**CHESAPEAKE BAY FOUNDATION**
*Saving a National Treasure*

November 20, 2015

Mr. Noller Herbert
Director, NRCS Conservation Engineering Division
USDA Natural Resources Conservation Service
1400 Independence Avenue, SW,
Room 0103-S, Washington, D.C. 20205

RE: National Conservation Innovation Grant Program grant # 69-3A75-11-136

Dear Mr. Herbert:

Please find attached our final narrative report for our CIG grant, *Estimating Nitrous Oxide Reductions from Nutrient Management in the Chesapeake Watershed.* Thank you again for granting an extension on this report, which allowed our team the additional time needed to ensure its accuracy. The final invoice was sent under separate cover in October.

If you have any questions regarding the report or its findings, please feel free to contact Dr. Beth McGee at (443) 482-2157. Thank you very much.

Kind regards,

Lauren Robinson

Lauren E. Robinson
Manager of Public Funding and Grants
Chesapeake Bay Foundation

Enclosures

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THE CHESAPEAKE BAY FOUNDATION'S
FINAL REPORT
FOR
THE U.S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE

**November 20, 2015**

<table>
<tr><td colspan="2">Project Title: Estimating Nitrous Oxide Reductions from Nutrient Management in the Chesapeake Watershed</td></tr>
<tr><td colspan="2">Agreement Number: #69-3A75-11-136</td></tr>
<tr><td colspan="2">Project Director: Beth McGee</td></tr>
<tr><td>Contact Information:<br>Chesapeake Bay Foundation<br>6 Herndon Avenue<br>Annapolis, MD 21403</td><td>Phone Number: 443-482-2157<br>E-Mail: bmcgee@cbf.org</td></tr>
<tr><td colspan="2">Grant Period: August 1, 2011 – July 31, 2015 (one year extension)</td></tr>
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**Proposed Project Deliverables:**

1. Enhanced nutrient management on 6,400 acres of corn and 900 small grains over two growing seasons
2. A user-friendly version of the DNDC model that includes underlying regional soil and climate databases and a simple user interface
3. Quantification of carbon offset credits associated with nutrient management projects.
4. A Greenhouse Gas Project Plan that is submitted to the American Carbon Registry (ACR)
5. Carbon offset credits certified on the ACR
6. Three workshops to educate farmers and technical assistance providers on carbon markets and potential use of DNDC model and ACR protocol
7. Final report summarizing farmer participation, credit certification and lessons learned.

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## EXECUTIVE SUMMARY

The goal of this three-year project was to encourage adoption of enhanced nutrient management techniques by facilitating the process by which Chesapeake Bay farmers can participate in, and financially gain from, carbon offset markets. Specifically, the main objective was to calibrate and develop a region-specific, user-friendly version of the Denitrification-Decomposition (DNDC) model and use it to estimate the nitrous oxide emissions reductions associated with different nutrient management approaches: soil testing/adaptive management on farms in South Central Pennsylvania and variable rate technology (i.e., GreenSeeker) on grain farms on Virginia's Eastern Shore. This project allowed us to compare and contrast these approaches in terms of greenhouse gas benefits, nitrogen application reductions, and obstacles to greater implementation. In addition, our hope was to certify resulting carbon credits in the American Carbon Registry (ACR). A unique aspect of this project was the leveraging of dollars from a partnership that the Chesapeake Bay Foundation (CBF) has with WGL Energy (formerly known as Washington Gas Energy Services) and Sterling Planet (SP), whereby WGL Energy and SP are donating some of the proceeds from the sale of carbon offsets to WGL customers into a Carbon Reduction Fund (CRF) that CBF uses for projects that benefit water quality and reduce greenhouse gases.

***<u>Successes:</u>***

- The DNDC model was calibrated for corn, rye, soy and wheat rotations in this region using a long-term dataset from a USDA-Agriculture Research Service Project in Beltsville, MD. In addition, we developed a web-based, user-friendly interface for DNDC that contains an entry portal for farm and crop management data; a Web-GIS interface for digitizing of farm fields; and automatic extraction of soil and weather data.
- The project resulted in the implementation of more than 2,000 acres under adaptive nutrient management in Pennsylvania and roughly 14,000 planted acres [1] (over 5 years) under variable rate technology (GreenSeeker) in Virginia (VA).
- The project succeeded in quantifying emission reductions from the implementation of the GreenSeeker. We were able to run DNDC model scenarios consistent with the ACR protocol and demonstrate the potential of this nutrient management approach to generate certifiable carbon credits. We are currently exploring the possibility of investing additional CRF funds to incentivize use of GreenSeeker and seek credit certification in the ACR.

***<u>Challenges</u>***

- Obtaining the necessary level of historic farm management data (~previous 5 years) to calibrate the DNDC model and to establish a reliable baseline proved to be a major challenge to nutrient management carbon credit generation. The Carbon registries should continue to pursue options that will reduce the need for farm-specific information regarding baseline.
- We had difficulty determining if the project met the requirements for additionality under the ACR protocol. In particular, since implementation of GreenSeeker was incentivized by supplemental EQIP dollars, we were unsure if the financial implementation barriers

[1] Note "planted acres" are more than "available acres" since typically a farmer plants more than one crop in a season.

faced by the project were solely overcome as a result of carbon market incentives. The GreenSeeker technology has the potential to be a viable credit generating approach. For one, the change between baseline and project scenarios is distinct. Second, the approach not only can reduce nitrogen application rates, but also nutrient use efficiency, resulting in less nitrogen emissions to air and water.

- Nitrous oxide (N2O) emissions factors for VA farms was quite low, likely due to soil types in this area. Consequently, soil properties should be used as a screening tool for potential carbon projects such that one could better target areas likely to have higher baseline N2O emissions and, therefore, more potential for emissions reductions.
- Model transparency is important for acceptance in ecosystem service markets. The outcome from this project and others, and discussed through the C-AGG process, highlighted the need for easier access to the DNDC science and model and a need to be able to integrate the DNDC model into offset project decision support tools.

## BACKGROUND

CBF has a partnership with WGL Energy and SP whereby WGL and SP donate some of the proceeds from the sale of carbon offsets into a CRF that CBF manages. The purpose of this fund is to implement projects, primarily with agricultural producers, which generate certified carbon offset credits while also reducing water pollution to the Chesapeake Bay. This innovative fund presents an opportunity for the Chesapeake Bay region's agricultural producers to participate in the nascent carbon markets. It also highlights some of the challenges of certifying credits generated via agricultural projects.

Many agricultural best management practices can yield greenhouse gas benefits, such as planting cover crops, grassed and forested buffers, no-till, nutrient management, and anaerobic digesters, to name a few. However, only a small subset of these practices can generate carbon credits that would currently be eligible to be certified and registered on the voluntary carbon registries available in the U.S. (i.e., American Carbon Registry, Voluntary Carbon Standard, and Climate Action Reserve). A significant challenge is that the registration process necessitates the use of an existing methodology or standard that has been approved by that registry. That list, for agricultural practices, is relatively small. In addition, some of the protocols are expensive and complicated to implement.

The list of eligible practices includes: afforestation, forest management, nutrient management, and animal waste management such as methane digesters and manure lagoon covers.
Of these approaches, we have targeted CRF investment to afforestation and nutrient management projects because of the clear benefits to reducing greenhouse gases and improving water quality. Of these two, advanced nutrient management probably has the greatest potential for scaling up in the Chesapeake watershed.

There are several different ways that farmers can better utilize applied nitrogen, thereby reducing nitrogen application rates. These approaches include the use of innovative precision farming technology, such as GreenSeeker,™ nitrogen or manure injection, and the use of corn stalk nitrate tests and other tools that lead to better nutrient management. Less applied nitrogen results in lower emissions of N2O, a very potent greenhouse gas.

The goal of the project was to encourage adoption of enhanced nutrient management techniques by facilitating the process by which Chesapeake Bay farmers can participate in, and financially gain from, carbon offsets markets. At the beginning of this project, there were two approved, or soon to be approved, methodologies that could be used to quantify the reductions in N2O emissions due to nutrient management.

One methodology requires projects outside of the Upper Mississippi to use the Intergovernmental Panel on Climate Change default emissions factor i.e., N2O emissions/reductions would be calculated to be one percent of the nitrogen fertilizer applied/reduced. In the Chesapeake region, we believed that in many areas N2O emissions would be a higher percentage of the applied nitrogen than this default factor. The relationship between applied nitrogen and N2O emissions is non-linear, that is, as more fertilizer is applied, the fraction of the additional fertilizer that is lost as N2O increases (McSwiney and Robertson 2005). Furthermore, many factors such as fertilizer type, rate, timing, placement, residue management and soil type affect N2O emissions. These factors are not considered in the methodology focused solely on reducing rate of application.

The second approach, approved by the American Carbon Registry (ACR), uses the DeNitrification-DeComposition (DNDC) model to estimate N2O emissions. The DNDC model estimates, for baseline and project scenarios, direct N2O emissions from fertilizer use and indirect emissions from leaching and ammonia volatilization. DNDC is a peer-reviewed and tested simulation model of carbon and nitrogen biochemistry in agro-ecosystems (Li et al. 1992; Li et al. 1994; Li 2000; Li 2007). This approach would give site-specific numbers, but it requires substantial amounts of data and local calibration to run the model, potentially leading to higher transaction costs. That said, if the amount of N2O emissions reductions were doubled or even tripled, the cost associated with the carbon credits would be cut in half or more. In addition, the ACR protocol is flexible in that the DNDC model tracks the full nitrogen balance, so it can estimate N2O emissions reductions not only from changes in application rates, but also due to other influencing factors such as method and timing of application.

## INTRODUCTION

CBF was the lead on an NRCS Conservation Innovation Grant (CIG) through the Greenhouse Gas (GHG) initiative with the main objective of creating a tool that will help reduce some of the technological and financial barriers to certifying carbon offset credits generated by nutrient management projects in the Chesapeake watershed. Specifically, our project involved calibrating and modifying the DNDC model so it is applicable in the Chesapeake region and is more user-friendly. We then applied the model to assess the greenhouse gas benefits of different nutrient management approaches. Our original project partners included: Environmental Defense Fund, Maryland Department of Agriculture, Virginia Tech, DNDC Applications, Research & Training LLC (model development); USDA ARS Beltsville Lab (provided data for model calibration); EcoFor LLC (consultant in GHG offset verification) as well as Sterling Planet and WGL Energy, who provided private dollars related to the sale of carbon offsets.

Our initial proposal included three nutrient management approaches to be implemented in three locations: soil testing/adaptive management on corn farms in the Upper Chester River Watershed led by the Environmental Defense Fund (EDF), manure injection in western and central Maryland led by the Maryland Department of Agriculture (MDA), and variable rate technology (i.e., GreenSeeker) on grain farms in Virginia's Onancock Creek watershed led by Virginia (VA) Tech that capitalized on an existing CBF grant. As detailed below, however, we made some changes during the grant period to the geography and approaches that were included.

