Nitrogen management in North Carolina agriculture: Results from five years of on-farm research

Acknowledgements

Special thanks to the farmers and crop consultants in Eastern North Carolina who participated in the farmer network. The generosity they showed of their time, land, data, and expertise was the foundation of this project. Thank you to Billy McLawhorn, Dr. Deanna Osmond, Robert Austin, Michelle Lovejoy, Keith Larick and David Williams for providing technical assistance and guidance throughout the effort. Photos appear courtesy of the North Carolina Farm Bureau.

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Key findings

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This report summarizes the results of a five-year on-farm participatory research effort to identify nitrogen fertilizer management solutions for North Carolina grain farmers. The farmer network involved 97 farmers in 26 counties across eastern North Carolina, as well as a collaboration between scientists, environmental and agricultural organizations and crop advisors. The trial results represent the most comprehensive data set to date of on-farm nitrogen management practices in the state. This report summarizes those results, including the baseline nitrogen management by the participating farmers, the potential to optimize nitrogen use and the effectiveness of several tools, technologies and products in increasing nitrogen use efficiency. It provides important information to growers, crop consultants, researchers and anyone invested in sustainable grain production in North Carolina's Coastal Plain.

Key findings from the research include:

Farmers in North Carolina are more likely to over apply nitrogen on corn than wheat.

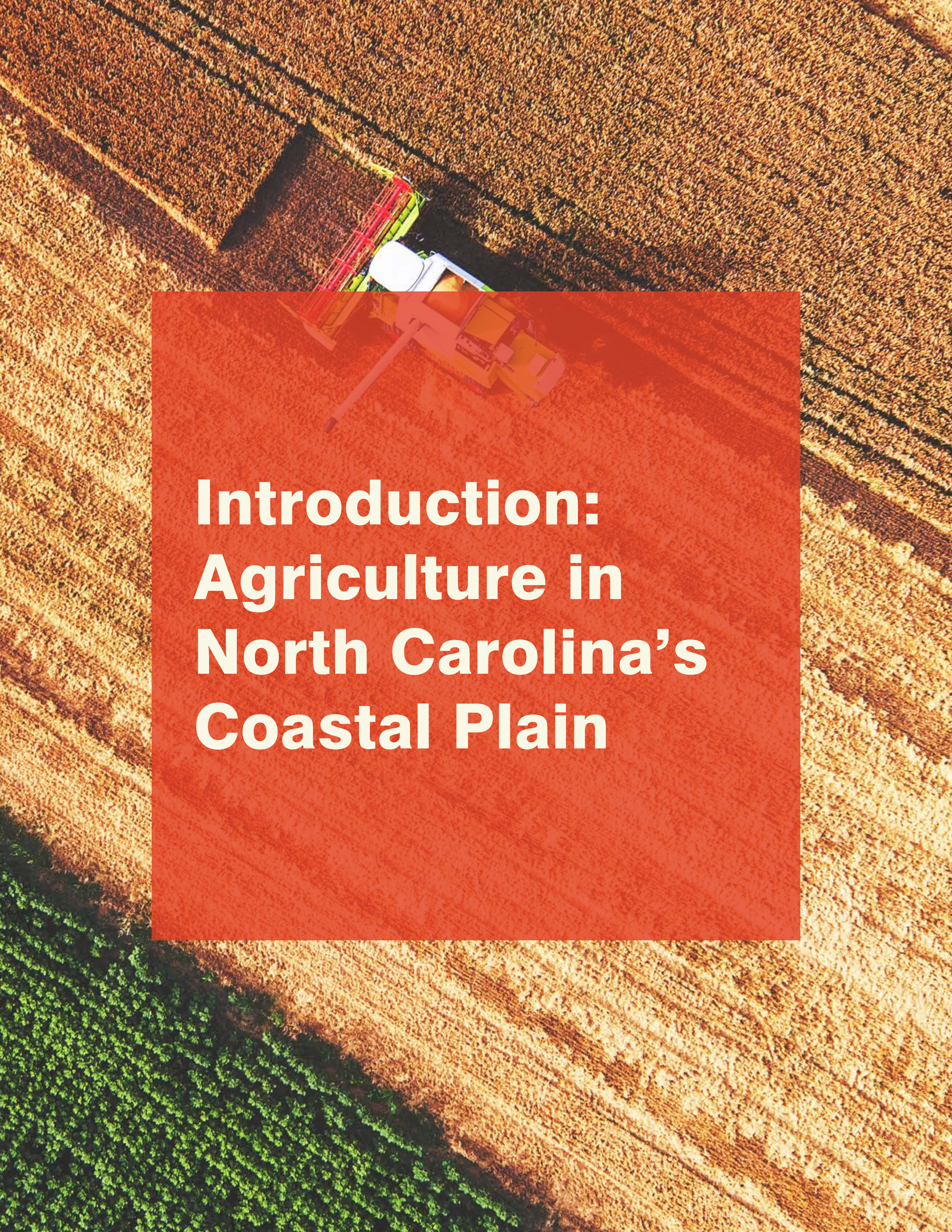
Over five years, farmers selected nitrogen rates that were above state recommendations and agronomic optimum rates more often in corn than in wheat. Winter wheat crops are less likely to be over-fertilized, partially due to the crop's lower relative value and a more climatically stable growing period that reduces the risk of N losses. In corn, farmers were applying an average of 26 lb N/ac more than the agronomic optimum N rate, but seeing yields that only met or slightly exceeded the optimum N rate yield. This means that a substantial number of farmers were applying nitrogen fertilizer at rates that did not improve corn crop yields and could be lost to the environment.

Products, tools and technologies to improve nitrogen management must be tested under local conditions.

The North Carolina Farmer Network provided a rare opportunity for farmers to be directly involved in large-scale field trials of products designed to help improve nitrogen management. Traditionally, these products are developed in the Midwest with small-plot trials and there is limited data available on how effective they may or may not be in the unique production environment of the Southeast. A handful of network trials revealed marginal benefits, while the majority did not provide yield or economic advantages.

The farmer network learning model can be an effective first step towards improved fertilizer management, but lessons must be shared more broadly.

The implementation of the farmer network learning model in North Carolina was successful in providing a framework to engage farmers in on-farm field trials. It resulted in valuable insights and the most comprehensive data set of farmers' nitrogen management practices in the state. Participation in the network did not lead farmers to make nitrogen management changes, as hypothesized at the outset of the project. However, there were valuable lessons and other outcomes for both participants and project partners that were shared more broadly and will continue to inform nitrogen management science and practice in the years ahead.



Introduction: Agriculture in North Carolina's Coastal Plain

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Agriculture is facing increasing public and regulatory pressure to decrease negative environmental impacts of food production, while simultaneously increasing yield to feed a growing population. Nitrogen (N) fertilizer is a significant contributor to several serious environmental issues, including water pollution and greenhouse gas emissions, but is also a critical component of crop production. How a farmer decides to manage their nitrogen has far-reaching implications, not only for their bottom line, but for the health of the ecosystem that will support future generations.

In Eastern North Carolina, the dilemma of how to balance agricultural and environmental concerns is felt deeply. Extending east of Interstate 95, the Coastal Plain is a unique swath of land that extends across the Southeast. More than 2.8 million people reside in North Carolina's Coastal Plain, in mostly small, rural communities. The region is characterized by sandy, low rolling hills with pine forests that blend in to low-lying flat lands spotted with swamps and wetlands. These 41 counties boast the majority of North Carolina's working lands, which includes cropland, rangeland, pastureland and managed forests, which are predominantly pine plantations. Approximately 90 percent of the state's cropland acres are located here, and pour forth a tremendous diversity of agricultural products. Corn, soybeans, tobacco, peanuts, sweet potatoes, cotton, livestock and more flourish in favorable soils and climatic conditions.

Agriculture is a major driver of the economy in the Coastal Plain, generating over $2 billion in crop values annually[1]. Farm receipts range widely by county and by farm. Several counties have high total farm receipts but a low average per farm, indicating that agricultural income is split between many growers who each bring in a small amount of revenue. The presence of relatively small farms (<200 acres) is a residual effect of the once-thriving tobacco industry that provided farmers with high incomes from small acreage. Today, growers typically tend 1,500-2,000 acres across several small tracts, many of which are leased. The farm economy is mirrored in the broader Coastal Plain population, where many are struggling. The average unemployment rate is 10.7 percent compared to the statewide average of 9.3 percent. Just over 20 percent of people in the region are living below the poverty line, compared to the state average of 18.9 percent. The average annual household income level of $55,192 is lower than the state average by $2,259[2].

[1] 2012 Census of Agriculture. USDA National Agricultural Statistics Service 2012.

[2] 2016 Population Estimates for North Carolina. US Census Bureau 2017.

Figure 1 - Map of North Carolina's regions (USGS). The Coastal Plain is in blue.

Current trends impacting Coastal Plain agriculture

Changing weather patterns and recent intense storm events have deeply affected farmers and their communities in the Coastal Plain. In October 2016, Hurricane Matthew created monumental flooding in North Carolina, earning the title of a 500-year flood[3] event with more than 24 inches of rain over less than 3 days recorded in some locations. The N.C. agriculture industry reported $400 million in losses from a storm so devastating many thought they would never see one like it again. However, in September 2018, Hurricane Florence came ashore with enough force to again create a 500-year flood. In some places more than 30 inches of rain fell. The storm wreaked havoc in the form of an estimated $1.1 billion in damages to crops and livestock in North Carolina alone. And while these major weather events are occurring more frequently and with more force, agricultural producers are also noticing the impacts of more subtle seasonal weather fluctuations. In a set of surveys released by the North Carolina Agriculture and Forestry Adaptation Work Group (N.C.-ADAPT) in 2017, growers in the state indicated they were most concerned about changes in water on the landscape, citing variability in precipitation, excess moisture and drought as some of the most difficult production challenges they face[4].

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[3] A 100-year flood event is defined by FEMA as flooding that extends to a site-specific level at a degree that is observed at a probability of 1% in any given year (a chance of 1 in 100 – which leads to the phrase "100-year flood," though scientists argue it may be misleading. A 500-year flood has a 1 in 500 chance of occurring in a given year, or a 0.2% probability. Source: Holmes, R.R., Jr., Dinicola, K. 2010. 100-Year flood–it's all about chance: U.S. Geological Survey General Information Product 106. https://pubs.usgs.gov/gip/106/

[4] North Carolina Agriculture and Forestry Adaptation Work Group. 2017. Keeping North Carolina's Farms and Forests Vibrant and Resilient through Adaptive Management: Priorities and Recommendations for Advancing Adaptive Management. Retrieved May 16, 2018 from https://www.sfldialogue.net/init_nc_adapt.html.

Uncertain markets add to financial stress for farmers, with crop prices fluctuating from year to year. Ongoing trade negotiations with China, Canada and Mexico, which together account for 43 percent of American farm exports[5] and are particular markets of importance for North Carolina livestock producers, have drawn recent attention. USDA estimated that soybean growers alone would lose nearly $3.2 billion in 2018 as a result of tariffs[6]. Soon after, the USDA released the Farm Income Forecast, which predicted the average net cash farm income to decline $16,600 (19.9 percent) to $66,700 in 2018. This would be the fourth consecutive decline since 2014 and the lowest average income recorded since the series began in 2010[7].

