cover crop cost-share program
• Working with the Maryland Department of Agriculture (MDA) to implement statewide geospatial management of cover crop cost-share programs – web enabled beta test in fall 2014
• Providing winter groundcover analysis in MD, PA, NY

Data:
• On-farm sampling of plants and soils: 1200+ samples over 7 years
• Wintertime vegetation measurement using Landsat and SPOT
• Geospatial toolkits have been programmed to assist analysis
Strategy

- Working directly with Soil Conservation Districts
- Protecting privacy of farm conservation data to meet Farm Bill (Section 1619) and state requirements
- Support adaptive management
MDA provides cost-share program farm enrollment data

- Field location
- Species (rye, barley, wheat, brassicas)
- Planting method (drilled, broadcast, aerial)
- Planting date (Mid-September to Nov 5th)
- Previous crop (corn grain, corn silage, soy)

This allows us to use remotely sensed measures of aboveground biomass as a *response variable*
Satellite Imagery
Landsat and SPOT

- Sometimes cloudy, sometimes clear
- Each image is a snapshot in time
- Fairly accurate mapping of agricultural vegetation
- We are most interested in mid-winter imagery
Overlap with winter cover crop farm enrollment data records

This normally private information was released to the public by the collaborating farmer.
Calculation of wintertime greenness

- Multispectral vegetation indices such as NDVI or MSAVI applied to satellite imagery surface reflectance

\[
\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}
\]
Calculate vegetation index for each cover crop field

Using SPOT and Landsat imagery

One average value per field

Use calibrations to translate vegetation indices into performance measures:

- Biomass
- N content
- % ground cover
On-farm field sampling for calibration

- Aboveground biomass
- Plant N, chlorophyll
- Surface reflectance
- % cover (RGB photos)
- Soil nitrate content
- ~ 30 fields per season
  - Dec/Jan (fall)
  - Mar/Apr (spring)
- ~ 1200 samples in 7 yrs

Extract vegetation index (e.g. NDVI) for each sampling location from satellite imagery
Use satellite imagery to predict biomass

2005-2010 field sampling data

These data are preliminary and are subject to revision
**A collaborating farm**
Talbot County, Maryland

- CC_Field Sampling Locations

**Map cover crop environmental outcomes**

**Species**
- Wheat
- Rye
- Barley
- Forage Radish
- Canola/Rape
- Spring Oats

**NDVI**
- Minimal biomass: 0.10 - 0.30
- Low biomass: 0.30 - 0.45
- Medium biomass: 0.45 - 0.60
- High biomass: 0.60 - 1.00

---

**2010-11 Cover Crop Enrollment**

**Species**
- Barley: 2.5 bu/ha
  - No-till drill
  - 9/14/2010 after Corn
  - avg NDVI 0.53
    - medium biomass

---

**Barley**
- 2.5 bu/ha
- No-till drill
- 9/17/2010 after Corn
- avg NDVI 0.57
  - medium biomass
Adaptive Management of Winter Cover Crops

- Produce county/watershed reports for local partners
- Provide field-specific information to farmers
- Target low-productivity fields for site visits
Remote sensing of winter cover crop performance

Forthcoming manuscript I (2014):

- Remote sensing of cover crop performance: calibration between satellite imagery and on-farm biomass measurements (Hively et al., for Journal of Applied Remote Sensing)

SPOT top of atmosphere (TOA) data shows similar slopes with date-to-date variability in intercept

Now working to convert SPOT to surface reflectance (SR) using FLAASH

Comparison will be made with Landsat TOA and Landsat SR provided by EROS Data Center

These data are preliminary and are subject to revision
Remote sensing of winter cover crop performance

Forthcoming manuscript II (2015):

- Six years of cover crop performance in Talbot County, MD, 2008-2013 (Hively et. al., invited paper for special issue on cover crops in Journal of Soil and Water Conservation)

---

Landsat 5 Satellite Imagery Jan 3rd, 2011

Vegetation Thresholds
- Water: -1.0-0.1
- Minimal biomass: 0.1-0.3
- Low biomass: 0.3-0.45
- Med biomass: 0.45-0.6
- High biomass: 0.6-1.0

Landsat 5 Satellite Imagery Jan 3rd, 2011
What factors affect cover crop crop success?
Planting date
Species choice

Wheat

Rye

Barley
Planting method

previous crop

nitrogen, soils, weather
### Analysis (example data for Jan 6th, 2011)

Assuming 2% N content for all cover crops. Data for use as example only.
These data are preliminary and are subject to revision. They are being provided to meet the need for timely ‘best science’ information.