One of the desired outcomes of this project was to gain a sense of whether or not we should consider investing future CRF funds in nutrient management projects, and if so, which approach was the most viable in terms of costs and greenhouse gas benefits.

Specific objectives of the project were to:

- Implement enhanced nutrient management on approximately 7,300 acres of cropland.
- Calibrate and validate the DNDC model for cropping systems in the Chesapeake Bay watershed.
- Create a more user-friendly version of DNDC model by developing the underlying regional soil and climate databases and a user-friendly interface.
- Apply the DNDC model to advanced nutrient management projects on participating farms, with EQIP-eligible producers, to determine the potential for carbon offset credits.
- Prepare and submit a Greenhouse Gas Project Plan to the ACR.
- Conduct three workshops to educate farmers and technical service providers on the pilot project, carbon markets and potential use of the ACR protocol and DNDC model.
- Achieve third party certification and validation of credits.
- Compare and contrast the greenhouse gas benefits and implementation costs of three different nutrient management approaches.

## FINDINGS

Below we provide details for how these objectives were, or in some cases were not, achieved and why.

**Implement enhanced nutrient management on approximately 7,300 acres of cropland**
*As of December 2014, this project has resulted in the implementation of more than 2,000 acres under adaptive nutrient management in Pennsylvania and more than 10,000 acres using variable rate technology (GreenSeeker) in VA.*

Details

Early in the grant period, NRCS granted a modification to our grant agreement to eliminate the manure injection component when it became clear that MDA would not be able to deliver on this portion of the project. In addition, EDF decided to work with farmers in Pennsylvania (PA) instead of Maryland. CRF funds were used in PA to cover most of the costs of implementing adaptive nutrient management on roughly 2,000 acres, including soil and corn-stalk sampling, data analysis, and consultations with producers.

CBF worked with NRCS state offices and project partners in both VA and PA on screening criteria and outreach for the EQIP dollars dedicated to support the CIG. We were particularly successful in VA where eight farmers requested nearly $1 million to implement GreenSeeker between 2013 and 2015. In PA, we had one farmer agree to adopt adaptive nutrient management on roughly 100 acres during 2014-16.

In addition, this grant leveraged an existing grant that CBF received from the National Fish and Wildlife Foundation (NFWF), in which we sought to promote GreenSeeker by purchasing three units for use by commercial applicators. As a result of both grants, between 2012 and 2016 14,154 acres on the Eastern Shore of VA used or have contracted to use GreenSeeker on a combination of barley, corn, and wheat via one of three commercial fertilizer applicators. Most of these acres were funded by the EQIP dollars dedicated to GHG CIG projects. In addition, it is worth noting that each farmer that participated agreed that the technology is viable and they would continue to use the technology in the future as available. In fact, five VA producers expressed interest in purchasing their own GreenSeeker system and partnered with VA Tech on a 2013 USDA-NRCS Conservation Innovation Grant submission; which would have required 50% cost-share to purchase their own unit (~$16,000 to $22,000 per unit cost-share, depending on their current equipment configuration). Although the grant was not funded, this activity demonstrated that farmers are now aware and more supportive of variable rate nitrogen application technology in VA as a result of both this grant and the related NFWF one.

**Calibrate and validate the DNDC model for cropping systems in the Chesapeake Bay watershed.**
*The project collaborated with Dr. Michel Cavigelli, ARS Soil Scientist at Beltsville Agricultural Research Center, and Carlos Freitas (visiting Scientist from EMBRAPA) to use a long-term dataset from Maryland to calibrate the DNDC model.*

<u>Details</u>
Dr. Cavigelli is the Project Lead Scientist for the long-term cropping systems trial, called the Beltsville Farming Systems Project (FSP). FSP was established to evaluate the sustainability of organic, no till, and chisel till cropping systems. The FSP is currently comprised of five cropping systems (three organic and two conventional systems) that differ in tillage, nutrient source, weed control method, and crop rotation. All agricultural plots are 0.1 ha in size (9.1 m x 111 m) and all are managed using full-sized farming equipment. Soils at the site are well-drained, moderately-well drained, and somewhat poorly drained Ultisols. Soils are similar to those found in some areas of the Eastern Shore of Maryland, an area where much of the feed grain for the Delmarva chicken industry is grown. Average rainfall in the area is 1110 mm $y^{-1}$, evenly distributed over the year, and average temperature is 12.8 $^{o}$C. The FSP goal was to evaluate the sustainability of the five systems by measuring agronomic performance, soil quality, nutrient dynamics, soil biological activity and community structure, and economic viability of the cropping systems."[2]

Using data from the FSP project and in collaboration with Drs. Cavigelli and Freitas, we compiled measurements of daily N2O fluxes, soil temperature and soil moisture (WFPS) and crop yields for the 24 different site treatments and blocks over a 3 year period (2005-2007). These field measurements covered years of data for 72 sites (24 blocks with annual measurements over 3 years). DNDC was calibrated against crop yields and then validated for soil moisture, soil temperature and daily/season N2O fluxes. The results of this calibration and validation work has yet to be published, but will once the field data have been published.

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[2] The Beltsville Farming Systems Project; Project Number 1265-21660-002-00D. See http://www.ars.usda.gov/News/docs.htm?docid=8816 for more information.

The validation results showed that DNDC generally captured the timing and magnitude of measured N2O peak fluxes (Figure 1). However, the model missed some extended peaks in a few of the organic treatments (Figure 2).

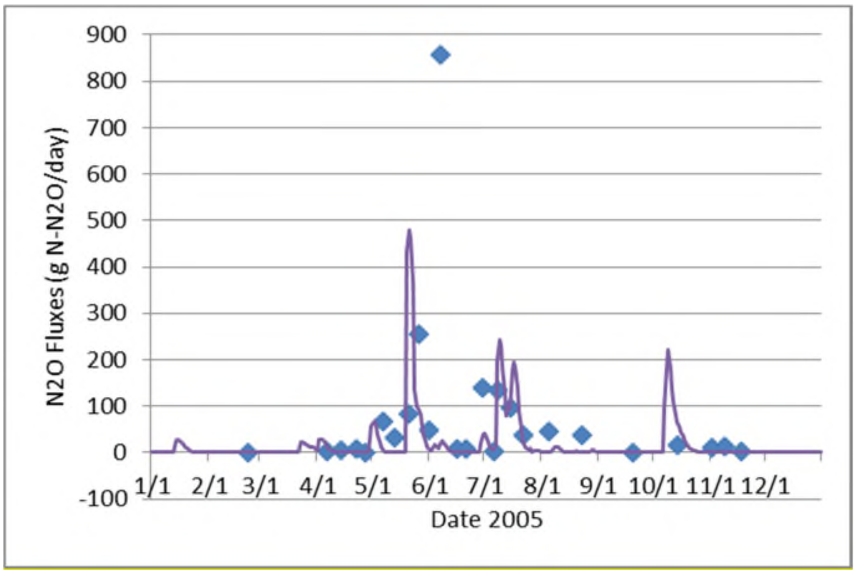


*Figure 1. DNDC Validation for no-till system in 2005 at FSP.*

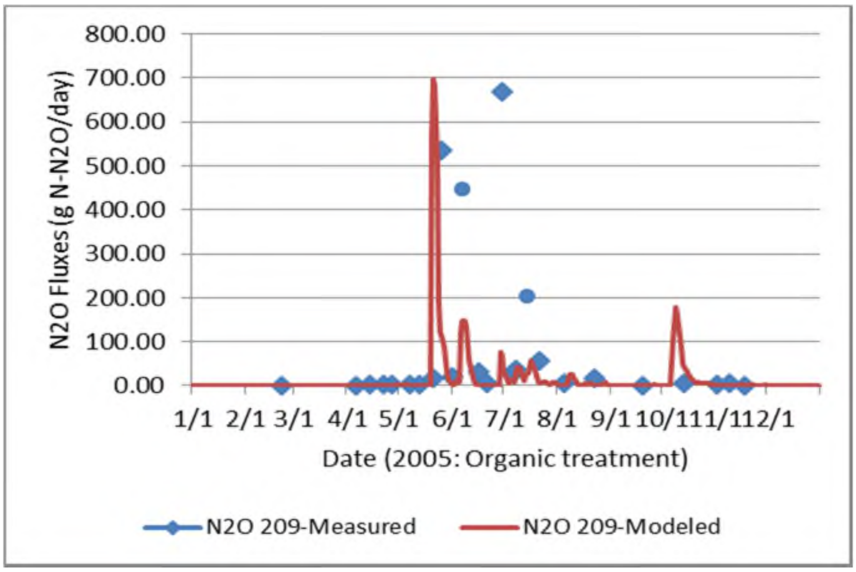


*Figure 2: DNDC validation for organic amendment system in 2005 at FSP*

**Create a more user-friendly version of DNDC model by developing the underlying regional soil and climate databases and a user-friendly interface.**
*A web-based user interface was built and used to accept information from researchers at VA Tech and technical consultants at Team Ag, a partner of EDF's working with producers in PA.*

Details
DNDC is a data-intensive model requiring potentially hundreds of data points and inputs for the simulation of any given field. The model does have a graphical user interface (GUI), however, that GUI is built to handle a multitude of potential crop management scenarios (including wetland crop management for such as rice, livestock grazing, perennial crops, and greenhouse crop production). Hence, our goal for this phase of the study was to build a tool whereby project partners could enter data on farmers, fields, and crop management in a database structured for annual upland crop management in the US. The tool would then automatically extract data from NRCS soil database and daily weather data (PRISM and weather stations) and process the data into DNDC input formats.

VA Tech (VT) and Team Ag acquired historical crop management data from numerous farm fields (>200) for several years (2-6). The tool was designed and built with their input and they entered the data based on their records. This effort became the final database which we used to support the DNDC simulations.

Features
The application has five major features:
1. Entry portal for farm and crop management data
2. Summary report of crop management
3. Web-GIS interface for digitizing farm fields
4. Automatic extraction of SSURGO soil data
5. Automatic extraction of weather data

Technical Background
The application's underlying database is built using Python/Django and stores the data in a PostgreSQL relational database. This framework facilitates the implementation of the web application using the conventional model-view-controller methodology. Each activity is represented as a separate model for which views exist (as a web form, for example) and which can be processed and saved to PostgreSQL for permanent storage. Additionally, PostGIS spatial extensions to PostgreSQL allow the storage of polygon locations as part of the model, which can be used later for integration with spatial soil and climate datasets.

In addition to managing user account and authorization data, the database stores farm information using the following hierarchy:
- **Landowner** (farmer): has one or more *parcels*
- **Parcels** (farm fields):
  - have one or more crop management *scenarios* (facilitates the comparison of multiple management options)
  - have a single set of soil attributes (clay content, organic matter content, bulk density, pH)

- **Scenarios** (crop management): have *activities* that define how the associated parcel is managed
- **Activities** include**:**
    - Cultivation (tillage)
    - Planting a crop
    - Harvesting a crop
    - Organic amendment (manure application)
    - Fertilizer application (synthetic N)
    - Irrigation water application
    - Crop cutting (for biomass removals not associated with a terminal harvest)
- **Crop parameters**: crops have characteristics (yield potential, water use efficiency, etc.) associated both with DNDC's input requirements and user-specified inputs (e.g. yield)
- **Soil attributes**: SSURGO soil attributes are extracted and stored for use as inputs into DNDC

Any data stored at the application is private and not shared outside of Applied Geosolutions, LLC.