In addition to uncertain financial and climate outlooks, farmers in the Coastal Plain are also the subject of scrutiny for water quality concerns. There are several watersheds in North Carolina that have a history of exceeding water quality standards for nutrients. Under the Clean Water Act, Total Maximum Daily Loads (TMDLs) have been established for certain pollutants or nutrients in these impaired watersheds. The Neuse and Tar-Pamlico River Basins (Figure 2), which account for nearly half of the water flow in the Coastal Plain, both have TMDLs in place for nitrogen, which allow for limits to be set for point (e.g. wastewater treatment facilities) and non-point (e.g. urban storm water runoff, agriculture) sources.

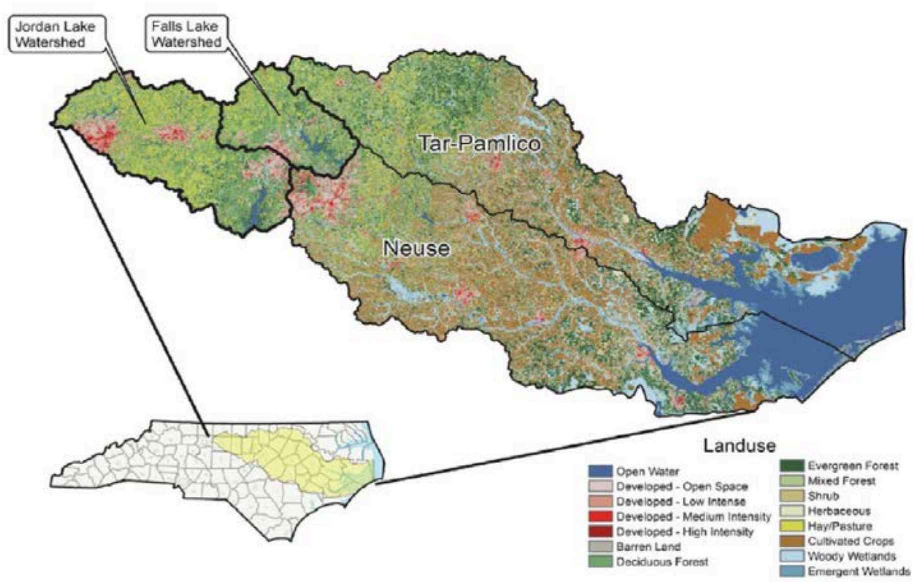

Figure 2. Map of Neuse and Tar-Pamlico Watersheds in North Carolina. Source: Osmond, Deanna & Hoag, Dana & Luloff, A.E. & Meals, Donald & Neas, Kathy. (2014). Farmers' Use of Nutrient Management: Lessons from Watershed Case Studies. Journal of Environment Quality.

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[5] Alan Bjerga and Mario Parker. Southeast Farm Press. July 17, 2018. Farmers stick with Trump even as soybean prices drop. https://www.southeastfarmpress.com/farm-policy/farmers-stick-trump-even-soybean-prices-drop

[6] Ibid

[7] USDA Economic Research Service. 2018. Highlights from the November 2018 Farm Income Forecast. https://www.ers.usda.gov/topics/farm-economy/farm-sector-income-finances/highlights-from-the-farm-income-forecast/.

Excess nitrogen is associated with negative environmental impacts, such as algae blooms, that have been regularly observed in the state. The N.C. Department of Environmental Quality (DEQ) has recorded an average of 8 algae blooms per year in the state's lakes, estuaries and sounds, noting an increase in occurrences as temperatures rise and drought conditions increase[8]. These blooms deplete oxygen in the water and can lead to fish kills. In some instances, the blooms can be toxic to humans and livestock. The DEQ has led efforts to develop point and non-point source nitrogen reduction strategies for these nutrient sensitive watersheds. The Neuse and Tar-Pamlico agriculture strategies call for a 30 percent reduction in nitrogen loading from a 1990's baseline and allow for locally-driven implementation of best management practices that will improve water quality and reduce nutrient loading. Both basins have exceeded agriculture N load reduction goals but broader nitrogen reduction goals for the watersheds have not been met and water quality issues have lingered. This suggests that additional nutrient controls or voluntary improvements for agriculture and municipalities may be needed to address nutrient pollution.

Nutrient management: Ensuring long-term economic and environmental viability for farmers

Agriculture has made contributions toward reducing nutrient pollution, yet water quality issues (caused by both point and non-point sources) persist. Increased adoption of nutrient management practices by farmers in the Coastal Plain will be critical to improve environmental outcomes and the long-term viability of their operations. However, the process of optimizing nutrient management is complex. Farmers must consider the unique soils, management practices, crop rotations and other variables impacting agriculture in the Southeast. Growers must also carefully consider which, if any, of the extensive market of products, tools and technologies designed to improve nitrogen management are appropriate and will return a benefit for their operation.

This report summarizes the results of a five-year on-farm participatory research effort to identify nitrogen management solutions for North Carolina grain farmers. The farmer network involved collaboration between scientists, farmers, environmental and agricultural organizations and crop advisors. The trial results represent the most comprehensive data set to date of on-farm nitrogen management practices in the state. This report summarizes those results, including the baseline nitrogen management by the participating farmers, the potential to optimize nitrogen use and the effectiveness of several tools, technologies and products in increasing nitrogen use efficiency. It provides important information to growers, crop consultants, researchers and anyone invested in sustainable grain production in the Coastal Plain.

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[8] Craig Jarvis. The News & Observer. August 17, 2018. Here's where toxic algae blooms threaten N.C. lakes this summer. https://www.newsobserver.com/news/local/article216896925.html.

Designing the North Carolina Farmer Network

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Designing the North Carolina Farmer Network

In 2013, Environmental Defense Fund (EDF) began consulting with experts from local universities, government and agricultural organizations to discuss common challenges and potential solutions. Many of these entities were already implementing ongoing projects related to cropland nitrogen management and water quality issues; they represented trusted institutions and contributed valuable knowledge and experience.

Project partners include:

Environmental Defense Fund

N.C. State University and Cooperative Extension

N.C. Division of Soil & Water Conservation

N.C. Foundation for Soil & Water Conservation

N.C. Association of Soil & Water Conservation Districts

USDA-Natural Resources Conservation Service

N.C. Department of Agriculture & Consumer Services

The partnership was solidified in the form of an advisory committee comprised of representatives of the project partners. The group was tasked with identifying objectives and actionable steps to meet those objectives. After several brainstorming and development sessions with the advisory committee, EDF selected the following guiding questions:

1. What is the current state of nitrogen management among grain farmers in North Carolina's Coastal Plain?
2. Can nitrogen rate changes improve environmental and economic outcomes?

In the network's second year, a third question was added:

3. Are there products, tools or technologies that can improve nitrogen management and provide environmental and economic benefits?

The farmer network model emerged as a possible framework to generate needed data to answer these questions[9]. A farmer network has three main components:

- Participatory learning and adaptive management using basic research principles.
- Use of commonly accepted protocols and standardized data collection procedures across all experiments conducted, assuring that results are scientifically valid and repeatable.
- Proven methods for sharing, discussing and communicating results of on-farm studies.

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[9] Environmental Defense Fund. May 2016. Farmer Network Design Manual, A Guide for Practitioners, Advisors and Research Partners. https://www.edf.org/sites/default/files/farmer-network-design-manual.pdf

The model calls for farmers to be engaged in participatory research on their own farms, supported by local advisors (e.g. crop consultants, university extension) in an iterative learning process that provides the farmer with data, social support and confidence to make changes in their management practices that improve economic and environmental outcomes. The farmer network learning model follows a repeating cycle of five steps: implement field trials, evaluate trial data, learn from data analysis, adjust management practices and plan for the next year of trials (Figure 3). EDF has been involved in similar projects in the Midwest since 2008, publishing and co-authoring the “Farmer Network Design Manual: A Guide for Practitioners, Advisors, and Research Partners” in 2016.

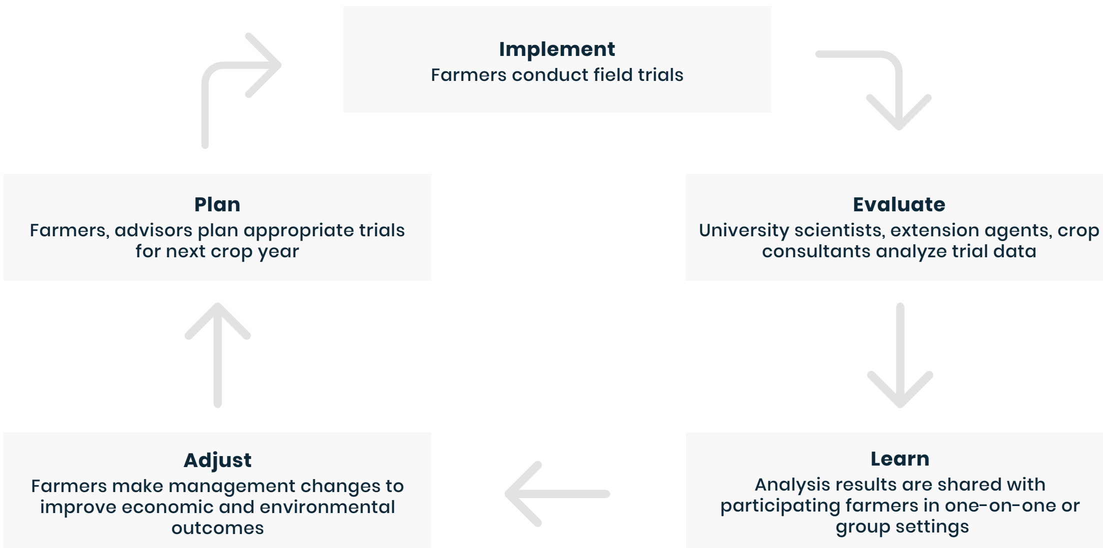

Figure 3 - General Farmer Network learning model, adapted from Farmer Network Design Manual (2016).

EDF and the North Carolina partners worked to adapt the farmer network model to the local expertise and available capacity. The result was a network of growers participating in on-farm field trials managed by N.C. State University (NCSU) and independent crop consultants, known as the North Carolina Farmer Network. The other partners continued to serve as advisors to the network and gathered each year to discuss the network results, lessons learned and adaptations.

The farmer network trials began with a focus on understanding growers’ current nitrogen management processes and selecting crops to study. Farmers typically seek advice from crop consultants, agricultural retailers or university extension agents for nitrogen rate guidance, and there is general agreement that N recommendations from each group are informed by the North Carolina Realistic Yield Expectation (RYE) database[10]. The database integrates historical N.C. data and soil characteristics to make field level N recommendations and provide expected yields for 32 crops.

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[10] Realistic Yield Expectations for North Carolina Soils. 2018. http://www.ncmhtd.com/rye/.

North Carolina has a long growing season and diverse cropping rotations that may include cotton, peanuts, soybeans, tobacco, winter wheat, sweet potatoes, and sorghum. Many farmers double-crop and are in the fields from February through November. The project partners made the decision to focus on corn, wheat, and for the first two years, sorghum.

