Evaluating and improving cover crop performance and adoption

W. Dean Hively
U.S. Geological Survey
Eastern Geographic Science Center
Winter cover crops for water quality

- Improve soil health
- 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
Use of winter cover crops can reduce nutrient and sediment loss to the Chesapeake Bay.

But, how much is captured? How much planted? 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.
Research strategy

- Use remote sensing to estimate winter ground cover, biomass and nutrient uptake on agricultural fields
- Combine remote sensing analysis with site-specific knowledge of agricultural field management
- Support conservation adaptive management, with a focus on winter cover crops
- Applications on farmland throughout the Chesapeake Bay watershed
Plants reflect brightly in the near infra-red (NIR) shown here as red.

- Evergreen forest
- Deciduous forest
- Winter cover crop
- Bare fallow
Plants reflect brightly in the NIR

Winter crops

No vegetation
Calculation of wintertime greenness

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

![Graph showing NDVI calculation]
Satellite vegetation indices

- Very accurate for within-image comparison of vegetation
- Some between-image calibration issues

Each image is a snapshot in time
What can be done with publicly available information?

- Use satellite imagery to map wintertime vegetative ground cover
- Use the USDA-NASS cropland data layer to identify summer crop type (corn, soy, hay, etc…)
- Combine these datasets to evaluate multi-year trends in wintertime agricultural vegetation
- Create reports at county or watershed scale
Satellite vegetation indices

- Very accurate for within-image comparison of vegetation
- Some between-image calibration issues

Each image is a snapshot in time
Biomass categories:

- **Min** = no cover crop; up to 10% light weed cover
- **Low** = cover crop early growth; groundcover <25%
- **Med** = good cover crop growth; groundcover >25%
- **High** = lush cover crop growth; groundcover >60%
Satellite vegetation thresholds

- Classification of satellite vegetation indices
- Fairly accurate but some calibration issues remains
National Cropland Data Layer (NCDL)

- Satellite-based maps of summer crop type by USDA-NASS
- Fairly accurate for large fields
- Annual maps
- 2008-present

This public dataset allows us to measure winter ground cover by crop type.
Winter vegetation by cropland type

- Combination of satellite vegetation index and crop map
- Uses only public data sources
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 study in Pennsylvania

2009-2012 wintertime groundcover analysis

Collaboration among USGS, USDA-ARS, Penn State, UMD
Without carrot or stick

- Penn State extension project promoting use of cover crops following corn silage harvest (best niche)
- Several years of on-farm trials, farmer field days, and farmer education and outreach
- Most active from 2010-2012
- Sjoerd Duiker, coordinator, funded by NFWF CIG
- Working from the theory that outreach can be more effective than incentives (the carrot) or regulation (the stick)

~ Can we measure the implementation results using remote sensing? ~
Windshield survey (Dec 2010)

Mapped routes driven by collaborators.

They scored fields for apparent vegetative ground cover and previous crop.

Data collection in December 2010.

Established a baseline, data also used for calibrating satellite imagery.

Nov 14, 2010 Landsat 5 image was used to match windshield survey data.
Windshield Survey (Dec 2010)

vegetative groundcover

previously crop type

0 = Minimal

1 = Low

2 = Medium

3 = High
# Windshield survey results

Windshield survey results for four Pennsylvania counties, December of 2010.

<table>
<thead>
<tr>
<th>Summer crop</th>
<th>Vegetative biomass category</th>
<th>Percent vegetated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n*</td>
<td>Minimal</td>
</tr>
<tr>
<td>Lancaster County</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All corn</td>
<td>65</td>
<td>24</td>
</tr>
<tr>
<td>Corn grain</td>
<td>31</td>
<td>18</td>
</tr>
<tr>
<td>Corn silage</td>
<td>34</td>
<td>6</td>
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<tr>
<td>Hay</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Soy</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>Lebanon County</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All corn</td>
<td>96</td>
<td>34</td>
</tr>
<tr>
<td>Corn grain</td>
<td>22</td>
<td>21</td>
</tr>
<tr>
<td>Corn silage</td>
<td>74</td>
<td>13</td>
</tr>
<tr>
<td>Hay</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Soy</td>
<td>48</td>
<td>35</td>
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</table>
NDVI threshold values for vegetative groundcover classes were established at minimal < low 0.29 < medium 0.40 < high 0.53.