<u>User Experience</u>
After registering an account, a user can add farm data starting with landowners (farmers). The application stores basic landowner information such as name and location. The following figures (3-7) illustrates the user experience and steps for entering field locations and crop management data for running the DNDC model. New parcels (farm fields) can be added either via on-screen digitizing or by uploading vector boundary data in ESRI shapefile format (Figure 3). The application's web-GIS interface includes a slippable Google Map background, navigation tools (pan, zoom, address search), and digitization tools (draw polygon, edit vertices). Parcel maintenance tools offer the ability to show, hide, and delete parcels as well as indicate whether or not data entry is complete.

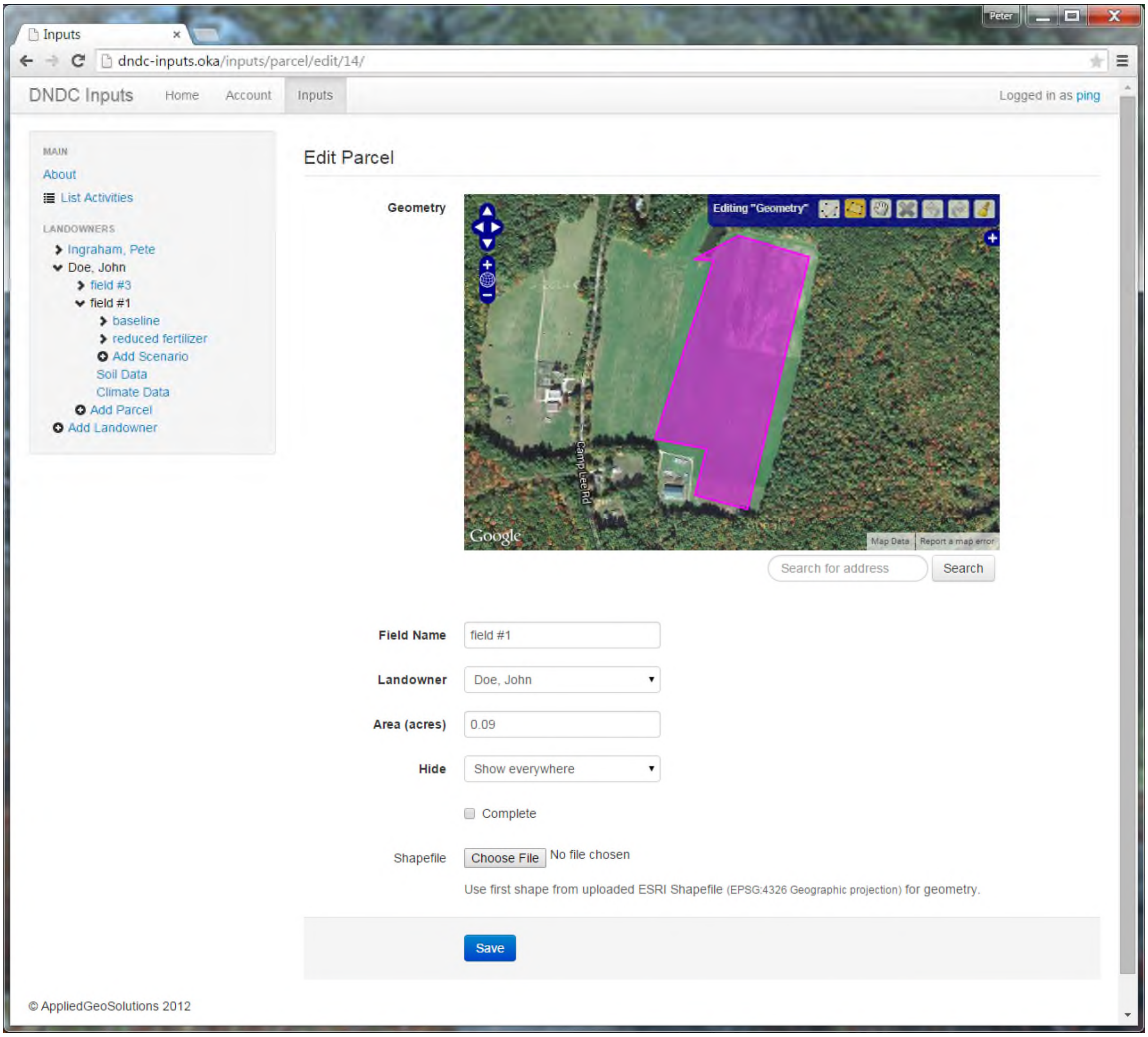


*Figure 3. Adding a new parcel*

Once a parcel is created, the application automatically extracts soil and weather data. This figure shows the parcel soil parameter interface (Figure 4). The tool automatically extracts, performs area weighting when individual fields cover multiple soil polygons, and stores SSURGO soil attributes – users can override SSURGO-modeled soil attributes by manually entering their own data.

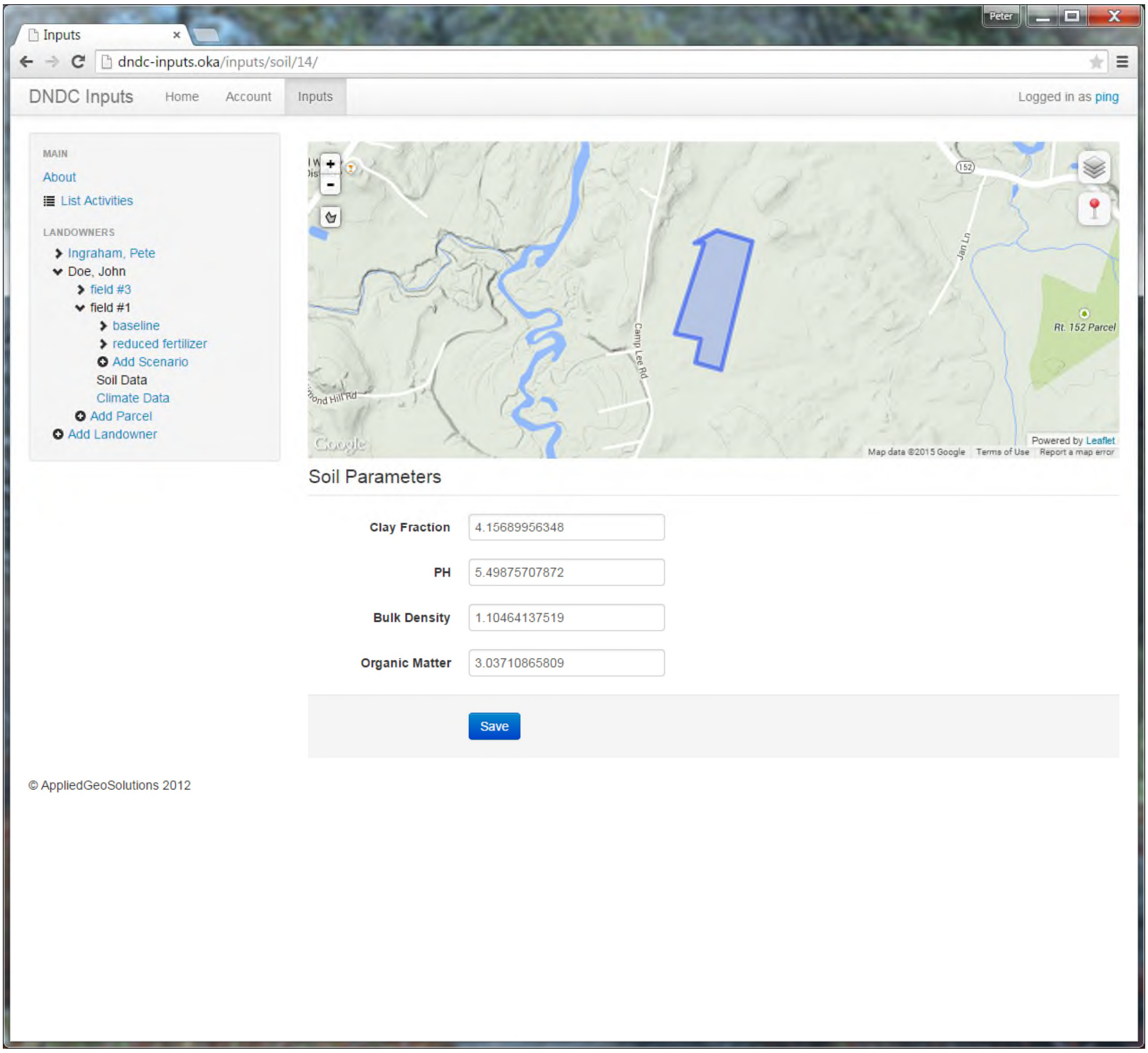


*Figure 4: Automatic extraction of soil data*

The application also extracts weather data automatically from one of numerous user-specified sources: the default source is the PRISM reanalysis product (PRISM 2015) however, based on availability at nearby weather stations, the application can also extract Weather underground user data and airport weather station data (Figure 5). Data can be downloaded in DNDC-required format (tab-delimited text files by year).