Corn represents the most nitrogen intensive grain or row crop, and for that reason, pre-existing farmer networks in other locations almost exclusively focus on it. In North Carolina, corn is a significant cash crop and the basis for the most common crop rotations.

Winter wheat is an important piece of the rotation for growers with corn in N.C. Often, wheat is planted in the months following corn harvest and provides the dual benefits of a cash crop and a winter cover crop.

Sorghum, in contrast, is less commonly planted in the state. However, at the outset of the project the advisory group expected sorghum acreage to grow. Smithfield Foods, a major grain buyer in the region, had a price premium program for sorghum to explore its potential for animal feed, and the Natural Resources Conservation Service was providing cost-share to growers who included it in their rotation. There was a lack of field-trial data on sorghum, which is a critical need for universities, crop consultants and other advisors to support growers in their efforts to meet market demands.

Smithfield Agronomics: Connecting on-farm research with supply chain sustainability initiatives

Smithfield, the world's largest pork producer, produces nearly 16.4 million hogs each year, with a large percentage of those raised on 225 company owned farms and approximately 750 contract farms in North Carolina's Coastal Plain. They source an increasing amount of grain annually. In 2013, the company made an industry-leading commitment to engage 75 percent of the acres (450,000 acres) from which it sources grain directly in sustainability initiatives that optimize fertilizer use. EDF and Smithfield formed a partnership to determine how the company could reach its goal, collaborating in the design of Smithfield's grain sustainability initiative, known as Smithfield Agronomics.

Smithfield Agronomics offers support to grain farmers interested in optimizing their fertilizer use or building the health of their soils. The program provides agronomic expertise, technology trials, low-cost cover crop seed and other opportunities to participating farmers.

The North Carolina Farmer Network research informed Smithfield's implementation of its grain sustainability initiative. EDF and N.C. State University identified a research gap in the efficacy of nitrogen efficiency tools, technologies and products. Most of these tools were developed in the Midwest and had limited research results in the Southeast. The Farmer Network helped fill that gap by testing four tools and informed Smithfield's decisions on which to offer through its sustainability program.

Network management

The North Carolina Farmer Network was designed to incorporate local expertise and leverage available capacity. Figure 4 highlights which stakeholders contributed to each step of the learning model.

The advisory committee realized that existing relationships with crop consultants in the Coastal Plain would be the most effective way to reach growers who may be interested in participating. These crop consultants, as trusted advisors to farmers, would also be the ideal avenue to deliver the trial results and provide recommendations on farmer-specific management adjustments. Each crop consultant worked with several farmers within a narrow geographic area to implement trials, collect field data and deliver trial results.

Growers were recruited through crop consultants, extension agents and word of mouth. Participants agreed to: share data on current grain crop nitrogen management practices with their crop consultant, set aside a specified area for in-field trials, manage those trials in accordance with the trial protocol, collect yield data at harvest, report that data to their crop consultants and attend a year-end meeting to discuss trial results. It is probable that this recruitment method and required effort by the farmer to participate created a selection bias. Generally, farmers who are willing to participate in formal farmer networks are more aware of nutrient management and water quality issues and more likely to have already adopted certain management or conservation practices to improve environmental outcomes[11]. As such, network participants may not be a truly representative sample of grain farmers in the Coastal Plain.

Participating crop consultants (alphabetical by last name):

Al Averitt, Protech Advisory Services Inc. (Lumber Bridge, N.C.)

Daniel Fowler, Fowler Crop Consulting Inc. (Weldon, N.C.)

Billy McLawhorn*, McLawhorn Crop Services Inc. (Cove City, N.C.)

Bruce Niederhauser, Total Agronomic Services Inc. (Washington, N.C.)

Bill Peele, Impact Agronomics Inc. (Pantego, N.C.)

Mary Wilks, Carolina Precision Consulting Inc. (Rocky Mount, N.C.)

Stan Winslow, Tidewater Agronomics Inc. (Camden, N.C.)

*Billy McLawhorn also served as managing crop consultant, advising EDF and supervising network crop consultants from 2016 to 2017.

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[11] Environmental Defense Fund. May 2016. Farmer Network Design Manual, A Guide for Practitioners, Advisors and Research Partners. https://www.edf.org/sites/default/files/farmer-network-design-manual.pdf

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At the outset, Dr. Deanna Osmond, Robert Austin and Daniel Hedgecock of NCSU led the grower and crop consultant recruitment process and managed the trial implementation, joined soon after by Al Averitt of Protech Advisory Services. As momentum grew, additional crop consultants and growers joined the network, though in some cases the participant population changed from year to year as interests shifted. In 2016, Billy McLawhorn of McLawhorn Crop Services, Inc., (MCSI) assumed management of the network, bringing more than 30 years of crop consulting expertise to the increasingly complex trials.

NCSU contributed to the development of the trial protocol, assisted in trial implementation, conducted data analysis and interpreted results. The advisory committee provided expertise and feedback on each year's trial results, as well as recommendations for the following year of trials. EDF provided strategic and administrative management of the network, including communicating with the advisory committee and other stakeholders, project planning, oversight of the project budget and contracts and project documentation.

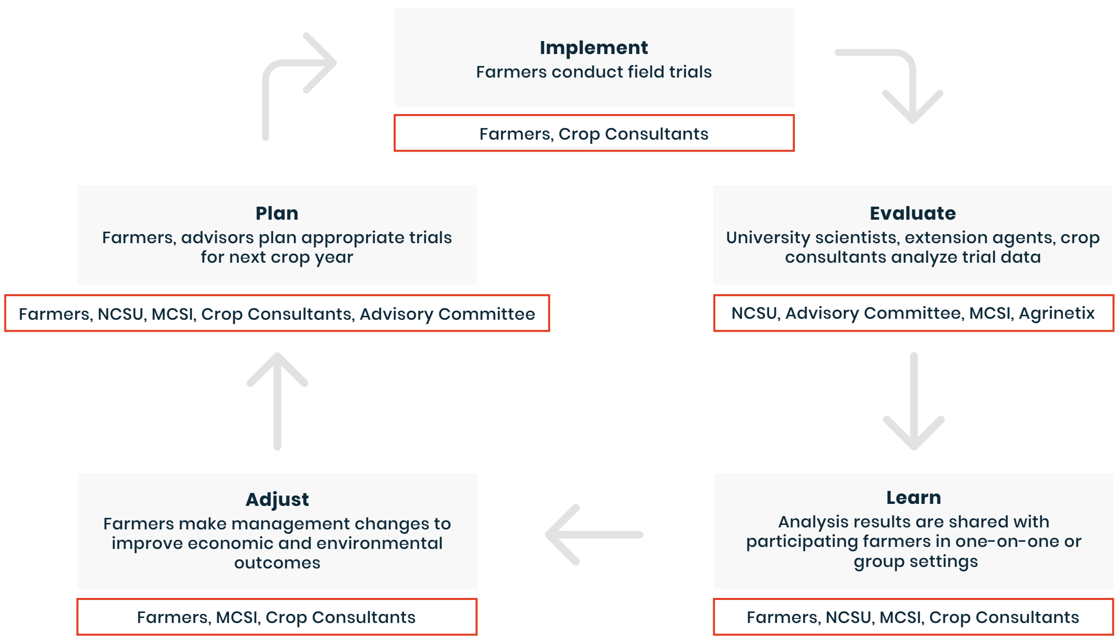

Figure 4 - North Carolina Farmer Network learning model. Orange boxes indicate actors for each step.

Trial protocol development

In early 2013, NCSU led the process of designing the trials, establishing a protocol that would ensure trial results could be interpreted using rigorous scientific and statistical analysis. As the trials advanced, the protocol was amended to address the addition of products, tools and technologies.

Nitrogen rate trials were designed to reflect the growers' actual behavior and field conditions. As such, the treatments included the grower's standard N rate (the rate they would choose to apply that year given predicted weather and price trends), +25 percent of the grower N rate (high rate) and -25 percent of the grower N rate (low rate). Growers fertilized their corn, wheat and sorghum as they normally would with a starter N rate at planting (20-30 lb N/ac on average). The remaining N was applied as a sidedress application at specified growth stages (V5-6 for corn, GS30 for wheat and the five-leaf stage in sorghum). Trials were laid out in equal width strips (8 rows wide in corn, 40 feet wide in wheat) with a minimum length of 250 feet. Treatments were randomly assigned to each strip and replicated four times in each field.

Prior to planting, soil samples were collected and sent to the North Carolina Department of Agriculture and Consumer Services for chemical nutrient analysis and to Waters Agricultural Labs, Inc. (Camilla, GA) for soil organic matter content. Yield data was collected at harvest with calibrated yield monitors on grower-operated combines, or in a few rare cases with data from a weigh wagon. The data was adjusted to standard moisture contents of 13.5 percent for wheat and 15.5 percent for corn. Other collected data included: variety, predominate soil mapping unit, planting and harvest dates, population, prior crop, tillage practice, N application rate and timing and any other applied agrichemicals.

Lessons learned

The protocol established uniform trial methodologies that were critical to creating consistent, useful data. The protocol was reviewed and updated each year as needed to accommodate new trials and to facilitate adjustments from the previous year. This was especially relevant after the 2013 harvest, when the wheat crop data were lost due to a lack of clarity surrounding harvest protocol. An NSCU staff member was on-site to calibrate the combine prior to each harvest, but did not advise the growers on how to line up the combine head to capture only the trial strip. Instead, two side-by-side trial plots with different treatments were harvested at the same time, confounding the data. This was addressed in subsequent years by requiring control strips between trial plots, which act as buffers between the trial strips. This creates the need for additional space in a given field and requires the grower to make extra passes during harvest, but provides much higher confidence in the data.

The 2016 and 2017 wheat crop also proved to be problematic in the lack of a contingency plan due to weather. In both years, a wet fall delayed or prevented planting, resulting in poor yields and narrow trial regions that did not represent the entire Farmer Network. This was compounded further by a general decrease in planted wheat acres due to declining wheat prices in 2015. In 2016, only seven wheat trials were planted, and in 2017 that number dwindled to three. In hindsight, more thought should have been given to whether or not to move forward past a certain plant date, especially when considering the potential statistical weakness of a limited number of trials. The wheat data from both years were excluded from the analysis due to poor yield and lack of statistical power.

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Data management

The process of collecting and sharing data from each trial required significant effort by the entire network and determined the viability of the subsequent evaluation step of the learning model. Each farmer recorded trial yield data with a yield monitor device installed on their harvest equipment. At the outset of the project, NCSU learned that many of the farmers who wanted to participate did not have the necessary yield monitoring equipment. The partners acquired funding to install several of these devices over the first few years of network trials. Raw data was then downloaded to a flash drive from the yield monitor, transferred to the farmer's computer and sent to their crop consultant via email. The crop consultant reviewed and formatted the raw data into a standardized Excel template that included farmer, field and trial information before sending the data to research partners for analysis.