<table>
<thead>
<tr>
<th>Species</th>
<th>Enrolled Fields</th>
<th>Observed NDVI</th>
<th>Predicted Biomass</th>
<th>Predicted N Content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>#</td>
<td>ha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>1726</td>
<td>15039</td>
<td>0.36</td>
<td>224</td>
</tr>
<tr>
<td>Rye</td>
<td>123</td>
<td>878</td>
<td>0.35</td>
<td>226</td>
</tr>
<tr>
<td>Barley</td>
<td>236</td>
<td>2761</td>
<td>0.36</td>
<td>248</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Planting Date</th>
<th>#</th>
<th>ha</th>
<th>NDVI</th>
<th>kg ha⁻¹</th>
<th>kg ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early &lt; Oct 1</td>
<td>1050</td>
<td>8492</td>
<td>0.38</td>
<td>279</td>
<td>5.6</td>
</tr>
<tr>
<td>Standard Oct 1-15</td>
<td>630</td>
<td>6183</td>
<td>0.36</td>
<td>206</td>
<td>4.1</td>
</tr>
<tr>
<td>Late &gt; Oct15</td>
<td>487</td>
<td>4713</td>
<td>0.30</td>
<td>128</td>
<td>2.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Planting method</th>
<th>#</th>
<th>ha</th>
<th>NDVI</th>
<th>kg ha⁻¹</th>
<th>kg ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerial</td>
<td>242</td>
<td>1404</td>
<td>0.31</td>
<td>139</td>
<td>2.8</td>
</tr>
<tr>
<td>Broadcast</td>
<td>100</td>
<td>651</td>
<td>0.32</td>
<td>155</td>
<td>3.1</td>
</tr>
<tr>
<td>Broadcast Stalk Chop</td>
<td>38</td>
<td>185</td>
<td>0.34</td>
<td>195</td>
<td>3.9</td>
</tr>
<tr>
<td>Broadcast Light Disk</td>
<td>659</td>
<td>5524</td>
<td>0.36</td>
<td>255</td>
<td>5.1</td>
</tr>
<tr>
<td>Conventional Drill</td>
<td>50</td>
<td>702</td>
<td>0.40</td>
<td>272</td>
<td>5.4</td>
</tr>
<tr>
<td>No-Till Drill</td>
<td>1078</td>
<td>10922</td>
<td>0.36</td>
<td>230</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Satellite + NCDL + Records
These data are preliminary and are subject to revision. They are being provided to meet the need for timely ‘best science’ information.
Remote sensing of winter cover crop performance

Forthcoming manuscript III (2014):

• Remote sensing to monitor cover crop adoption in southeastern Pennsylvania (Hively, Duiker, and McCarty, for Journal of Soil and Water Conservation)

- Landsat, SPOT
- National Cropland Data Layer
Geospatial toolkit for winter ground cover analysis

- ArcMap toolkit combine satellite imagery with cropland data to evaluate wintertime biomass on agricultural fields

Results are applied to adaptive management of winter cover crops and soil conservation.
Remote sensing to monitor cover crop adoption in southeastern Pennsylvania

- Identified multi-year trends in increasing use of cover crops
- Separated from effects of weather
- Results will be useful to agricultural conservation planners

These data are preliminary and are subject to revision.
Proximal Sensors

Using on-the-go proximal sensors linked with GPS

Work conducted at USDA-ARS Beltsville Agricultural Research Center
Proximal Sensors

Objective:
Evaluate the effective ranges of various reflectance indices for measuring the biomass, fractional ground cover, and nitrogen content of winter small grain cover crops.

Dataset:
Repeat sampling of five cover crop fields throughout the winter of 2012-13 (wheat, triticale, barley, rye, ryegrass)
- Surface reflectance (Crop Scan, Crop Circle, ASD)
- Percent ground cover (RGB photos, Sample Point)
- Aboveground biomass, N content, soil N (lab analysis)
- Satellite imagery (Landsat, SPOT)

PhD student in Geography, Kusuma Prabhakara, is writing up the analyses for her dissertation.
Proximal Sensors

Some results:

<table>
<thead>
<tr>
<th>Index</th>
<th>Wheat</th>
<th>Triticale</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDVI</td>
<td>0.970</td>
<td>0.890</td>
</tr>
<tr>
<td>GNDVI</td>
<td>0.960</td>
<td>0.890</td>
</tr>
<tr>
<td>SR</td>
<td>0.880</td>
<td>0.870</td>
</tr>
<tr>
<td>SAVI (L=1)</td>
<td>0.970</td>
<td>0.890</td>
</tr>
<tr>
<td>G-R</td>
<td>0.900</td>
<td>0.860</td>
</tr>
<tr>
<td>EVI</td>
<td>0.960</td>
<td>0.880</td>
</tr>
<tr>
<td>TVI</td>
<td>0.950</td>
<td>0.860</td>
</tr>
<tr>
<td>NGRD</td>
<td>0.920</td>
<td>0.920</td>
</tr>
<tr>
<td>VARI</td>
<td>0.920</td>
<td>0.920</td>
</tr>
<tr>
<td>NDREI</td>
<td>0.940</td>
<td>0.880</td>
</tr>
</tbody>
</table>

• Various indices are approx. equivalent in predicting biomass

• Species-specific growth curves linked to environmental endpoints

These data are preliminary and are subject to revision
Outcomes

Abilities

• Satellite imagery can be used to measure vegetated ground cover and biomass, eventually nitrogen content
• In Maryland, the state cost share program is adopting a geospatial management system
• In Pennsylvania (and elsewhere in the United States) the National Cropland Data Layer can be used to determine groundcover and winter biomass by crop type

What is missing?

• Nutrient application rates and yields
• Adapt-N and farm data to predict residual soil N
Remote Sensing of Cover Crop Performance

Acknowledgements:

• Thanks to Dan Jones and Kusuma Prabhakara for data processing. Antonio Pereira, Megan Parry for lab analysis, Maryland Department of Agriculture for ongoing collaboration

Funding:

• USDA-ARS Choptank River Conservation Effects Assessment Project
• National Fish and Wildlife Foundation – Innovative Nutrient and Sediment Reduction Grant Program
• USGS Priority Ecosystem Studies
• USGS Climate and Land Use Change