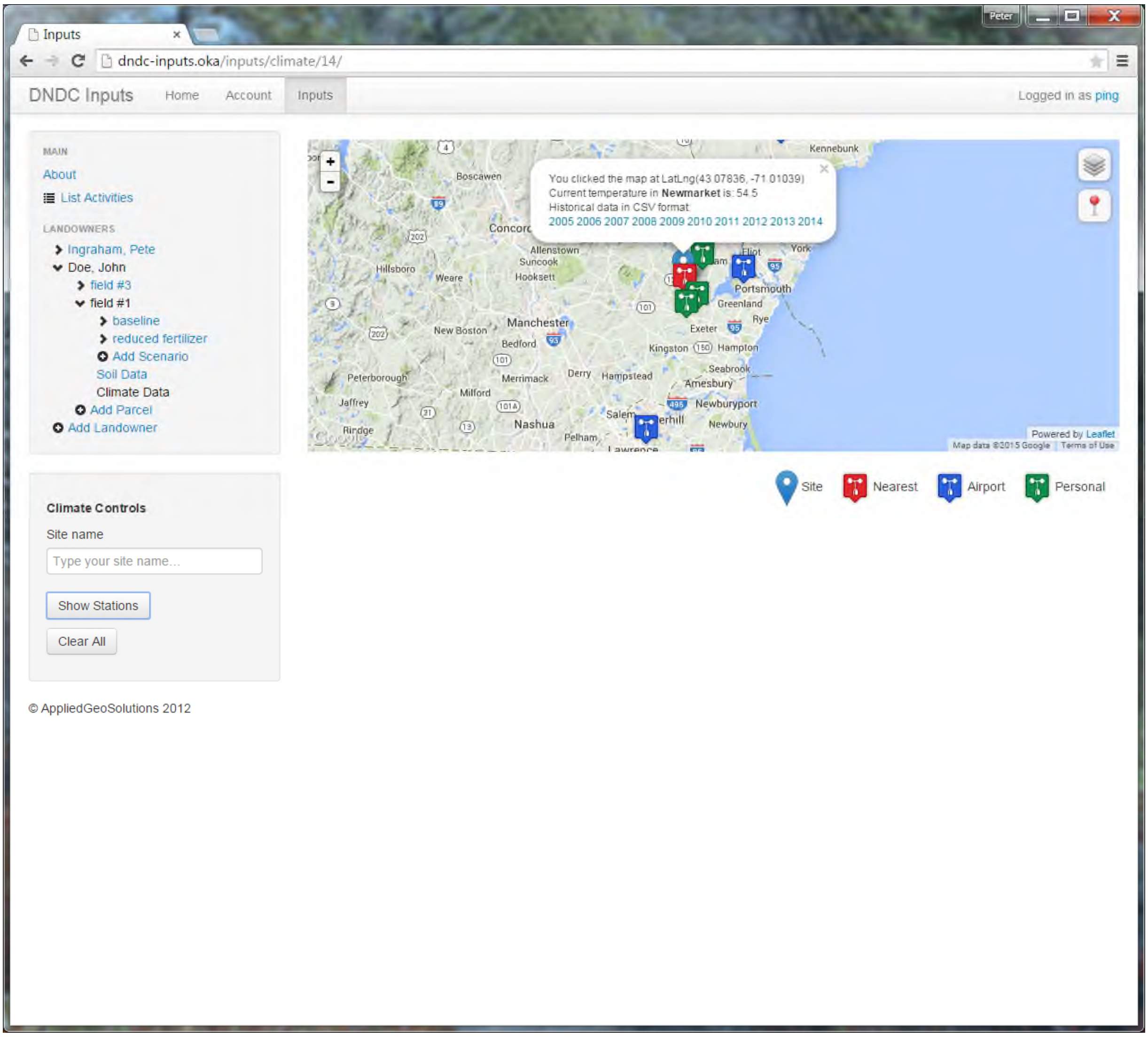


*Figure 5: Automatic extraction of weather data*

Once a user has created a parcel, one or more crop management scenarios can be established for a parcel. In the case that the user is interested only in a simulation of baseline conditions, a single scenario will suffice; in cases where multiple scenarios will be compared, scenarios (once complete) can be copied and adjusted to suit the particular needs of the study.

Specific crop management activities make up a scenario. Activities are associated with a single date and generally represent a specific agronomic action. Figure 6 shows an example of the data entry page for an activity: in this case, a fertilization. Note that the application includes an intuitive navigation tree at the upper left which lists activities, landowners, parcels, scenarios, and activities in chronological order.

Once a scenario and its activities are complete, they can be listed in report form and exported for use outside of the application (Figure 7).

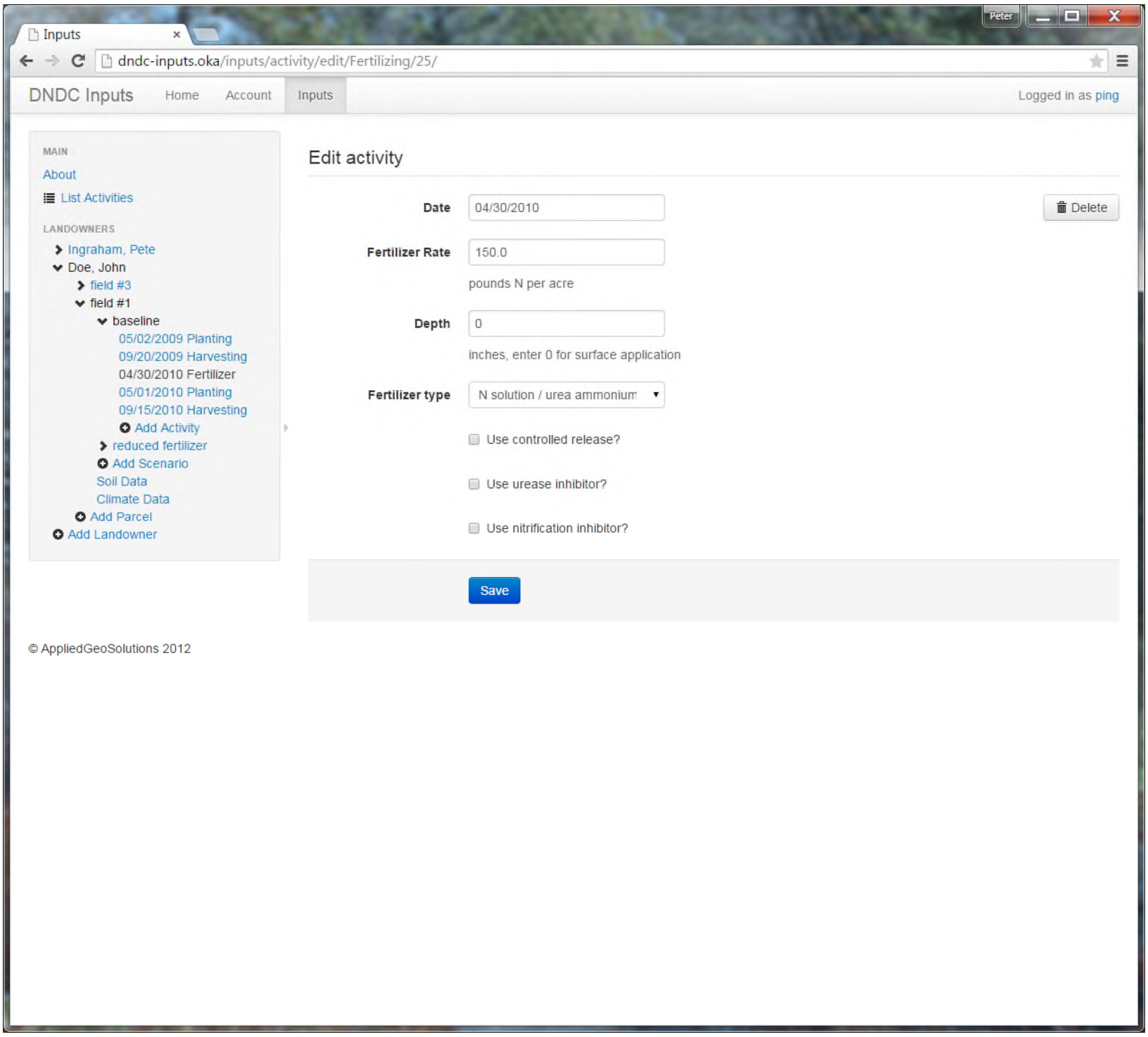


*Figure 6: Adding a new crop management activity (synthetic fertilizer application)*

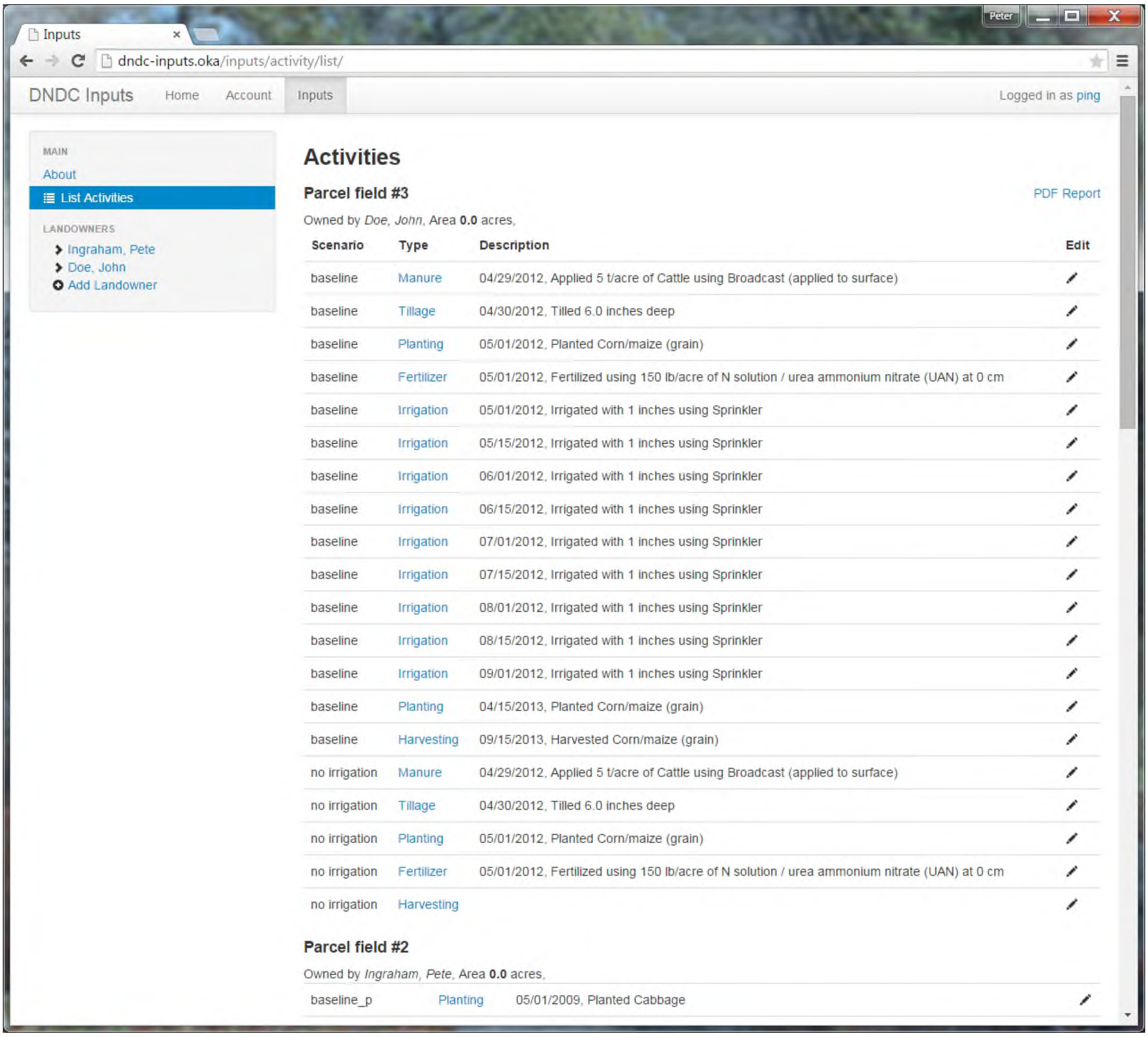


*Figure 7: Activity report*

The application includes a system of internal logical checks (for instance, planting and harvest events are related such that a crop cannot be harvested twice or harvested when not planted). A set of warnings indicate when missing data needs to be entered to facilitate a more smooth data entry process (for instance, planted crops with no specified harvest and tillage activities that take place after planting but prior to harvesting are flagged).