For the first three years of the network, Robert Austin of NCSU collected, processed and analyzed trial data. At the outset of the season, he prepared an Excel sheet with the required data fields for each trial and distributed it to consultants. They returned the completed data sheets post-harvest. For reporting purposes, Austin removed farmer identifying information and assigned each farmer, field and trial with a unique identification code. Personal identifying information was never shared with EDF or the advisory committee. The data then passed through an extensive quality assurance (QA) process before Austin conducted a statistical analysis. In 2016, as the number and complexity of trials increased, Agrinetix LLC[12] an agriculture technology company based in upstate New York, was contracted to receive data from the consultants and carry out the QA process under Austin's supervision.

At the conclusion of each crop year, the anonymized trial data was shared with NutrientStar[13], a third-party science-based program that evaluates the performance of commercially available products, tools and technologies designed to improve farmers' nutrient use efficiency. The incorporation of the data into this national, publicly-available resource provides growers with accurate information on how a product may perform in their unique production environment, whether it be in North Carolina or another region.

[12] Agrinetix, LLC. http://www.agrinetix.com/.

[13] NutrientStar. http://nutrientstar.org/

Lessons learned

Data management emerged as one of the most challenging aspects of the Farmer Network. It was a significant realization for the partners that many of the participating farmers were not directly monitoring crop yields prior to their participation in the network, preventing them from accurately assessing the impacts of management changes on their crops. The installation of yield monitoring devices created more confidence in the yield data and a common data output format. They also provided data that could create detailed yield maps to understand field-level variability, an output that growers found valuable.

Standardization of the data was difficult, even when consultants were given pre-set data fields to complete. Each field had unique trial treatments, layouts and raw data formats. Consultants often did not have the time to fully clean the data, either because they had large amounts to process or were waiting on final data components from growers. This added considerable time to the QA process once the data was transferred to NCSU or Agrinetix. The issue became more pronounced as the complexity and scale of the trials increased, with each additional product, tool or technology requiring specific experimental protocol and data points to be collected. The addition of Agrinetix for data processing support did help address some of these challenges, though Agrinetix personnel changes in 2017 required additional time to ensure continuity of the analysis. This highlights the need to be more explicit of data expectations with partners and consultants, including the well-defined boundaries of what data are needed from each unique trial; and the need for more regular communication with consultants and growers to provide data assistance as needed.

Sharing results with farmers

Communicating the results to farmers is a key point in the farmer network learning model, one that aims to provide data and support to inform N management improvements or changes. The results of the analysis conducted in the previous evaluation step were compiled into simple grower packets that included individualized trial layout, soil and yield maps, soil test reports and summary statistics to explain how each treatment performed. From 2013 to 2015, these packets were delivered to consultants and growers at year-end meetings held at the Sampson County Extension Office in Clinton, N.C., by Dr. Osmond and Robert Austin. The goal of these meetings was to encourage peer-to-peer learning and inspire a social environment that would enable decision support for improved N management. Osmond and Austin also presented trial results to the advisory committee. In 2016 and 2017, Agrinetix prepared the individual grower packets and NCSU authored a bigger picture summary report of all trials. For the latter two seasons, each grower received their packet and overall summary report through their crop consultant in a one-on-one setting, in lieu of a year-end grower meeting. MCSI also held yearly meetings with their broader client base and Network participants to discuss trial results and associated opportunities for improvement.

Lessons learned

The grower meetings held in 2013, 2014 and 2015 were poorly attended, even after adjusting timing, offering meals and sending the invite from different hosts. It's difficult to pinpoint why the large grower meeting format didn't appeal to participants, but it became clear that delivering information in one-on-one meetings between growers and consultants was more effective. In these situations, the crop consultant was able to take a deeper dive into the trial results and provide additional context based on their knowledge of the specific farmers' management practices. One grower expressed appreciation for the project saying, "It's been a great mutual learning process. It's made me better at what I do and more confident in my decision making." Unfortunately, several crop consultants noted that the delivery of the trial results was beyond the point when growers had already made decisions about the coming year, a timeline issue that was difficult to reconcile with the required data processing time.

Overall, this data set did not capture significant changes in farmer behavior in terms of nitrogen management over the course of the project. This could be due to shifts in the participant population (growers joining or departing over the course of the network), adaptive responses to seasonal weather, a project timeline that was too short to reflect long-term trends or simply because the farmer network model did not inspire changes in nitrogen management. The possibility that the model may not be the most effective way to way to create change – especially at the scale needed to observe broad environmental benefits – shifted the partners' focus to other ways to spur change, namely by sharing the data and outcomes more broadly with other stakeholders interested in supporting management improvements.

N balance: Using trial results to inform management changes

The network also provided the opportunity to consider N balance as a measurement of grower's progress towards reducing N losses. N balance captures the benefits gained from improved N management and quantifies environmental outcomes with a simple calculation. N balance is a measure of how much nitrogen remains in a field after harvest[14]. An ideal N balance maximizes fertilizer efficiency and yield while minimizing losses to the environment. In its most simple form, N balance is calculated as: Total N inputs minus total N outputs. Inputs are fertilizers or manures; outputs are the N removed at harvest in grain or in plant residue. When N inputs are high and yields are low, the result is a high N balance. When N inputs are high and yields are high, the N balance is more likely to be low. We can assume added N above the amount in the crop will be: 1) incorporated as soil organic matter and potentially available for subsequent crops, or 2) lost to the environment. The goal is to find a balance where soil organic matter is maintained, but N losses are minimized.

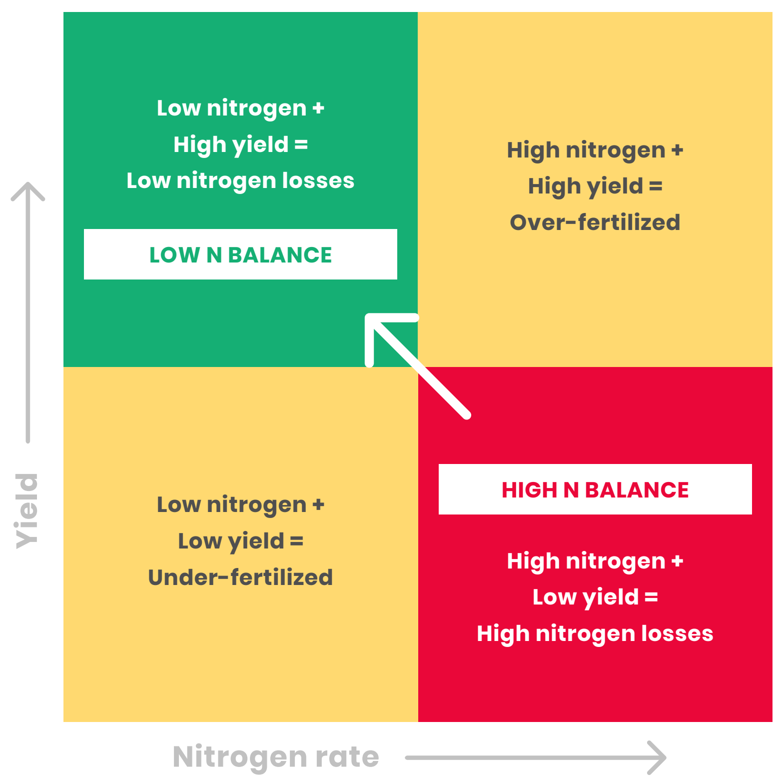

Figure 5 - N balance outcomes given different input and yield scenarios.

[14] McLellan, et al. 2018. The Nitrogen Balancing Act: Tracking the Environmental Performance of Food Production. Bioscience, 68(3), 196.

A five-year view of North Carolina Farmer Network results

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The Farmer Network trials began in 2013 with 33 growers in 7 counties and eventually grew to include 97 unique growers in 26 counties across eastern North Carolina in five years. The trials started with the premise of considering the efficiency of growers' standard nitrogen rates and expanded to evaluate several products, tools and technologies that could return potential environmental and economic benefits. A total of 293 trials were conducted with corn (n=133), wheat (n=143), and sorghum (n=17) on nearly 750 acres.

Year-by-year overview

2013	2014	2015	2016	2017
33 growers in **7** counties	**63** growers in **22** counties	**62** growers in **22** counties	**25** growers in **19** counties	**18** growers in **10** counties
Testing conducted: Nitrogen Rate	**Testing conducted:** Nitrogen Rate, Adapt-N	**Testing conducted:** Nitrogen Rate, Adapt-N, Greenseeker	**Testing conducted:** Nitrogen Rate, Adapt-N, Greenseeker, Instinct II	**Testing conducted:** Nitrogen Rate, Adapt-N, Greenseeker, Instinct II, ESN
Total Trials: 75 Corn - 31 Wheat - 29 Sorghum - 15	**Total Trials: 92** Corn - 38 Wheat - 52 Sorghum - 2	**Total Trials: 75** Corn - 23 Wheat - 52	**Total Trials: 28** Corn - 23 Wheat - 5	**Total Trials: 23** Corn - 18 Wheat - 5
Total Acres: 111	**Total Acres: 256**	**Total Acres: 256**	**Total Acres: 90**	**Total Acres: 111**
Trial Counties: Bladen Cumberland Duplin Harnett Johnston Sampson Wayne	**Trial Counties:** Beaufort Camden Craven Cumberland Duplin Edgecombe Greene Halifax Harnett Johnston Jones Lenoir Nash Northampton Pasquotank Perquimans Pitt Robeson Sampson Suffolk Wayne Wilson	**Trial Counties:** Bertie Beaufort Camden Craven Cumberland Gates Greene Halifax Harnett Johnston Jones Lenoir Nash Northampton Pasquotank Perquimans Pitt Robeson Sampson Suffolk Wayne Wilson	**Trial Counties:** Beaufort Camden Craven Greene Halifax Hertford Johnston Jones Hertford Lenoir Nash Northampton Pasquotank Perquimans Pitt Robeson Sampson Suffolk Wayne Wilson	**Trial Counties:** Beaufort Camden Craven Greene Lenoir Northampton Perquimans Pitt Robeson Suffolk Wayne

Note: Number of growers presented is total participating in that given year. The participating grower population shifted year to year as growers joined or departed the network. The significant decrease in grower participation in 2016 was due to decrease in wheat trials

Nitrogen rate trials

Five years of N rate trials provided important insight into the current state of grower N management in North Carolina. The average grower's standard N rate for corn and wheat shifted from year-to-year, likely a reflection of predicted weather, price trends or participant population (Table 1).

- The observed average grower N rate for wheat was 117 lb N/ac with a range of 115 to 120 lb N/ac.
- In corn, the average grower N rate was 174 lb N/ac with a larger range of 160-190 lb N/ac.
- The sorghum trials presented a unique case and are discussed separately below

Based on anecdotal evidence, many partners at the outset of the project thought that farmers were applying N rates that aligned with reasonable recommendations. However, in a comparison of the grower N rate (GR), +25 percent of the grower N rate (high rate) and -25 percent of the grower N rate (low rate), the optimum agronomic treatment was, more often than not, the low rate (Table 1), indicating that farmers may be applying above recommended N rates. The optimum agronomic treatment was determined statistically as the lowest rate without a significantly different yield, essentially the point at which applying additional N would return little to no yield benefits. An N application rate above the optimum would be expected to increase the proportion of each additional pound of N lost to the environment. The low rate was sufficient to reach the agronomic optimum in anywhere from 40 to 67 percent of wheat trials and 53 to 88 percent of corn trials. Therefore, in some cases, a 25 percent reduction from the grower N rate would likely result in a significant reduction in N losses without a major reduction in yield.