More vegetation (higher NDVI) was observed following corn silage harvest (COS) relative to corn grain harvest (COG).

December 2010 Landsat 7 imagery
### Groundcover Tool Output

#### Lebanon, PA Landsat7 February 6th 2012

<table>
<thead>
<tr>
<th>Ground Cover Thresholds</th>
<th>Entire Area</th>
<th>Minimal Biomass</th>
<th>Low Biomass</th>
<th>Medium Biomass</th>
<th>High Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Entire Area</td>
<td>Minimal Biomass</td>
<td>Low Biomass</td>
<td>Medium Biomass</td>
<td>High Biomass</td>
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<tr>
<td></td>
<td>Area</td>
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<td>pct</td>
<td>pct</td>
<td>pct</td>
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<tr>
<td>Entire area of interest</td>
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<td>31077</td>
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<td></td>
<td>100.0</td>
<td>34.3</td>
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<tr>
<td>Deciduous Forest</td>
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<td>13403</td>
<td>20081</td>
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<td></td>
<td>41.3</td>
<td>35.8</td>
<td>53.6</td>
<td>9.4</td>
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<tr>
<td>Corn</td>
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<td>6771</td>
<td>4629</td>
<td>2906</td>
<td>1371</td>
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<tr>
<td></td>
<td>17.3</td>
<td>43.2</td>
<td>29.5</td>
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<tr>
<td>Other Hay</td>
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<td>3604</td>
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<td>Developed/Low Intensity</td>
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<td>1828</td>
<td>2799</td>
<td>1908</td>
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<td>2045</td>
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<td>24.5</td>
<td>39.8</td>
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<tr>
<td>Shrubland</td>
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<td>762</td>
<td>1968</td>
<td>1518</td>
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<tr>
<td></td>
<td>4.9</td>
<td>17.0</td>
<td>44.0</td>
<td>33.9</td>
<td>4.8</td>
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<tr>
<td>Soybeans</td>
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<td>1159</td>
<td>486</td>
<td>81</td>
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<tr>
<td></td>
<td>4.2</td>
<td>54.9</td>
<td>30.2</td>
<td>12.7</td>
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<tr>
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<td>1165</td>
<td>823</td>
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<td></td>
<td>2.6</td>
<td>11.6</td>
<td>48.8</td>
<td>34.5</td>
<td>5.2</td>
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<tr>
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<td>1093</td>
<td>407</td>
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<td>14</td>
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<tr>
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<td>2.0</td>
<td>60.5</td>
<td>22.6</td>
<td>7.1</td>
<td>0.8</td>
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<tr>
<td>Developed/High Intensity</td>
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<td>513</td>
<td>73</td>
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<td>2</td>
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<tr>
<td></td>
<td>1.2</td>
<td>47.5</td>
<td>6.7</td>
<td>2.1</td>
<td>0.2</td>
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</table>

Area of Interest shapefile name: LEBANON.shp
CLU shapefile name: _shp
NDVI image file name: LE70150322012037EDC00_toa_06_FEB_2012_NDVI_WGS84.tif
Cropland data file name: cdI_pa_2011_30m_utm18_8majBclean.tif
Multi-year trends in vegetative groundcover

Vegetation class

- Minimal
- Low
- Medium
- High

0 = Minimal 1 = Low 2 = Medium 3 = High

Lancaster

Lebanon
Multi-year trends in vegetative groundcover

**Vegetation class**
- Minimal
- Low
- Medium
- High

Berks

York

0 = Minimal  
1 = Low  
3 = Medium  
4 = High
Are the trends from weather?

Images depicted similar growing degree totals:

- Accumulated GDD (March 20, 2010) = 876
- Accumulated GDD (March 7, 2011) = 713
- Accumulated GDD (February 6, 2012) = 865
- Accumulated GDD (April 6, 2013) = 895

Date:

- Oct. 1
- Oct. 15
- Nov. 1
- Nov. 15
- Dec. 1
- Dec. 15
- Jan. 1
- Jan. 15
- Feb. 1
- Feb. 15
- Mar. 1
- Mar. 15
- Apr. 1
- Apr. 15
- May 1

Biweekly precipitation (cm):

- 0
- 2
- 4
- 6
- 8
- 10
- 12
- 14
- 16
- 18
- 20
- 22
- 24

GDD:

- 0
- 200
- 400
- 600
- 800
- 1,000
- 1,200
- 1,400
- 1,600
- 1,800
- 2,000
Are trends from weather?