At this time, the application does not feed data directly to DNDC. However, we built a set of Python scripts which translates a database dump into a DNDC-accessible format for batch simulation.

Improving DNDC Model Transparency
In addition to lessons learned about making it easier to use DNDC for quantification of emission reductions, through this project we found that model transparency is important for acceptance in ecosystem service markets. The outcome from this project and others, and discussed through the C-AGG process, highlighted the need for easier access to the DNDC science and model and a need to be able to integrate the DNDC model into offset project decision support tools.

There are well over 200 peer reviewed publications on the DNDC model. However, beyond the traditional set of DNDC users in academia and national research centers, over the past decade there has been a significant increase in the demand for DNDC applications by a growing set of stakeholders that are interested in the development of decision support tools for assessing agricultural management impacts on ecosystem services. This interest was seen through the selection of several CIG grant projects focused on use of DNDC as a tool for GHG markets. Uptake and adoption of DNDC by these stakeholders has been hampered because the code has not been available through open source code repository and, like most research code, the code is difficult to understand due to the design. Re-writing the DNDC code into engineering code framework, and provision as an open source project will enhance the availability of DNDC science to a broader set of stakeholders and preserve the science in DNDC to support future development of decision support tools for understanding complex nutrient cycling and environmental performance of agro-ecosystems.

This CIG project contributed to a community effort to:

1. Improve model transparency through documentation of the DNDC scientific algorithms
2. Enhance use and potential for improvement of DNDC code by rewriting the model in to a modern codebase with modular components and infrastructure.
3. Expand access, use and development of DNDC model by releasing the code as an open source project.

**Apply the DNDC model to advanced nutrient management projects on participating farms, with EQIP-eligible producers, to determine the potential for carbon offset credits.**
*We used the DNDC model to estimate N2O emissions and nitrogen leaching from participating farms with EQIP eligible producers in PA and VA during the project period. In VA, we were able to discern a difference between the baseline and project scenarios and estimate potential carbon offset credits from using GreenSeeker. We were not able to discern a change in nutrient management among the PA farmers, nor a corresponding change in N2O emissions. In addition, for reasons noted below, we have varying levels of confidence in the model outputs.*

Details
As reported in our semi-annual reports, one of the biggest challenges of this grant was obtaining the necessary information to run the DNDC model – particularly, the historic (e.g., previous 5 years) data needed to reliably establish a baseline and to calibrate the model. This challenge was particularly acute in PA. Through EDF, we worked with Team Ag, an agricultural consultant who enrolled farmers in the adaptive management program and also helped obtain the data. We even modified our grant agreement to provide the necessary funds for Team Ag, to work with six farmers currently enrolled in the adaptive nutrient management program and help them go through their records to obtain the information necessary to run the DNDC model. Despite these efforts, there were still sizable gaps in the provided data and so the DNDC modelers

needed to make some assumptions to fill in these gaps. Due to this uncertainty in model inputs, we do not have a great deal of confidence in the modeling results.

The other challenge in PA was that the farmers chosen to participate by EDF/Team Ag were ones who had already been involved for years in their “farm stewardship” program, which was promoting adaptive management and better use of soil and corn stalk testing to determine nutrient application. As noted earlier in our semi-annual reports, this approach would likely result in a gradual improvement in nutrient use efficiency over time. As a result of this, and the high variability and uncertainty in the model output due to significant uncertainty of model inputs, we were not able to detect any systematic changes in N2O emissions or nitrate leaching over time, and in fact, for most farms, changes in nutrient application rates were not apparent, at least not when averaged across all parcels for each farm (Figures 8-10).

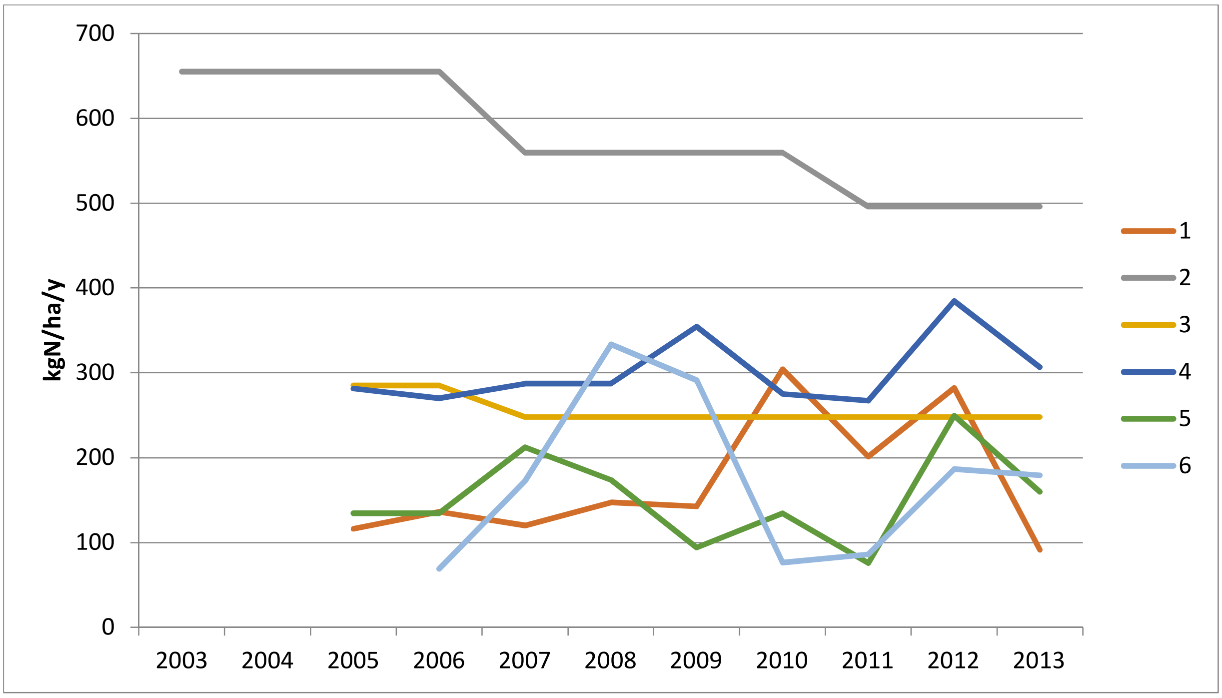


*Figure 8. Total annual nitrogen application rate (manure and fertilizer) averaged across all parcels for PA farmers (labeled 1-6) using adaptive nutrient management.*

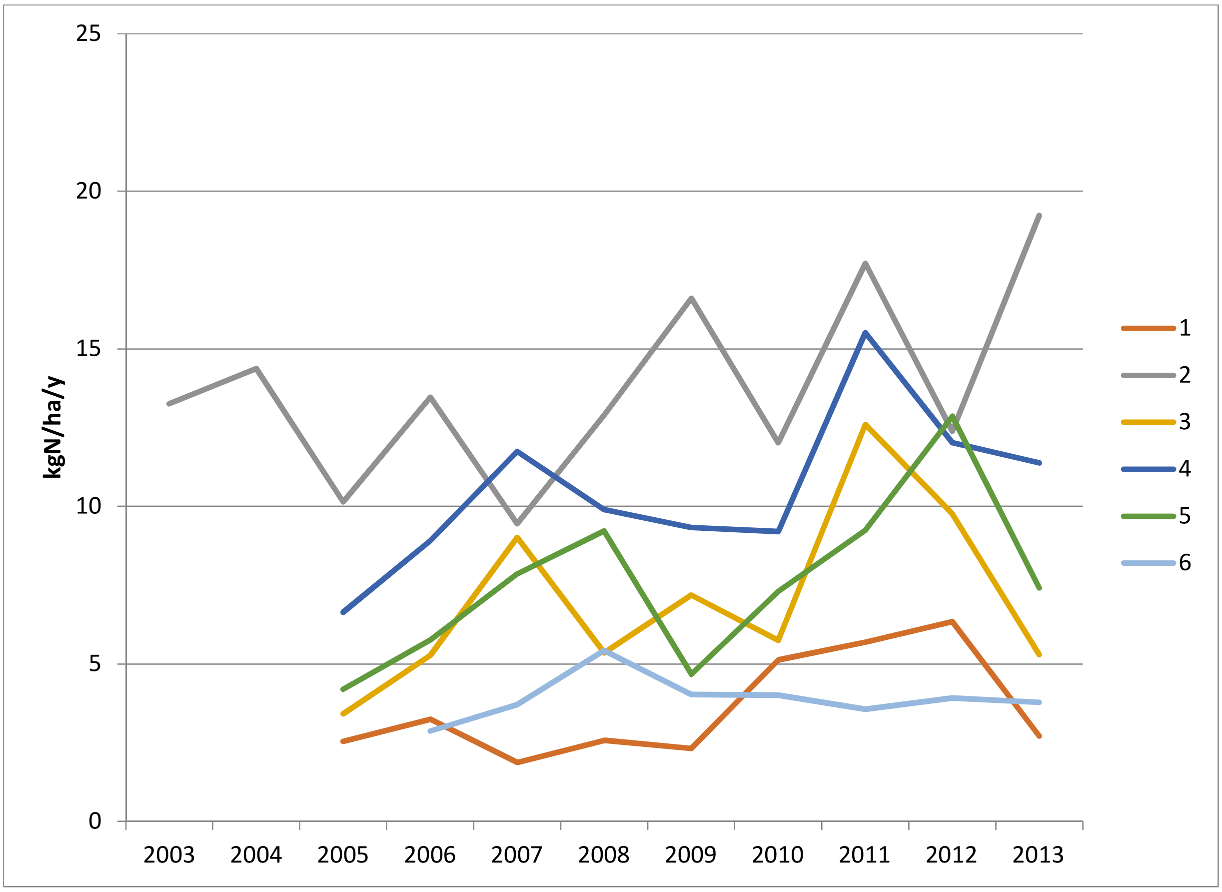


*Figure 9. Total annual N2O emission rate by farm over time averaged across all parcels for PA farmers (labeled 1-6) using adaptive nutrient management.*