		Optimal Agronomic Treatment						*N Rates*			*Yields*			**Best N Rate**	**Best Yield**
		(# of trials)			*(% of trials)*			*(lb/ac)*			*(bu/ac)*				
Year	**# of Trials**	**Low**	**GR**	**High**	**Low**	**GR**	**High**	**Low**	**GR**	**High**	**Low**	**GR**	**High**	***(lb/ac)***	***(bu/ac)***
								Wheat							
2014	39	19	11	9	49	28	23	87	115	144	66	71	76	108	73
2015	40	19	13	8	48	33	20	94	120	147	63	67	72	114	70
Average								***90***	***117***	***145***	***65***	***69***	***74***		
								Corn							
2013	26	23	2	1	88	8	4	120	160	199	182	187	190	126	185
2014	23	16	5	2	70	22	9	128	171	214	156	166	169	145	164
2015	18	13	5	0	72	28	0	132	175	219	133	141	144	145	137
2016	19	10	3	6	53	16	32	132	175	219	154	164	173	163	167
2017	14	13	2	1	86	7	7	148	190	232	170	174	178	161	173
Average								***132***	***174***	***216***	***159***	***166***	***171***		

Table 1- Summary of number of trials by year, average grower selected N rates, average measured yields, and agronomic best N treatments, N rates and yields. The best N rate and yield represent the average of the statistically 'optimum' N rates and yields.

A deeper look at the grower N rate confirms N was more likely to be over-applied on corn than on wheat (Table 2). In wheat, grower N rates aligned fairly close with both the RYE recommended rates and the statistically determined optimum N rate. The grower yield exceeded the RYE expected yield by an average of 12 bu/ac, but met the optimum yield within 2 bu/ac each year. This indicates that there is minimal over-application of nitrogen to wheat. Winter wheat crops are less likely to be over-fertilized partially due to the crop's lower relative value and to a more climatically stable growing period that reduces the risk of N losses.

In corn, the average grower N rate consistently exceeded both the RYE N rate and the optimum N rate by an average of 43 and 26 lb N/ac, respectively. In five out of six years, the grower rate returned an 11-40 bu/ac greater yield than the RYE N rate. However, the grower N rate (averaging 26 lb N/ac more than the optimum N rate), only met or slightly exceeded the optimum yield. This means that growers were applying more N for a minimal yield return.

> **"It's so difficult to change farmer behavior. At the end of the day these guys are going to make their own decisions based on what they think is best. So, while we may not have had 'light-bulb' moments with all the participating growers, I have seen a general shift in how they talk about nutrient management and how they ask for more information. And I think it's made them more aware of the differences within and between their fields. When we set up these trials on their farms they can really see how tweaking rates can make a big difference and it's led them to thinking more carefully about field-level, more refined management.**
>
> *Billy McLawhorn,*
> *The Network's Managing Crop Consultant*

It should be noted that in some situations minor yield gains may not be statistically significant in an analysis but may be economically attractive for growers. For example, in 2013 the average grower N rate yield was 5 bu/ac greater than the low rate, which may seem like a small number. If input prices are low and market prices are favorable, it could add up to a profit. The challenge for farmers is to predict yield outcomes and market prices at the beginning of the season when they make nitrogen fertilizer decisions.

Wheat

		N Rate Difference (lb N/ac)			Yield Difference (bu/ac)	
	Grower N Rate (lb N/ac)	RYE N Rate	Best N Rate	Grower Yield (bu/ac)	RYE Yield	Best Yield
2014	115	-3	7	71	13	-2
2015	120	4	5	67	1	-2

Corn

		N Rate Difference (lb N/ac)			Yield Difference (bu/ac)	
	Grower N Rate (lb N/ac)	RYE N Rate	Best N Rate	Grower Yield (bu/ac)	RYE Yield	Best Yield
2013	160	31	34	187	40	2
2014	171	41	27	166	17	2
2015	175	42	30	141	-12	4
2016	175	43	12	164	11	-2
2017	190	57	29	174	28	0

Table 2 - Comparison of Grower, RYE, and Best N rates and yields in corn and wheat.

In 2017, there were approximately 890,000 acres of corn grown in North Carolina (USDA-NASS, 2018), a large majority in the Coastal Plain. If we assume the average grower N rate for each trial year represents normal grower practices across those acres, roughly 117.5 million more pounds of N were applied from 2013 to 2017 than would have been at the optimum N rate. Shifting even 20 percent of corn acres to that year’s optimum N rate reduces that number to 94 million pounds of N, while maintaining productivity. This could potentially prevent 23.5 million pounds of N from being lost to the environment while creating a healthier profit margin for growers by reducing fertilizer expenditures.

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N balance: Corn

N balance provides a useful way to compare the efficiency of the grower, optimum and RYE[15] N rates in corn over the five-year trial period. The grower N rate had generally higher N balances than the optimum and RYE rates, which means the potential for N losses was also higher at the grower rate (Table 3). The grower rate exceeded the N balance of the optimum N rate by a range of 13 – 32 lb N/ac, and exceeded the N balance of the RYE N rate by a range of 4 – 50 lb N/ac.

Corn

	Grower N Rate (lb N/ac)	N Rate Difference (lb N/ac)	
		RYE N Rate	Best N Rate
2013	34	-4	-32
2014	60	-30	-25
2015	80	-50	-28
2016	65	-35	-13
2017	74	-38	-26
Average	***63***	***-31***	***-26***

Table 2 - Comparison of Grower, RYE, and Best N rates and yields in corn and wheat.

The grower N rate returned a greater N balance than the RYE or best rate in each trial year. The RYE and best rate N balances were an average of 31 and 26 lb N/ac less than the grower N balance, respectively.

However, the currently accepted N balance “safe zone”, where yield and soil quality is optimized and losses are minimized, is 25 – 75 lb N/ac. This zone will likely be narrowed as additional data is analyzed and the recommendations are refined. There were only two points where the average N balance fell outside of this range: in 2013 with a very low N balance with the optimum N rate and in 2015 with a grower N rate high N balance (Figure 6). This result may appear overly positive, given that these participating farmers manage their nitrogen fairly closely, attributable to selection bias. Even within the safe zone, farmers should consider the economic and environmental implications of excess N left in the field at harvest and adjust for the following year.

[15] RYE N rates were not included in field trials. The RYE N balance calculation uses recommended N rate and expected yield as determined by the RYE database.

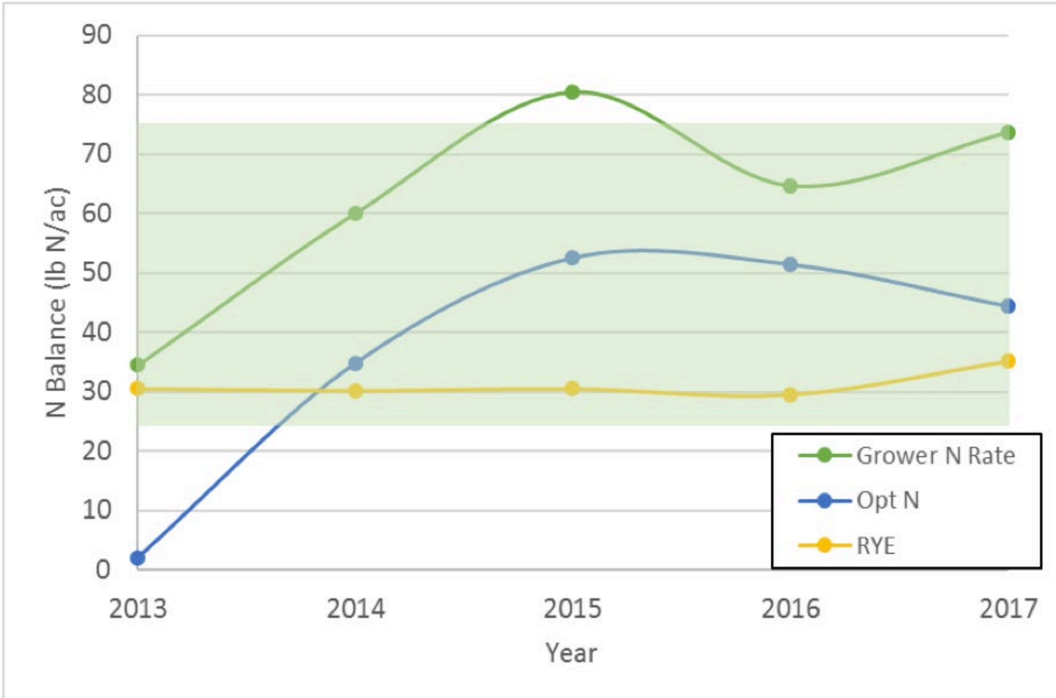

Figure 6 - Average N balance by year and N rate in corn.

At the conclusion of the 2017 crop year, N balance analysis was included in the grower reports and presented by EDF at a grower meeting. This was an opportunity to begin socializing the framework with a small group of participating growers as well as gauge their reactions and collect feedback. The group was most interested in the anonymous benchmarking results, where growers' N inputs, yield and N balances were graphically compared to others. This led to a discussion about what one grower may be doing differently than the others, sparking a bit of a competitive spirit, a potentially helpful motivator. This peer benchmarking has been theorized as a way to influence behavior change and encourage adoption of practices that improve N balance[16].

Nitrogen rate trials: Sorghum

Sorghum was included in the first two years of N rate trials. In 2013, 15 sorghum trials were planted, though weather caused late planting of the plots. Of those, eight were left unharvested due to very low yields and those that were harvested were also relatively low yielding. In 2014, only 2 sorghum trials were planted, which also yielded poorly. It became clear that sorghum was not well suited for the Coastal Plain and the decision was made to discontinue the trials.

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[16] McLellan, et al. 2018. The Nitrogen Balancing Act: Tracking the Environmental Performance of Food Production. Bioscience, 68(3), 196.

Lessons learned: Sorghum

It was difficult to recruit growers to plant sorghum trials, especially given the experimental nature of the crop and the low yields observed in the first year. Sorghum didn't fit into the rotation of growers as easily as the partners and crop consultants initially thought, so available fields were limited. There were also equipment adjustments that had to be made for harvest, an additional step that many growers found to be a burden. Even with incentives from Smithfield Foods and NRCS, growers were hesitant about the true market demand. While the opportunity seemed ripe for introducing sorghum, the trials may have been more successful with a gradual introduction to several growers who could fine tune their management and serve as models for others.

Products, tools and technologies results[17]

There are a wide array of nitrogen management solutions targeted to farmers. Participating growers expressed previous interest in several options, noting that the cost and uncertainty of results kept them from trying them on their own. Based on grower feedback, the advisory committee and crop consultants identified potentially promising products, tools and technologies that were integrated into the Farmer Network trials. While some trials revealed potential benefits, the varied results suggest that implementation of these products should be carefully considered on a case-by-case basis.