Images depicted wintertime conditions prior to springtime ‘green up’
Results

- Remote sensing analysis was successfully applied to four PA counties where the ‘without carrot or stick’ cover crop projects was promoting the planting of cover crops after corn silage harvest.
- Detected 5 year trends in wintertime ground cover that were likely associated with farmer adoption of cover cropping practices.

Caveats

- Landsat 30m pixels were too large to measure strip cropped fields.
- Imagery coverage was insufficient for 3 of 7 counties.
Remote sensing to monitor cover crop adoption in southeastern Pennsylvania

W.D. Hively, S. Duiker, G. McCarty, and K. Prabhakara
Measuring cover crops in the field

Physical sampling of plants
- Biomass (fresh – dry weight = water content)
- Ground cover (% vegetation measured by beaded string, or RGB photo analysis, )
- Plant nitrogen content, C:N ratio
- Plant growth stage, tillering, etc…
Measuring cover crops in the field

Physical sampling of soils

- Nitrogen content (nitrate/nitrite), carbon content
  - Soil cores to 12” give N availability in surface horizon
  - Deep core sampling to groundwater (1-3m) gives N leaching profile
- Permeability, aggregate stability, soil health
Measuring cover crops in the field

Proximal reflectance sensors
- Greenseeker (G,R,RE,NIR)
- Crop Circle (G,R,RE,NIR)
- **Cropscan** (16 bands in visible-NIR)
- ASD (hyperspectral vis-NIR and SWIR)
- RGB cameras and cellphones
- Human eyeballs
Wintertime field reflectance spectra

Surface reflectance of triticale cover crops (CropScan, 16 bands)

Various band ratio indices can be calculated to measure vegetative biomass and ground cover (NDVI, etc…)

680nm chlorophyll adsorption feature (ASD)

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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

Kusuma Prabhakara\textsuperscript{a,}\textsuperscript{*}, W. Dean Hively\textsuperscript{b}, Gregory W. McCarty\textsuperscript{c}
Proximal Sensors

Some results:

Various indices are about equivalent

NDVI is a ok

Indices saturate at high growth

- ~2000 kg/ha biomass
- ~80% ground cover

Table 3: Goodness of fit associated with spectral index prediction of cover crop biomass

<table>
<thead>
<tr>
<th>Index</th>
<th>Wheat1</th>
<th>Barley2</th>
<th>Ryegrass</th>
<th>Triticale</th>
<th>Barley1</th>
<th>Rye</th>
</tr>
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<tbody>
<tr>
<td>r²</td>
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<td>0.960</td>
<td>0.970</td>
<td>0.900</td>
<td>0.900</td>
<td>0.900</td>
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<td>NDVI</td>
<td></td>
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<tr>
<td>GNDVI</td>
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<tr>
<td>SR</td>
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<td>SAVI (L=1)</td>
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<td>G-R</td>
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<td>EVI</td>
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<tr>
<td>TVI</td>
<td>0.950</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>NGRD</td>
<td>0.920</td>
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<td>NDREI</td>
<td>0.940</td>
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</tr>
</tbody>
</table>

Prabhakara et al., 2015 IJAEOG
Proximal Sensors

Some results:

Winter conditions can affect the relationship between biomass and NDVI

Prabhakara et al., 2015 IJAEOG
In-field instruments

- Linking sensors to biomass, vegetated ground cover
- Providing calibration for satellite interpretation

- Automated daily measurements of NDVI, PRI, and RGB photos
Catchment scale measurements – closing the N balance

- **Lysimiters** (buried in soil to detect N leaching)
- **Anion resin bags** (buried in soil to detect N leaching)
- **Stream weirs**
- **N isotopes**

![Image of a cornfield with a lysimeter]

**Graph:**
- **Continuous Corn, 140 lbs N / ac (30 plt + 110 sd)**
- **Groundwater nitrate-N (mg/L)**
- **Severe drought**
- **Started using rye winter cover crops**

*Staver and Brinsfield 1998*
Landscape scale measurements

Stream water monitoring ~ can we detect changes in water quality resulting from implementation of sustainable management practices?