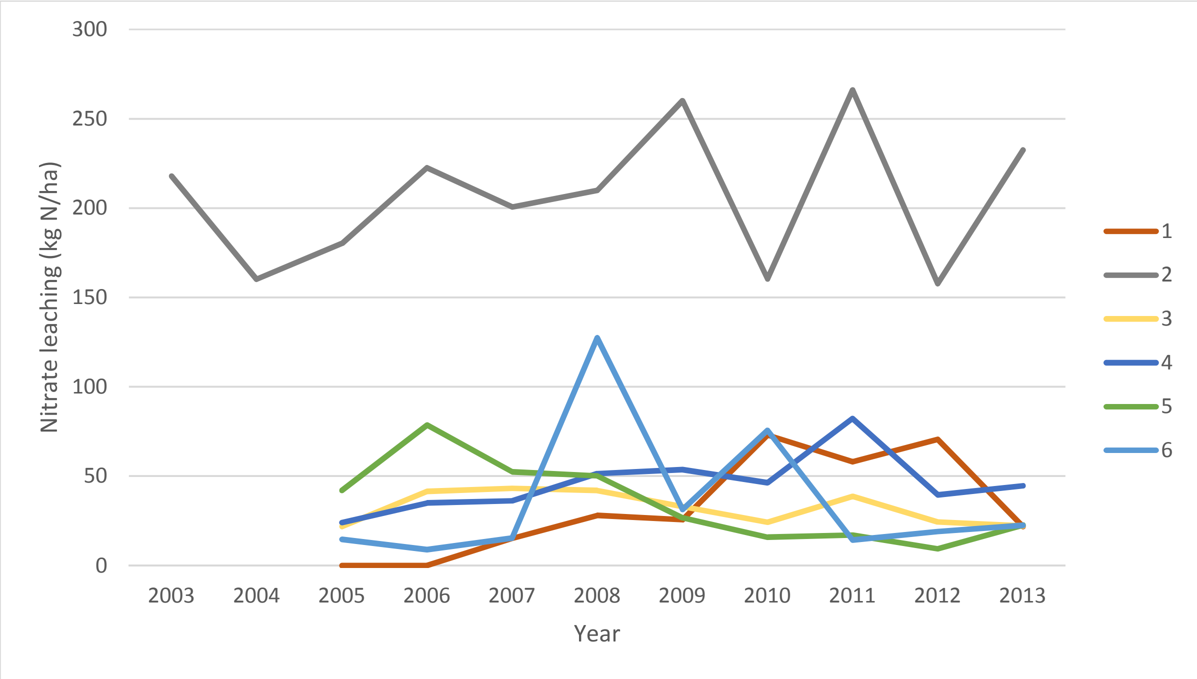


*Figure 10. Total annual nitrate leaching averaged across all parcels for PA farmers (labeled 1-6) using adaptive nutrient management.*

Given the lack of baseline data for the PA farmers, we ran DNDC using a hypothetical baseline to examine emission reduction potential. We selected a nitrogen fertilizer reduction of 30 lb/acre. Figure 11 illustrates modeled reductions from one of the PA farmer fields. The 30 lb/acre reduction in N applied resulted in a modeled emission reduction of 19% of nitrogen leaching and 12% reduction in net CO2eq. The modeled net GHG reduction was 0.38 $tCO_2eq/ha$.

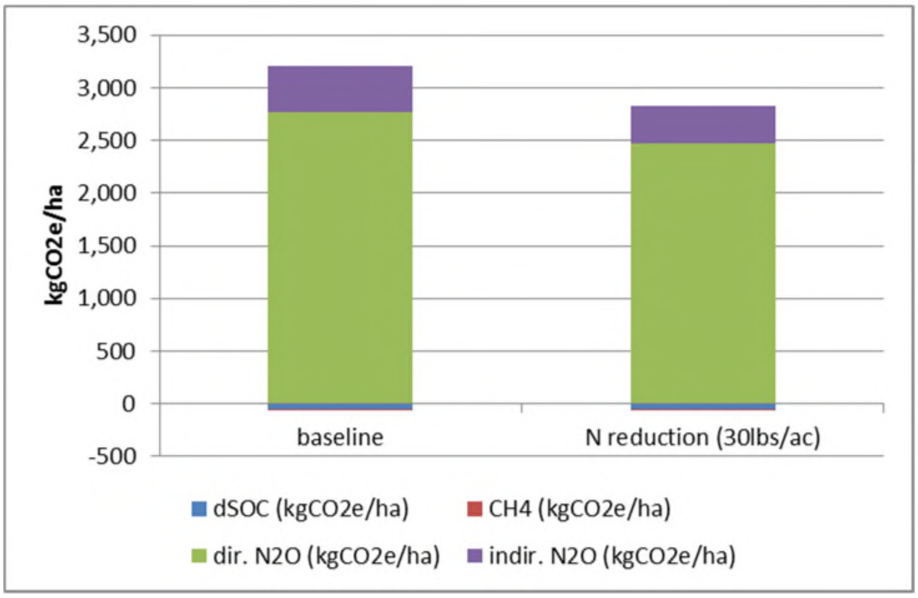


*Figure 11. Modeled emission reductions for a PA field with reduction of fertilizer N by 30 pounds per acre. Direct $N_2O$ emission reduction was the largest source of GHG emissions reduction.*

We also struggled to obtain the necessary data from the farmers using GreenSeeker in VA, but in the end, we were somewhat successful and have higher confidence in these data, though there were still some gaps. Participating farmers were, for the most part, quite progressive, and typically kept reasonable historic records. More importantly, unlike "adaptive management" the change from the baseline condition to the project condition using GreenSeeker was definitive, not gradual. As a result, we were able to establish a baseline condition using historic data and then compare with the use of GreenSeeker in 2013.

VA Tech researchers entered all of the agronomic information via the web application to the DNDC model as described earlier. Information was entered for 107 parcels from seven farmers, but only a subset of fields/farms could be used because of data limitations. The final analysis included four farmers, 91 parcels and almost 4,000 planted acres. Agronomic history ranged from one to seven years; five years was the most frequent (44 parcels) and 80% of the fields had three or more years of data. To simulate each field, we required complete management data (including the year Greenseeker was used), the date Greenseeker was used, and the file which reported the fertilizer N rates that Greenseeker used during its application.

All fields were generally a mix of commodity crops (corn, winter wheat, and soybean) over the dataset duration. Fertilizer and manure applications varied substantially among farmers. Table 1 provides a summary of key parameters by farmer.

*Table 1. Summary of VA Farm Agronomic Information.*

| Farmer | # Parcels | Acres | Mean Field Acreage | Crops | Manure Application | Tillage |
|---|---|---|---|---|---|---|
| 1 | 18 | 543 | 30.2 | Corn | all parcels (applies in at least 2 years on all parcels) | tills on all parcels |
| 2 | 39 | 2,300 | 58.9 | corn, wheat, soybean | most parcels (applies in at least 1 year on 36 parcels) | tills on 36 parcels |
| 3 | 2 | 68 | 34.2 | Wheat | never applies | no till |
| 4 | 32 | 1,111 | 34.7 | corn, wheat, soybean | few parcels (applies in at least 1 year on 3 parcels) | no till |

Greenseeker data was provided separately from other agronomic data. Greenseeker records high resolution N application rate data to text files – each point returned from the unit represents approximately 300 $m^2$. We integrated parcel-level tables of points and lists of application dates by parcel into a single table.

Earlier studies with GreenSeeker conducted by VA Tech showed that the same grain yields or slightly better could be achieved with 21% less nitrogen for corn and 10% less nitrogen for wheat using GreenSeeker compared to the corn and wheat grown using the most advanced whole-field recommendations made by VA Tech. [3]

In our study, the average commercial nitrogen fertilizer reduction using GreenSeeker was roughly 6% for corn (from an average of 107 lbs N/ac to 101 lbs N/ac) and 6 % for wheat, when estimated using weighted average of planted acres, but as noted in Table 2, these reductions for corn are driven by one farm (Farmer 4), that dropped nitrogen application by roughly 38%. [4] For the remaining two farms, nitrogen fertilizer rates on corn actually increased using GreenSeeker. As will be discussed below, however, this increase in fertilizer application coincided with an increase in yield and a corresponding increase in nitrogen use efficiency.

[3] Thomason, W.E. and M.S. Reiter. 2011. The GreenSeeker® optical sensor: Improving nitrogen utilization in VA wheat and corn. Mid-Atlantic Regional Agronomist Quarterly Newsletter. March 2011.

[4] We reviewed our records to determine if this low application rate for Farmer 4 was a data entry error. We have no evidence that it was and instead we have anecdotal evidence that Farmer 4 was impressed with the nitrogen reduction results using GreenSeeker.

*Table 2. Fertilizer application rate based on weighted average of planted acres for corn and wheat comparing baseline and GreenSeeker in VA.*

| CORN | | | BASELINE | | GREENSEEKER | |
|---|---|---|---|---|---|---|
| Farmer | Planted acres | # of Parcels | Individual Fertilizer N rate (lbs N/acre) | Individual TOTAL Fertilizer N rate (fert & manure) (lbs N/acre) | Individual Fertilizer N rate (lbs N/acre) | Individual TOTAL Fertilizer N rate (fert & manure) (lbs N/acre) |
| 1 | 543 | 18 | 165 | 306 | 182 | 323 |
| 2 | 1,323 | 22 | 40 | 174 | 63 | 196 |
| 4 | 817 | 25 | 176 | 180 | 109 | 113 |
| Total Acres | 2,683 | **Weighted Average** | **107** | **202** | **101** | **196** |

| WHEAT | | | BASELINE | GREENSEEKER |
|---|---|---|---|---|
| Farmer | Planted acres | # of Parcels | Individual Weighted Avg Fert. N rate (lbs N/ acre) | Individual Weighted Avg Fert. N rate (lbs N/ acre) |
| 2 | 977 | 16 | 80 | 79 |
| 3 | 68 | 2 | 122 | 82 |
| 4 | 194 | 7 | 107 | 81 |
| Total Acres | 1,239 | **Weighted Average:** | **84** | **79** |

Similarly, we found that use of GreenSeeker would result in similar or increased grain yields. The overall average yield using GreenSeeker versus conventional nutrient management was 158% for corn and 101% for wheat. Even Farmer 4 whose nitrogen fertilizer application dropped significantly using GreenSeeker on corn in 2013, achieved 96% of his average corn yield under baseline nutrient management (Table 3). All farmers improved their nutrient use efficiency using GreenSeeker (Table 3 and 4).

*Table 3. Average actual corn yields (lbs dry matter/acre) and nutrient use efficiency under baseline nutrient management versus GreenSeeker for each farmer.*

| | **Average corn yield (lbs dm/acre)** | | **Total N application (lbs/acre)** | | **N use efficiency (yield/applied N)** | |
|---|---|---|---|---|---|---|
| **Farmer** | Baseline | GreenSeeker | Baseline | Greenseeker | Baseline | GreenSeeker |
| 1 | 1,464 | 2,671 | 306 | 323 | 5 | 8 |
| 2 | 2,672 | 3,396 | 174 | 196 | 15 | 17 |
| 4 | 3,052 | 2,910 | 180 | 113 | 17 | 26 |

*Table 4. Average actual wheat yields (lbs dry matter/acre) and nutrient use efficiency under baseline nutrient management versus GreenSeeker for each farmer.*

| | **Average wheat yield (lbs dm/acre)** | | **Total N application (lbs/acre)** | | **N use efficiency (yield/applied N)** | |
|---|---|---|---|---|---|---|
| Farmer | **Baseline** | **GreenSeeker** | **Baseline** | **GreenSeeker** | **Baseline** | **GreenSeeker** |
| 2 | 1,607 | 1,592 | 80 | 79 | 20 | 20 |
| 3 | 1,987 | 2,104 | 122 | 82 | 16 | 26 |
| 4 | 1,666 | 1,659 | 107 | 81 | 16 | 20 |

DNDC Model Simulations

Because of the size and complexity of these simulations, we used a simple and straightforward calibration method. For all crops, we converted reported yield in standard units per acre (bushels, tons, etc.) to kilograms of C per hectare by converting native units to kilograms per hectare, correcting for standard moisture content, and assuming dry matter is 40% C. For any crop on any parcel, we simply used the maximum reported yield for the maximum biomass parameter as $yield_{max} * frac_{grain}^{-1}$. Figure 12 shows the post-calibration DNDC modeled yields versus reported yields. This calibration step included soybean, alfalfa, grain corn and silage corn.