	2013		2014		2015		2016		2017	
Testing Conducted	Corn	Wheat	Corn	Wheat	Corn	Wheat	Corn	Wheat	Corn	Wheat
Nitrogen Rate	X	X	X	X	X	X	X	X	X	X
Adapt-N			X		X		X		X	
GreenSeeker®					X		X		X	X
Instinct®							X		X	
ESN®									X	X

Table 4 - Summary of products, tools and technologies evaluated in the Farmer Network.

[17] The discussion of these results is largely based on analysis completed by Robert Austin, NCSU in year-end summary reports provided to growers and stakeholders.

Adapt-N

Adapt-N (Yara International) is a software tool that makes nitrogen recommendations for corn based on soil types, field management and real-time crop characteristics and weather[18]. The tool has been evaluated in the Northeast and Midwestern growing regions and had not yet been field tested in the unique production environments of the Southeast[19].

In 2014, Adapt-N was added to the Farmer Network trials to compare Adapt-N recommended N rates to the grower's standard N rate, +25 percent of the grower N rate (high rate) and -25 percent of the grower N rate (low rate). All plots received the same amount of N fertilizer at planting. The software was used to make mid-season sidedress N recommendations, with the recommended rate applied to replicate strips alongside the grower rates. These trials continued through the 2017 crop year.

Adapt-N results: Corn

A total of 38 Adapt-N trials were conducted on corn from 2014 to 2017. Of those, there was a statistically significant yield difference between treatments in 17 trials (Table 4). The grower N rate returned higher yields in 4 trials by an average of 20 bu/ac. In 12 trials, there were overall yield effects, but the grower N and Adapt-N rates returned yields that were not statistically different. In one trial the grower N rate had a lower yield than the Adapt-N rate. On average, Adapt-N recommended 14 lb N/ac less than the grower rate and returned an average yield of 3 bu/ac less.

The results suggest that 58 percent of the time farmers could have lowered N rates by approximately 25 percent without a statistically significant yield penalty, although the low rate had on average lower yields: 5 bu/ac less than the Adapt-N rate, 7 bu/ac less than the grower N rate and 10 bu/ac less than high rate. Similar to the nitrogen rate trials discussed earlier, N rates associated with the grower rate minus 25 percent treatments (low rate) were on average nearly identical to RYE N rate recommendations[20].

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[18] Adapt-N. http://www.adapt-n.com/

[19] Osmond, D.L., R. Austin, S. Shelton, H. van Es, and S. Sela. 2018. Evaluation of Adapt-N and Realistic Yield Expectation Approaches for Maize Nitrogen Management in North Carolina. Soil Sci. Soc. Am. J. doi: 10.2136/sssaj2018.03.0127

[20] Osmond, D.L., R. Austin, S. Shelton, H. van Es, and S. Sela. 2018. Evaluation of Adapt-N and Realistic Yield Expectation Approaches for Maize Nitrogen Management in North Carolina. Soil Sci. Soc. Am. J. doi: 10.2136/sssaj2018.03.0127

Grower N > Adapt N

Farm ID	Year	Low N Rate	Grower N Rate	High N Rate	Adapt-N Rate	Grower N Rate	Adapt-N Rate	RYE N Rate
		Corn Yield (bu/ac)				N Rate (lb N/ac)		
Farm 2	2014	204 b	220 a	225 a	204 b	223	153	124
Farm 3	2014	149 d	183 b	203 a	165 c	155	127	135
Farm 6	2014	191 a	195 a	195 a	174 b	159	52	135
Farm 11	2015	127 b,c	146 a,b	148 a	122 c	203	145	138
Average		**168**	**186**	**193**	**166**	**185**	**119**	**133**

Grower N = Adapt N

Farm ID	Year	Low N Rate	Grower N Rate	High N Rate	Adapt-N Rate	Grower N Rate	Adapt-N Rate	RYE N Rate
		Corn Yield (bu/ac)				N Rate (lb N/ac)		
Farm 3	2015	78 b,c	82 ab	75 c	83 a	117	157	121
Farm 6	2015	156 b	181 a	190 a	180 a	205	204	140
Farm 8	2015	101 b	110 ab	113 a	104 b	167	166	148
Farm 10	2014	165 b	189 a	184 a	178 a	136	134	144
Farm 14	2016	173 b	187 a	194 a	194 a	150	145	121
Farm 20	2016	91 b	90 b	99 a	92 ab	103	88	102
Farm 21	2016	166 b	215 a	214 a	218 s	225	250	128
Farm 23	2016	174 b	179 b	205 a	194 ab	170	170	143
Farm 27	2016	89 c	115 b	136 a	120 ab	286	281	148
Farm 29	2016	100 b	116 b	150 a	122 ab	140	144	135
Farm 30	2016	120 b	127 ab	134 a	132 a	160	162	135
Farm 31	2017	199 b	219 a	227 a	220 a	225	205	135
Average		**134**	**151**	**160**	**153**	**174**	**176**	**133**

Grower N < Adapt N

Farm ID	Year	Low N Rate	Grower N Rate	High N Rate	Adapt-N Rate	Grower N Rate	Adapt-N Rate	RYE N Rate
		Corn Yield (bu/ac)				N Rate (lb N/ac)		
Farm 18	2016	205 c	214 b	232 a	231 a	173	205	138

Table 5 - Comparison of corn yield with Adapt-N and grower rates. Different lowercase letters indicate which treatments are statistically different. Yields with the same letter are not statistically different.

Lessons learned

Overall, Adapt-N performed similarly to the grower N rate with small trade-offs between yield and N applied. This analysis did not consider the technology fee associated with Adapt-N, which growers may be hesitant to incur if the benefits are not significant. The software was also found to be fairly sensitive to certain data inputs, such as soil organic matter, which could be problematic if a grower has not had a recent soil test.

GreenSeeker®

GreenSeeker® (Trimble) is a crop sensing system that uses optical sensors to take real-time measurements of the crop's development and variability. The device is mounted to a grower's spray boom (the piece of equipment typically used to apply N fertilizer) and instantly translates the collected information into an application of nitrogen for which the rate varies as needed across the field. This type of precision management tool helps growers reduce excessive N applications by identifying areas that need less N, but can be expensive and difficult to calibrate. For example, the system requires the operator to set an application algorithm as well values for days from plant, previous nitrogen applied, yield potential and N use efficiency (NUE). In these trials, a southeastern regional-specific algorithm developed by Virginia Tech was used and NUE was set between 0.45-0.55 for wheat and at 0.5 for corn.

GreenSeeker® trials were conducted in 2015 and 2016 on corn and in 2017 on both corn and wheat. The trials were placed in strips (minimum length of 300 feet) with four replications. The GreenSeeker® was calibrated to each field site, then used to apply sidedress N across the strips based on real-time sensor readings. These strips were compared to the high, grower's standard and low rates in the N rate trials to understand how N rate and yield varied.

GreenSeeker® results: Corn

Eleven GreenSeeker® trials were completed in corn in 2015. On average, the GreenSeeker® N rate was 137 lb N/ac compared to the grower's standard N rate of 178 lb N/ac – a 23 percent difference. However, in all but three trials, the average yield from the GreenSeeker® treatments fell within 5 bu/ac of the yield from plots treated with the grower's standard N rate. The GreenSeeker® yields, achieved with less N, indicate that the tool could contribute to an overall decrease in N applications on a field without a major yield reduction.

However, a 5 bu/ac change in yield can affect growers' profits. Based on a partial budget analysis[21], the grower's standard rate returned the largest net return at $431/ac, followed closely by GreenSeeker® at $429/ac. This budget analysis did not consider the cost of the GreenSeeker® system, which can be $20,000 or more.

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[21] A partial budget analysis was performed using dollar amounts that reflected national basis nitrogen and grain prices for the 2015 season (cost of nitrogen = $0.70/lb, price received for grain = $3.80). Using these assumptions, a net return was calculated for the average nitrogen expense and yield observed by treatment.

In the second year of trials (2016), the average N rate applied with GreenSeeker® (142 lb N/ac) was again much lower than the average grower's standard rate (181 lb/N ac). Unfortunately, the lower N rates were not able to match the standard rate yield as they did in 2015. Yields from the GreenSeeker® treated plots were 10 bu/ac lower than yield from the grower's standard treated plots (140 bu/ac). In six of the 10 trials, the grower would have seen an average loss of profit of $36/ac in using GreenSeeker® over their standard rate[22]. In the four trials where the return was positive, GreenSeeker® returned an average net profit of $3/ac.

In 2017, the GreenSeeker® N rate again averaged less than the grower's standard rate, though by a slimmer margin (171 lb N/ac and 193 lb N/ac, respectively, for an average of 22 lb N less/ac). However, GreenSeeker® did not always apply less than the growers' standard rate and in two trials it applied more. In one trial, GreenSeeker® applied 31 lbs N/ac more than the growers' standard rate of 170 lbs N/ac. Interestingly, this trial resulted in the largest difference in yield and greatest net profit, however with a relatively poor N efficiency. On average, GreenSeeker® yields were lower than the growers' standard but were within 10 bu/ac (five trials had lower yields, two had greater).

GreenSeeker® results: Wheat

Four GreenSeeker® trials were conducted on wheat in 2017. On average, GreenSeeker® applied 33 lb N/ac less N than the grower's standard rate, returning yield consistently lower than the grower's standard rate by 5 bu/ac. In terms of profit, GreenSeeker® treatments averaged $10/ac less than the grower's standard rate.

Lessons learned

The GreenSeeker® technology consistently applied lower N rates than the grower's standard rates in corn and wheat over 3 trial years. The lower N rates returned lower yields by an average of 5-10 bu/ac in corn and 5 bu/ac in wheat, accompanied by profit losses in the range of $2-$36/ac.

The nature of the GreenSeeker® technology presented several challenges in conducting these trials. First, the application and calibration of the Virginia Tech algorithm was difficult. Upon analysis of the 2015 corn data, researchers reflected that this may not have been done properly. It could also be possible that the

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[22] Analysis assumes a cost of $0.36/lb nitrogen and a price received of $3.85/bu corn. A GreenSeeker technology fee is not included in this analysis and thus does not represent the total cost of using GreenSeeker to make a recommendation.

regional-specific algorithm was applied correctly, but the conditions in the field were unique enough to not fall within the algorithm's specified ranges. This raises the question of how much time and funding should be invested into refinement of the tool at smaller-scales, particularly when the profit margin of using it already appears to be thin. Second, the potential value to the grower of using GreenSeeker® increases when fields are highly variable and adjustments in N rates can be made as appropriate across a field. However, to minimize variables in N rate trials, the experimental design protocol calls for trial strips to be set out on portions of fields that have uniform soil types. An amendment to the protocol in 2017 sought to include more soil variability and a larger spatial area, but researchers were unable to reach a conclusion on the impact of this with only one year of observations. As such, these trials may not have captured GreenSeeker® reaching its full potential. Finally, integrating an additional piece of equipment can complicate the data collection process. In 2015, data from three trials was lost to equipment failure, with one more being lost to issues with harvest machinery.