- Continuous or synoptic sampling of stream flow and chemistry: nitrogen, phosphorus, sediment, agrichemicals, organic matter, stream health

Can we detect (and support) increased use of cover crop practices?
Landscape scale measurements

Mapping winter groundcover
- Windshield surveys
- Farmer surveys
- Cost-share implementation data
- Remote sensing imagery analysis
Cropland remote sensing analysis

Satellites (also planes and UAV’s)
- Reflectance measurements of plant growth: biomass, groundcover, N content, canopy structure

Winter groundcover analysis (Landsat, SPOT, Worldview)
- Detected multi-year trends in PA (Hively Duiker et al.)
- Similar project in NY (Cortland SWCD CIG grant)
- Similar applications in Showcase Watersheds (PA, MD, VA) and on the Eastern Shore
- The groundcover tool is available and relatively easy to apply in ArcGIS, our calibration research is ongoing
Remote sensing study areas

- 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
Satellite Imagery
Landsat, SPOT, Worldview3 imagery

- Sometimes cloudy, sometimes clear
- Each image is a snapshot in time
- Fairly accurate mapping of agricultural vegetation
- We are most interested in mid-winter and early spring
Winter crops
No vegetation

Plants reflect brightly in the NIR
Overlap with winter cover crop farm enrollment data records

This normally private information was released to the public by the collaborating farmer.

Cover Crop Species
- Wheat
- Rye
- Barley
- Radish
- Canola
- Spring Oat

A collaborating farm
Talbot County, Maryland

Barley 2.5 bu/ha
No-till drill
9/14/2010 after Corn

Barley 2.5 bu/ha
No-till drill
9/17/2010 after Corn
What factors affect cover crop success?
These data are preliminary and are subject to revision. They are being provided to meet the need for timely ‘best science’ information.
Link performance to climate

These data are preliminary and are subject to revision. They are being provided to meet the need for timely ‘best science’ information.
These data are preliminary and are subject to revision. They are being provided to meet the need for timely ‘best science’ information.
**Summarize cover crop performance**

(2005-6 data from Hively et al., 2009)

These data are preliminary and are subject to revision. They are being provided to meet the need for timely ‘best science’ information.
### Analysis (example data for Jan 6th, 2011)

#### Satellite + NCDL + Records

Assuming 2% N content for all cover crops. Data for use as example only. 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>
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</thead>
<tbody>
<tr>
<td></td>
<td>#</td>
<td>ha</td>
<td></td>
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<tr>
<td>Wheat</td>
<td>1726</td>
<td>15039</td>
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<tr>
<td>Rye</td>
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<td>Barley</td>
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<td>Planting Date</td>
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<tr>
<td>Early &lt; Oct 1</td>
<td>1050</td>
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<td>Late &gt; Oct 15</td>
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<td>No-Till Drill</td>
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<td>0.36</td>
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</table>

DRAFT

USGS

These data are preliminary and are subject to revision. They are being provided to meet the need for timely ‘best science’ information.
Adaptive Management of Winter Cover Crops

- Target low-productivity fields for site visits
- Produce county/watershed reports for local partners
- Provide field-specific information to farmers
Green is good

But is greener always better? When/where are nutrients in excess? Where are the best cover crops?

Is there a lower threshold for cover crop success?
How do we define success?

- Successful strategies fit in with climate and farming systems
- Awareness of constraints and opportunities
- Experimentation and sustainability

Carrots, sticks, knowledge, and experience
Scientific challenges

- Inter-image variability in index threshold values and (in)stability of calibration equations: Is surface reflectance consistent? Are some indices more stable?
- How much collection of calibration data is necessary and how can we supply it?
- How does small grain phenology and reflectance change over the wintertime and into the spring?
- What is the best time of year for analysis, and can we consistently obtain good imagery at that time?
Communicate results to farmers/stakeholders

Provide timely information to influence crop management and supporting adaptive management

Link mapped outcomes to successful management practices (use of robust cover crops within diverse crop rotations)

Support the growth of cover crops, soil health, and sustainable agriculture

Your suggestions are welcome!
Thank you! ~ Questions?

W. Dean Hively, Research Physical Scientist
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