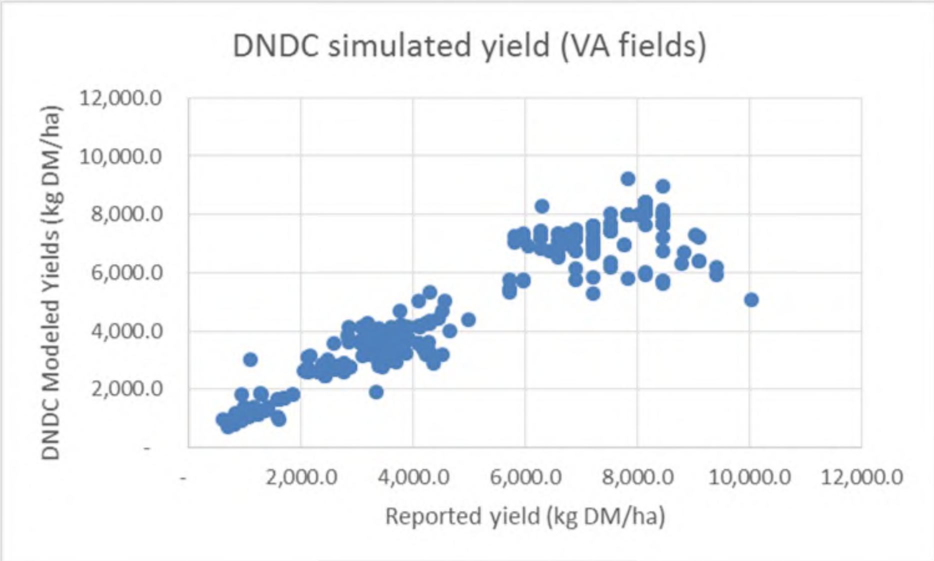


*Figure 12. The post-calibration modeled yields versus actual yields.*

In this study, parcels that had previously received single-rate N applications switched to Greenseeker-based applications in 2013. The DNDC model was used to simulate a hypothetical nutrient application condition in 2013 (based on historic nitrogen application rates) and compare it to the actual field practice using GreenSeeker. To ensure that soil organic carbon dynamics were simulated appropriately, we initialized the model with several years of management data: we considered the Greenseeker year (2013) the focus of the simulations and considered prior years the "historical" timeframe; historical years were repeated in sequence three times prior to running the Greenseeker year based on the assumption that the field was managed in a similar way prior to the historical years. For example, a hypothetical field with a five-year management dataset (2009-2013 where 2013 is the Greenseeker year) would be run as a 13-year simulation where the 2009 to 2012 is repeated three times and 2013 is simulated once.

We ran two parallel simulations (scenarios): one where Greenseeker was used in the Greenseeker year and one where conventional N applications were made in the Greenseeker year; historical years were always simulated in the same way. This approach is consistent with the N2O estimation methods contained in the American Carbon Registry Protocol for nutrient management. We ran model simulations at the Greenseeker point level: that is, for each point on each parcel where Greenseeker reported an application, we ran a simulation across all years for each scenario. Results were post-processed to calculate an area-weighted, parcel-level mean.

DNDC model estimates indicate that weighted average amounts of nitrate leaching and direct N2O emissions were lower under the GreenSeeker scenario, but the results did vary by farmer (Table 5 and 6). Model estimates of N2O emissions suggested direct emissions were lower for all farmers (on a lbs N/acre basis), yet nitrate leaching was higher for Farmer 1 and 2 under the GreenSeeker scenario, likely reflecting higher overall nitrogen application rates, tillage practices and significant application rates of manure. The Greenseeker technology uses remote sensing of red and near-infrared reflectance to map crop vigor and adjust N applications rates. It is important to note that the technology gives an indication of current plant growth which is driven by growing conditions and nitrogen availability.  Manure nitrogen availability is more varied than chemical fertilizer and driven by nitrogen mineralization rates. Researchers are still working on GreenSeeker algorithms to better predict nitrogen release from manure. Much of the manure nitrogen mineralization may occur outside of the crop growth season, and lead to increased nitrogen leaching rates and lower nitrogen use efficiency (see Tables 3 and 5).

*Table 5. Results of DNDC model estimates of annual rates of nitrate leaching for VA farms. Results represent weighted averages for each farmer, weighted based on 'physical area' of the individual parcels.*

| | | | Baseline | | Greenseeker | |
|---|---|---|---|---|---|---|
| **Farmer** | **# of parcels** | **Acres** | **Leaching $NO_3$ lbs N/acre** | **Leaching N/ N applied** | **Leaching $NO_3$ lbs N/acre** | **Leaching N/ N applied** |
| 1 | 18 | 543 | 100 | 33% | 111 | 34 % |
| 2 | 39 | 2,300 | 40 | 30% | 43 | 29% |
| 3 * | 2 | 68 | 54 | 47% | 42 | 42% |
| 4 | 32 | 1,011 | 51 | 32% | 38 | 31% |
| **Total/ Weighted Average** | **91** | **3,923.1** | **52** | **31%** | **51** | **30%** |

* Farmer 3 only used GreenSeeker on wheat.

*Table 6. Results of DNDC model estimates of annual rates of direct $N_2O$ emissions for VA farms. Results represent weighted averages for each farmer, weighted based on 'physical area' of the individual parcels.*

| | | | Baseline | | Greenseeker | |
|---|---|---|---|---|---|---|
| **Landowner** | **# of parcels** | **Acres** | **Direct $N_2O$ lbsN/acre** | **$N_2O$ Emission Factor** | **Direct $N_2O$ lbsN/acre** | **$N_2O$ Emission Factor** |
| 1 | 18 | 543 | 0.88 | 0.29% | 0.81 | 0.25% |
| 2 | 39 | 2,300 | 0.46 | 0.43% | 0.46 | 0.38% |
| 3 | 2 | 68 | 0.18 | 0.16% | 0.16 | 0.17% |
| 4 | 32 | 1,011.50 | 0.52 | 0.33% | 0.45 | 0.44% |
| **Total/ Weighted Average** | **91** | **3,923** | **0.53** | **0.38%** | **0.50** | **0.37%** |

As noted earlier, this project resulted in roughly 14,154 crop acres (5,728 ha) using GreenSeeker over five years (Table 7).  However, since farmers may plant more than one crop on an acre of land during the year, we do not know how many physical acres these numbers represent. Consequently, to provide a conservative estimate of the benefits of this project, we applied the

*Table 7. Total corn, barley, and wheat acreage applied using GreenSeeker on sandy loam soils on the Eastern Shore of Virginia between 2011 (planting of wheat) and 2016†.*

| | Year Crop Harvested | | | | | |
|---|---|---|---|---|---|---|
| Crop | 2012 | 2013 | 2014 | 2015 | 2016† | Total |
| | ----------acres---------- | | | | | |
| Corn | 412 | 2827 | 1396 | 1413 | 0 | 6,048 |
| Barley | 0 | 423 | 377 | 0 | 0 | 800 |
| Wheat | 78 | 2875 | 2908 | 1365 | 80 | 7,306 |
| Total | 490 | 6,125 | 4,681 | 2,778 | 80 | 14,154 |

†*Acreage for 2016 are currently under contract via the USDA-Natural Resources Conservation Service's enhanced nutrient management cost-share program and will utilize GreenSeeker® technology. Data from Virginia Tech.*

area weighted average rates of nitrate leaching reduced (1 lb /acre; Table 5) and N2O reduced (0.03 lbs N/acre or 14 lbs CO2 equivalents/acre; Table 6) from using GreenSeeker to the available acres of farmers directly involved in this project (3,923 acres; Table 6) to get a rough estimate of the environmental benefits. We estimate using GreenSeeker on these acres reduced nitrogen leaching by roughly 3,923 lbs/year and greenhouse gas emissions by roughly 24.4 metric tons of CO2 equivalents per year.

**Prepare and submit a Greenhouse Gas Project Plan to the American Carbon Registry.**
*We did not submit a Greenhouse Gas Project Plan to the American Carbon Registry due to concerns about data quality and meeting the test of additionality.*

Details

We were not able to discern any benefits (in terms of N2O emission reductions) associated with the implementation of adaptive nutrient management on farms in PA. This was due to a lack of information on baseline practice against which to quantify emission reductions. We were able to discern a difference between the baseline and project scenarios on farms implementing GreenSeeker in VA. However, as noted above, we had some concerns about the quality of the data. In addition, we have questions about whether the acres under GreenSeeker would pass the additionality test given that the implementation was largely driven by EQIP funding at a rate of $40/acre.

ACR's three-pronged approach combines three tests that help determine whether GHG emission reductions and removals from an offset project are above and beyond the "business as usual" scenario. Table 8 summarizes this test.

The answer to the first two questions for the use of GreenSeeker is “No.” In terms of the third prong, given the limited uptake of this practice, one could assume there are technological barriers for implementation, but the role that carbon market incentives played in overcoming these barriers is unclear. On the one hand, one could argue that “but for” this grant focused on greenhouse gases, those additional EQIP dollars would not have been available and therefore the answer is “yes”. However, one could also argue that the EQIP dollars are not directly related to the carbon market per se, hence the answer would be “no”. We have consulted with Rori Cowan at the American Carbon Registry (ACR) on this subject. Rori felt fairly confident that this project would pass the additionality test of ACR should we decide to pursue registration of some of the GreenSeeker credits.

*Table 8. Three-prong additionality test from the American Carbon Registry standard protocol (retrieved from: http://americancarbonregistry.org/carbon-accounting/standards-methodologies/american-carbon-registry-standard/acr-standard-v3-0-february-2014.pdf)*

| Test | Key Questions |
|---|---|
| **Regulatory Surplus** | Is there an existing law, regulation, statute, legal ruling, or other regulatory framework in effect as of the project Start Date that mandates the project activity or effectively requires the GHG emissions reductions?<br>**Yes = Fail; No = Pass** |
| **Common Practice** | In the field or industry/sector, is there widespread deployment of this project, technology, or practice within the relevant geographic area?<br>**Yes = Fail; No = Pass** |
| **Implementation Barriers** | *Choose one of the following three:* |
| ***Financial*** | Does the project face capital constraints that carbon revenues can potentially address; *or* is carbon funding reasonably expected to incentivize the project's implementation; *or* are carbon revenues a key element to maintaining the project action's ongoing economic viability after its implementation?<br>**Yes = Pass; No = Fail** |
| ***Technological*** | Does the project face significant technological barriers such as R&D deployment risk, uncorrected market failures, lack of trained personnel and supporting infrastructure for technology implementation, or lack of knowledge on practice/activity, and are carbon market incentives a key element in overcoming these barriers?<br>**Yes = Pass; No = Fail** |
| ***Institutional*** | Does this project face significant organizational, cultural, or social barriers to implementation, and are carbon market incentives a key element in overcoming these barriers?<br>**Yes = Pass; No = Fail** |
| ***If the project passes the Regulatory Surplus and Common Practice tests, and at least one Implementation Barrier test, ACR considers the project additional.*** | |

**Conduct three workshops to educate farmers and technical service providers on the pilot project, carbon markets and potential use of the ACR protocol and DNDC model.**
Our original plan was to conduct one workshop for each of the three geographies/nutrient management approaches included in our proposal. Unfortunately, as noted earlier, we dropped the manure injection early in the project and the data from PA were inconclusive. We do want to present the results of the GreenSeeker evaluation in VA and will be working with VA Tech to determine appropriate venues for this discussion. A likely option is the Annual Eastern Shore Ag Conference and Trade Show in Melfa, VA in late January.