At the outset of the trials, Smithfield purchased five GreenSeeker® units to be used by participating growers for a trial period. This significant investment contributed to the successful implementation of the GreenSeeker® trials, but failed to spark consistent adoption of the tool, even when offered at no cost. Of the five units, only one is still being used by a grower, who has been experimenting with its application in alternate crops, such as tobacco. The others have been returned to crop consultants and continue to be used in informal experiments.

Instinct®

Instinct® II (Dow AgroSciences), a nitrogen stabilizer, was applied to corn with N fertilizer at the product's recommended application rate. The product is designed to inhibit the microbial activity that converts N fertilizer N from ammonium (NH_4^+) to nitrate (NO_3) in a process called nitrification. Plants prefer to take up N as NO_3, but it is the form that is most susceptible to be lost from the soil via leaching. If nitrification can be delayed, the risk of N losses to the environment can be decreased and NO_3 will become available to the crop for an extended period beyond the application date. Instinct® is widely used in the Midwest, where applications can improve grain yield and reduce nitrification,[23] though data on its performance in the unique soil and climate conditions of the Southeast is limited.

Instinct® trials were conducted in 2016 and 2017 in corn. The product was mixed with urea ammonium nitrate (UAN, a liquid fertilizer product most commonly used in the Southeast) at the manufacturer's recommended rate of 37 oz/ac. Instinct® was added to the low nitrogen rate (-25 percent of the grower's standard rate) and the grower rate to evaluate the impact on yield. Each treatment was replicated four times.

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[23] Nutrientstar. 2016. Instinct II and N-Serve Research Findings. http://nutrientstar.org/tool-finder/nitrapyrin-research-findings/

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Instinct® results: Corn

In 2016, 13 Instinct® trials were conducted. On average, the difference in yield between the low rate and low rate + Instinct® was 0 bu/ac. The same was true of the average difference in yield between the grower's standard rate and the standard rate + Instinct®. In six of the 13 trials, both the low rate + Instinct® and the grower standard rate + Instinct® resulted in an agronomic loss compared to the same rate without the product. The average profit loss with Instinct® treatments was $12/ac, which is essentially the material cost of the product[24].

In 2017, the results were similar between the low rate and low rate + Instinct®, with an average loss of 2 bu/ac with the product. However, the addition of Instinct® to the grower's standard rate appeared to have a positive effect with an average yield advantage of 7 bu/ac. This translated to an average profit of $14 more per ac when Instinct® was used at the grower rate than when it was not[25]. The difference in effectiveness of the product at different N rates is unusual and may reflect management or environmental factors.

Lessons learned

The nitrification process is heavily influenced by weather and soil moisture content, with the process optimized under moist, aerated soil conditions. Weather differences between the two crop years could have influenced yields. The 2017 crop year was wetter and less variable across trial sites than 2016 (25 inches compared to 23 inches, respectively), creating an environment where nitrification was likely to happen quickly and Instinct® could be more effective (Austin, forthcoming). While Instinct® may offer yield benefits in years with specific climatic conditions (such as those in the Midwest), it does not appear to provide enough of a yield benefit that would encourage a grower to apply less N to reach the same yield goal.

ESN®

ESN® (Nutrien) is a 44 percent urea granule with a polymer coating that delays the release of N. As soil moisture and temperature increase, conditions that align with plant growth, the polymer dissolves and N is released. This means less N is available to be lost to the environment before the crop enters a period of rapid growth and N uptake.

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[24] Economic analysis assumes a cost of $0.36/lb nitrogen and a price received of $3.85/bu corn. The average cost for Instinct® II was $44/gallon (~$12.70/ac).

[25] $3.88/bu received, $0.36/lb UAN, $12.70/ac Instinct II

In 2017, ESN® was evaluated in corn and wheat as a blend of 75 percent ESN® and 25 percent ammonium sulfate (38-0-0-6S). The blend assures some N is available at application in the form of ammonium sulfate. All plots received uniform applications of N at plant in the form of UAN. At sidedress, the ESN® blend and the grower standard treatments were applied at the same N rate to identify yield effects of the different N sources. The trials were replicated in strips.

ESN® results: Corn

The nitrification process is heavily influenced by weather and soil moisture content, with the process Across 12 corn trials, there was no difference in yield or related profit on average between the ESN® and the grower's standard rate treatments. When the cost of the product was factored in, ESN® treatments returned an average $51/ac profit loss.

ESN® results: Wheat

In three trials, the yield difference between ESN® and the grower's standard rate ranged from a 5 bu/ac loss to a 5 bu/ac gain but yield was not significantly different under statistical analysis. When the price of ESN®[26] was factored into the profit analysis, losses varied widely ($2 to $65/ac) but averaged $26/ac loss.

Lessons learned

It is difficult to draw clear conclusions from a single year of trial data. As with similarly themed N fertilizer products, ESN® is likely to perform differently from year to year based on weather and soil conditions, as well as other management factors. For example, ESN® is a solid fertilizer that is broadcast on the soil surface. One grower reported that an unexpected heavy rain came through soon after he applied ESN®, sweeping the granules away completely. On the other hand, one grower found the delayed-release mechanism to be helpful in managing his time and has been conducting his own ESN® trials with various blends on his wheat and soybeans.

[26] The cost of ESN® as of January 2015 was $0.69/ac.

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Products, tools and technologies results summary

The evaluation of these products, tools and technologies in on-farm trials was an important component for participating growers. Their engagement provided them firsthand experience of trial protocols and direct observations of how a product may or may not be appropriate for their operation.

While there were a few instances where the tested product revealed marginal benefits, the majority of trials did not appear to provide yield or economic benefits to participants in the North Carolina Farmer Network. The adoption of these tools should be considered carefully on a case-by-case basis.

Corn

	N Rate	Yield	Economics
Trial			
Adapt-N	On average, Adapt-N recommended 14 lb N/ac less than the grower rate.	On average, Adapt-N recommended rates returned an average yield of 3 bu/ac less	Did not conduct economic analysis with technology fee.
GreenSeeker®	Over three years of corn trials, GreenSeeker® N rate was consistently lower than the grower rate.	GreenSeeker® yields averaged 5-10 bu/ac lower than the grower rate.	GreenSeeker® returned both positive and negative economic outcomes, but the full cost of adopting GreenSeeker® technology was not considered in analysis.
Instinct®	There was no evidence that the use of Instinct® provided incentive to reduce N rate.	In one case, the product provided a yield advantage of 7 bu/ac. In all other trials, there was no yield gain or a slight loss in yield.	Instinct® was associated with a profit in one trial. The material cost of the product returned economic losses in all other trials.
ESN®	There was no evidence that the use of ESN® provided incentive to reduce N rate.	There was no difference in yield when using ESN® compared to the grower rate.	The material cost of the product returned economic losses in all trials.

Wheat

	N Rate	Yield	Economics
Trial			
GreenSeeker®	On average, GreenSeeker® applied 33 lb N/ac less than the grower rate.	Yield consistently lower than the grower rate by 5 bu/ac.	GreenSeeker® treatments averaged $10/ac less profit than the grower rate. Full cost of adopting GreenSeeker® technology was not considered in analysis.
ESN®	There was no evidence that the use of ESN® provided incentive to reduce N rate.	In 3 trials, the yield difference between ESN® and the grower's standard rate ranged from a 5 bu/ac loss to a 5 bu/ac gain but yield was not significantly different under statistical analysis.	When the price of ESN® was factored into the profit analysis, losses varied widely ($2 to $65/ac) but averaged $26/ac loss

Translating findings into action

The Farmer Network results provide farmers, scientists and environmental and agricultural organizations with a better understanding of nitrogen management in North Carolina and opportunities to address over-application where it exists. Lessons-learned and data generated from this project have already proven to have impacts reaching growers, academia, industry and policy makers. The network also provides insight into the real-world applicability of the farmer network learning model.

The application of the model in North Carolina (Figure 4) demonstrated a participatory learning and adaptive management environment using basic research principles and the use of the appropriate data collection methods and protocols to assure that results are scientifically valid and repeatable, which are two important components highlighted in the Farmer Network Design Manual.

> **We have one grower we had been working with for a few years and he was great. I was trying to get one of his neighbors to participate as well, but he just never would. Turns out, every time I came to the participating grower's farm to do anything – set up trials, apply fertilizer, give the yearly report – the neighbor was coming over within 10 minutes after I left to get the scoop! I didn't find this out until it had been going on for about three years, when the grower told me his neighbor was complaining that the report was a bit later than usual and the neighbor just couldn't wait to see the results. So, even in situations where we may not see huge on-farm changes, the neighbors are watching like hawks. They're seeing what's going on and learning, as well.**
>
> *Billy McLawhorn,*
> *The Network's Managing Crop Consultant*

The third component, the development of proven methods for sharing, discussing and communicating results of on-farm studies, proved to be more challenging. Participating farmers were given individualized reports at the end of each year and these reports were adapted through the project to include more meaningful interpretations and relevant data. However, the project was not able to consistently bring together a group of farmers to discuss these results and create a more engaging, peer-driven learning experience. There may be opportunities to improve this aspect in future efforts with a better understanding of the social drivers of farmers in North Carolina and the Southeast. The effectiveness of the learning model to generate broad behavior change is largely dependent on peer-to-peer learning and creating a social environment that encourages change.

Though individual participants in the North Carolina Farmer Network responded positively to the project, the model in itself may not be enough to drive behavior change. The data did not capture significant changes in N management over the course of five years. This type of outcome has been observed in other networks, too. In Indiana, the average network participant response to the statement, “I have changed the N management on my farm based on what I learned through the network,” fell between neutral and agree[27]. Given this limitation, it is important that the valuable data and lessons learned are integrated into other pathways that may lead to positive change.

The following outcomes amplify the results from the North Carolina Farmer Network:

Provide useful information to farmers. Growers have reacted positively to the individualized grower reports that they receive at the end of each crop year. They expressed more interest in their unique reports than in participating in a larger group discussion or idea exchange, which is an important observation for future knowledge-sharing initiatives. The intensive data analysis process conducted by NCSU, Agrinetix, and McLawhorn Crop Services provided important benchmarks and helped explain variability from year to year and from field to field. Farmers appreciate results that are specific enough to explain the impact that climate or soils may have had on that crop and they indicated that information is useful for making future decisions. Growers also voiced their confidence in the farmer network data for the strict trial protocols and unbiased oversight of trials and data analysis, noting that the results carry more weight when they are large-scale field trials on their own operations rather than small-plot trials managed by others.

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[27] Pape, A. and L.S. Prokopy. 2017. Delivering on the potential of formal farmer networks: Insights from Indiana. Journal of Soil and Water Conservation 72(5):463-470.

Advance scientific understanding of N management. Insights on N management in North Carolina will be shared broadly in two academic articles in peer-reviewed journals. The first, published in the Soil Science Society of America Journal in 2018 focuses specifically on the suitability of Adapt-N for making N recommendations in the Southeast, which may have implications for how the model is calibrated for this and other regions[28]. The second, currently pending publication, documents the five years of the North Carolina Farmer Network and explores conclusions from the N rate trials. Preliminary data has also been presented at numerous conferences and events by Dr. Deanna Osmond of NCSU and by EDF. Results have been used to update N.C. Cooperative Extension fact sheets related to nutrient management, available online and in each of the 101 extension offices in the state. Results have also been incorporated into the American Society of Agronomy's Certified Crop Advisor (CCA) continuing education modules, which are available to more than 13,000 CCAs nationwide.