**Achieve third party certification and validation of credits.**
We did not achieve this objective, see details above on page 26, under “Prepare and submit a greenhouse gas project plan...”

**Compare and contrast the greenhouse gas benefits and implementation costs of three different nutrient management approaches.**
As noted earlier, we were not able to discern the baseline from project condition with the producers implementing adaptive nutrient management in PA. This approach would likely result in a gradual improvement in nutrient use efficiency over time. As a result of this, and the high variability and uncertainty in the model output, we were not able to detect any systematic changes in N2O emissions or nitrate leaching over time. On the other hand, the change from the baseline condition to the project condition using GreenSeeker was definitive, not gradual. As a result, we were able to establish a baseline condition using historic data and then compare with the use of GreenSeeker in 2013, making this a viable nutrient management approach for carbon offset projects. We found, however, that N2O emissions rates were very low in the participating farms. We were able to use DNDC model estimates to compare N2O emissions rates from these two participating groups of farmers. This comparison provides insights to the importance of soil properties on N2O (N2O) emission rates – a factor to consider for targeting future carbon offset projects.

## QUALITY ASSURANCE

As noted earlier, we have concerns about the quality of the producer data used to run the DNDC model, particularly in PA. In addition, we should note that one reason for the delay in submitting our final report is that in analyzing and trying to summarize the findings, we found some discrepancies in the data. We eventually were able to resolve these issues, but they point to the challenges of managing and manipulating a large amount of data. One inconsistency was caused by the data being entered into the tool in acres and not being converted to hectares. This mistake did not affect the DNDC model output, but did affect the aggregated results (e.g., estimate total reductions of N emissions over all cropland). In addition, we also discovered an error in the application rate for one of the farmers. The model was re-run with the new information. Overall, the experience highlights the potential for human error to introduce some data inconsistencies, arguing perhaps for a more simplistic approach in estimating nitrous oxide benefits.

## CONCLUSIONS AND RECOMMENDATIONS

The goal of our project was to try to reduce some of the technological and financial barriers to certifying carbon offset credits generated by nutrient management projects. At the time, there were two approved, or soon to be approved, methodologies that could be used to quantify the reductions in N2O emissions due to nutrient management in the Chesapeake region. One methodology required projects outside of the Upper Mississippi to use the Intergovernmental Panel on Climate Change default emissions factor i.e., N2O emissions/reductions would be calculated to be one percent of the nitrogen fertilizer applied/reduced. [5]

The second approach, approved by the ACR,[6] uses the DNDC model to estimate N2O emissions. Although much more data intensive than using the default value, our thinking was that perhaps in the Chesapeake region N2O emissions are a higher percentage of the applied nitrogen than the IPCC default factor. Furthermore, many factors such as fertilizer type, rate, timing, placement, residue management and soil type affect N2O emissions; these are estimated by the DNDC model. If the amount of N2O emissions reductions were doubled or even tripled as compared to the IPCC default, the cost associated with the carbon credits would be cut in half or more and might be worth the additional resources needed to obtain the agronomic information.

Though nitrogen application rates were roughly similar between PA and VA farmers (Table 9), average N2O emission rates per unit of applied nitrogen was roughly 0.38% for the VA farms (Table 6) under baseline conditions and 2.71 % for the PA farms (Table 9), roughly a 7 fold difference.

*Table 9. Fertilizer application rate based on weighted average of planted acres for corn comparing VA baseline and PA farmers in 2013.*

| | **Fertilizer Application – CORN 2013** | | | | | |
|---|---|---|---|---|---|---|
| | **Land owner** | **# of parcels** | **Planted Area (ha)** | **Fertilizer lbs N/acre** | **Manure lbs N/acre** | **Total Fertilizer lbs N/acre *** |
| **PA 2013** | 1 | 5 | 165 | 120 | 10 | 129 |
| | 2 | 6 | 240 | 79 | 364 | 443 |
| | 3 | 10 | 80 | 110 | 111 | 221 |
| | 4 | 10 | 1,010 | 135 | 148 | 283 |
| | 5 | 5 | 57 | 142 | 0 | 142 |
| | 6 | 8 | 527 | 154 | 37 | 191 |
| **VA Baseline** | 1 | 18 | 543 | 165 | 142 | 306 |
| | 2 | 22 | 1,323 | 40 | 134 | 174 |
| | 4 | 25 | 817 | 176 | 4 | 180 |

* Total may not equal manure plus fertilizer due to rounding errors.

[5] The Verified Carbon Standard initially adopted this methodology, but since, then the ACR has also adopted a version of this approach as well.

[6] http://americancarbonregistry.org/carbon-accounting/standards-methodologies/emissions-reductions-through-changes-in-fertilizer-management/acr-methodology-for-n2o-emission-reductions-through-changes-in-fertilizer-management_v2-0-final.pdf

*Table 10. Results of DNDC model estimates of annual rates of direct $N_2O$ emissions for PA farms. Results represent weighted averages for each farmer, weighted based on 'physical area' of the individual parcels.*

| **N2O Emission Factors<br>By landowner and weighted average** | | | |
|---|---|---|---|
| **Land Owner** | **# of Parcels** | **Physical Area** | **$N_2O$ Emission Factor** |
| 1 | 10 | 274.9 | 1.54% |
| 2 | 6 | 240 | 3.19% |
| 3 | 10 | 78.6 | 1.99% |
| 4 | 10 | 561.9 | 3.53% |
| 5 | 10 | 88.4 | 4.09% |
| 6 | 10 | 472.2 | 2.04% |
| | | **Weighted Average:** | **2.71%** |

Use of the IPCC default factor in this case would have over-estimated benefits in VA and underestimated them in PA. The differences in emissions rate can partially be explained by differences in soil properties. Several factors affect N2O emissions, including: aeration, compaction, temperature, moisture, pH, organic matter, available N, C/N ratio, and textures. [7] Soil organic carbon averaged roughly 1.3% for the PA farms and the soil type was classified as loam or sandy-clay-loam. Soil organic carbon for VA soils was nearly 50% less, averaging 0.7% and soils were characterized as either sandy loam or loamy sand. Meta- and statistical analyses corroborate our modeling results by indicating that soils with higher soil organic carbon and finer texture have higher nitrous oxide emissions. [8] In addition, soil pH varied between the two areas, ranging from 4.6 – 5.20 in VA to 5.40 - 6.7 in PA. N2O reductase is inhibited by low pH and in the presence of oxygen. Generally, if denitrification is the main source of N2O, higher pH values decrease the soil N2O emissions, but if nitrification is the main process of N2O production, then an increase in the soil pH stimulates production. *Hence, one lesson learned from the current project is that soil properties should be used as a screening tool for potential carbon projects such that one could better target areas likely to have higher baseline N2O emissions and, therefore, more potential for emissions reductions.*

To evaluate the potential for carbon offsets under different nutrient application and emissions scenarios, we developed a spreadsheet that allows one to manipulate emissions, nitrogen applied, etc. and then see the relative costs and greenhouse gas benefits (see attached). Two example scenarios are presented below (Table 11). In the first, we estimate the cost of purchasing a GreenSeeker unit (~ $40,000) and determine what the payment per ton of CO2

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[7] Signor, D. and C.E.P. Cerri. 2013. N2O emissions in agricultural soils: a review. Pesq. Agropec. Trop., Goiânia, v. 43, n. 3, p. 322-338, jul./set. 2013. Retrieved from: http://www.scielo.br/pdf/pat/v43n3/a14.pdf.

[8] Stehfast and Bouwman. 2006. N2O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data and modeling of global annual emissions. 74:207-228. Nutrient Cycling in Agroecosystems.

equivalents would need to be, in order to simply offset the costs of purchase over an expected life span.

In this scenario, the average reduced N applied is 77 lbs/acre (a best case scenario based on VA Farmer 4) and the N2O emissions factor is 1% (which is more than we observed in VA, but less than in PA). Under this scenario, assuming the unit is used for 5 years on at least 1,000 acres of corn annually, the carbon offset price would need to be $48 per ton to compensate for the purchase.

In the second scenario, we assumed that farmers could receive $40/acre payment under EQIP for implementing GreenSeeker. This amount per acre would equate to a payment of roughly $251 per ton. In other words, carbon markets may not be able to compete with Farm Bill programs directly. As noted earlier, the question of additionality is key here – current adoption rates are very low in the Bay watershed, so demonstrating that there are technological barriers to adoption that could be overcome by carbon incentives might be a way to move future GreenSeeker projects into the marketplace.

In terms of future investments of the Carbon Reduction Fund, we make the following observations. First, acquiring the information needed to run the DNDC is a challenge and, in the case of the VA farmers, was probably not worth the effort given the low N2O emissions on these farms. Second, GreenSeeker does appear to be a very viable technology to facilitate nitrogen application reductions and there is a distinct change in practice that can be modeled. Soil properties are critical to N2O emissions and should be a consideration in prioritizing the location of future projects.

*Table 11. Examples of varying costs and benefits on the potential for Carbon Offsets from using GreenSeeker.*

**Analysis of GreenSeeker Carbon Offset Potential**

| Cost | unit | Anticipated Lifespan (years) | Acres Corn (annual) | Average reduction in N applied (lbs/acre) | Total reduction in N applied (lbs/ac) | Total reduction in N applied (metric ton, per lifespan of unit) | Emissions factor (N2O % emitted per unit of N applied) | CO2 Equiv Reduced (tons, per lifespan of unit) | Cost of carbon removed (per ton) |
|---|---|---|---|---|---|---|---|---|---|
| $22,000 | per unit | 5 | 1,000 | 77 | 385,000 | 174.68 | 0.01 | 796 | $28 |
| $40 | acre | 1 | 1 | 77 | 77 | 0.03 | 0.01 | 0.16 | $251 |

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McSwiney C.P. and G.P. Robertson. 2005. Nonlinear response of N2O flux to incremental fertilizer addition in a continuous maize (Zea mays L.) cropping system. Global Change Biology 11: 1712–1719.