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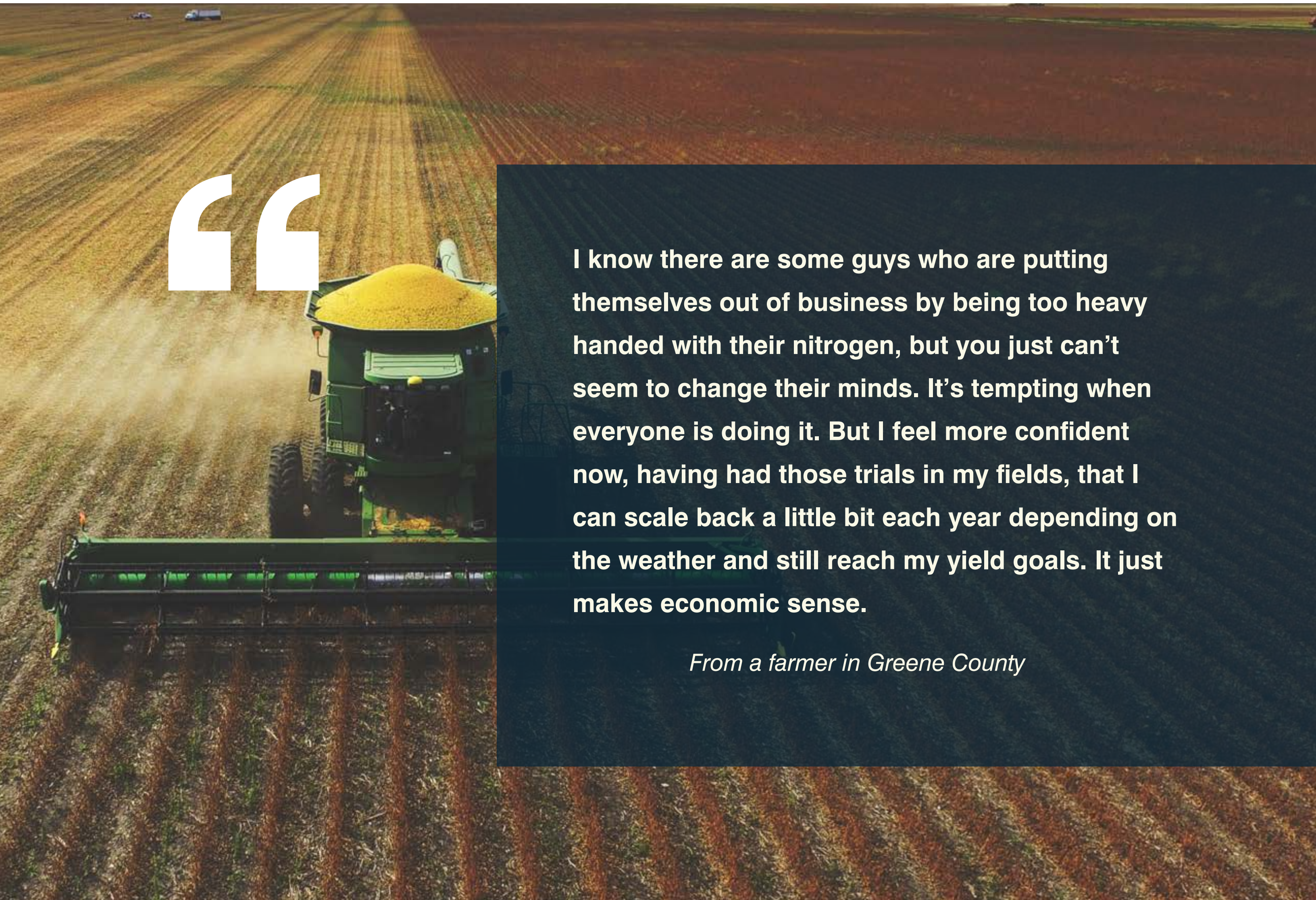
[28] Osmond, D.L., R. Austin, S. Shelton, H. van Es, and S. Sela. 2018. Evaluation of Adapt-N and Realistic Yield Expectation Approaches for Maize Nitrogen Management in North Carolina. Soil Sci. Soc. Am. J. doi: 10.2136/sssaj2018.03.0127



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I know there are some guys who are putting themselves out of business by being too heavy handed with their nitrogen, but you just can't seem to change their minds. It's tempting when everyone is doing it. But I feel more confident now, having had those trials in my fields, that I can scale back a little bit each year depending on the weather and still reach my yield goals. It just makes economic sense.

From a farmer in Greene County

Establish Southeast as example of data excellence. Data has also been incorporated into NutrientStar[29], a third-party science-based program that evaluates the performance of commercially available products, tools, and technologies designed to improve farmers' nutrient use efficiency. The inclusion of the N.C. data is a major milestone for several reasons. First, much of the testing done on these types of products is conducted by the manufacturers, creating a potential source of bias. Growers took an active role in these trials and reported higher levels of trust in the results.

Second, the Network data provides an important Southeastern perspective. Many of these products are developed with the Midwest in mind and may not perform as well in the Southeast's climate, soil types and management practices. These scientific data provide growers in North Carolina with confidence to make decisions about which tools are most appropriate for their operation.

Finally, the Network trials set a higher standard for improved product testing through field-scale plots and data transparency. The development and implementation of the robust trial protocol by the project partners demonstrates broad support for trials that are both scientifically sound and reflect the grower experience, an approach that should be applied more broadly in the Southeast and in other major production areas.

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[29] NutrientStar. http://nutrientstar.org/

[30] North Carolina Interagency Nutrient Management Committee. 2018. http://nutrients.soil.ncsu.edu/interagency/

[31] North Carolina Department of Environmental Quality Animal Feed Operations Program. 2018. Facts about North-Carolina's Animal Feeding Operations Program. https://deq.nc.gov/about/divisions/water-resources/water-resources-permits/wastewater-branch/animal-feeding-operation-permits/afo-program-summary.

Validate and refine nutrient management recommendations. The North Carolina Interagency Nutrient Management Council[30] (INMC) is currently reviewing the Farmer Network data to inform the statewide N rate recommendation program. The INMC consists of representatives from N.C. Cooperative Extension, NCSU Crop and Soil Sciences Department, N.C. Department of Agriculture & Consumer Services Agronomic Division, Division of Soil & Water Conservation, and Environmental Programs Division, N.C. Department of Environmental Quality and the USDA Natural Resources Conservation Service. The INMC conducts the data collection and review process that informs the development of the RYE database, which is used statewide by growers and crop consultants as the basis for N rate recommendations. Upon publication of the pending academic article with Farmer Network N rate trial results, the INMC will consider the data and determine if adjustments to specific N management recommendations in the RYE database are warranted.

The INMC also develops technical recommendations and resources related to manure nutrient management. North Carolina requires all permitted animal operations to have a Certified Animal Waste Management Plan that details manure applications to crop fields[31]. An operation must be permitted if it holds more than 250 swine, 100 confined cattle, 75 horses, 1,000 sheep or 30,000 poultry with a liquid waste management system. The nearly 2,600 operations must reference the RYE database for rates at which manure can be applied to crops.

Data Inform supply chain sustainability initiatives with impactful data. Smithfield, the world's largest pork producer, produces nearly 16.4 million hogs each year, with a large percentage of those raised on 225 company-owned farms and approximately 750 contract farms in North Carolina's Coastal Plain, and sources an increasing amount of grain annually. In 2013, the company made an industry-leading commitment to engage 75 percent of the acres (450,000 acres) from which it sources grain directly in sustainability initiatives that optimize fertilizer use. EDF and Smithfield formed a partnership to determine how the company could reach its goal, collaborating in the design of Smithfield's grain sustainability initiative, known as Smithfield Agronomics.

Smithfield Agronomics offers support to grain farmers interested in optimizing their fertilizer use or building the health of their soils. The program provides agronomic expertise, technology trials, low-cost cover crop seed and other opportunities to participating farmers.

The North Carolina Farmer Network research informed Smithfield's implementation of its grain sustainability initiative. EDF and N.C. State University identified a research gap in the efficacy of nitrogen efficiency tools, technologies and products. Most of these tools were developed in the Midwest and had limited research results in the Southeast. The Farmer Network helped fill that gap by testing four tools and informed Smithfield's decisions on which to offer through its sustainability program.

Taking the next step: Tomorrow's Farmer Network

Taking the next step: Tomorrow's Farmer Network

Nitrogen management decision making is complex and influenced by ever-shifting variables. In the Coastal Plain, growers face changing weather patterns and often unpredictable markets. They have been challenged to increase productivity while reducing environmental impact, and face a vast array of guidance and products offered to them to achieve that goal.

The North Carolina Farmer Network equipped growers with five years of data from science-based in-field trials to inform their nitrogen management decisions. Aside from the vital data and knowledge generated by the Farmer Network, it also served as a spark to raise important questions, to identify and advance a common goal and to develop meaningful partnerships. In that spirit, there was a recognition that field trials would not continue in perpetuity and 2017 marked the final year of trials. However, there is undeniable value in the diversity of relationships that is the foundation of the Farmer Network. Participants and partners will continue to be a source of inspiration, posing challenges and raising issues that are best solved together.

The insights gained from the North Carolina Farmer Network can benefit farmers, state agencies, environmental organizations and others interested in sustainable grain production, ensuring farmers' economic success, preserving agricultural productivity and improving environmental outcomes in the Coastal Plain and beyond. Moving forward, these stakeholders should take the following conclusions into consideration:

Farmers in North Carolina are more likely to over-apply nitrogen on corn than wheat. The data shows that corn is more often over-fertilized than wheat, and that in a majority of cases, a reduction of up to 25 percent in total N applied can reduce N losses without sacrificing yield. Future work to improve nitrogen management should focus on corn as part of a diverse rotation to better understand farmers' motivations for choosing higher N rates. Conservation practice funding and other management initiatives should focus on areas where corn is a predominant crop.

Products, tools and technologies to improve nitrogen management must be carefully considered. Marginal benefits were observed in a few network trials, but in a large majority, the evaluated products, tools and technologies did not appear to provide yield or economic benefits. These trials provided important geographical context for products that have limited data on their performance in the Southeast. Farmers were eager to participate and experiment with products they had heard of, but did not had the resources or opportunity to try on their own. They told crop consultants they had higher levels of confidence in the large plot, in-field trials than the small plot trials commonly used in industry trials.

The farmer network learning model can be an effective first step, but lessons learned must be shared more broadly. While the data did not reflect changes in farmers' nitrogen management within the scope of the project, network participants gave positive feedback to researchers and crop consultants about their experiences. This conclusion led project partners to identify additional pathways to create an environment that is supportive of behavior change, such as: partnering with North Carolina State University to advance scientific understanding of the issue, sharing data with NutrientStar to highlight the success of farmer-led, large plot field trials and create geographically relevant information, consider data in refining state-level nitrogen recommendations and involve corporate partners to identify opportunities for sustainable supply chain improvement.

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