2015

Success Stories on User Engagement

Global Science & Technology, Inc.

Case Study 1: Adapt-N

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Acronyms used

ASOS: Automated Surface Observation System
ATC: Agronomic Technology Corporation
CWC: Center for Weather and Climate
DTN: (formerly known as) Data Transmission Network
EPA: Environmental Protection Agency
GHCN-D: Global Historical Climatology Network Daily
GST: Global Science & Technology Inc.
MPE: Multi-sensor Precipitation Estimates
N: Nitrogen
NCEI: National Centers for Environmental Information
NRCC: Northeast Regional Climate Center
PNM: Precision Nitrogen Management
RAP: Rapid Refresh Model
RCC: Regional Climate Centers

1 Success stories on user engagement

This report serves as the first of three in-depth case studies that examine user engagement with National Centers for Environmental Information's (NCEI) climate and weather data. The case studies demonstrate the value that the free and publicly available provision of NCEI's climate and weather data has provided to key sectors utilizing this service, and also to society at large. Each case study focuses on a different NCEI weather and data product, in-situ, satellite, radar, or blended product and explains the application of these data to an essential sector in the US economy. The extensive research and interviews that inform these case studies detail how an organization or company has used NCEI's climate and weather data, for what purpose, and ultimately what benefit the use of these data has provided to either their own business and/or the final end users. The three case studies demonstrate that climate and weather data are an indispensable public and societal good that is informing smart economic and environmental decision-making.

This first case study focuses on Adapt-N, a decision-support tool designed to help corn growers optimally manage applications of nitrogen fertilizer. Nitrogen is a critical input to corn production increasing yields of a commodity that represents the most widely planted crop in the United States. The value of corn to the American economy was estimated at $51.9 billion USD in 2014 (National Corn Growers Association, 2015).

The full rationale for selecting this case study within the context of the use of NCEI data is presented in Appendix 2.

2 What is Adapt-N?

Adapt-N is a web-based decision support tool that helps growers optimally manage their nitrogen inputs for corn production.

'Nitrogen is a critical input to crop growth and productivity, but 50% of it is wasted due to complexity, mobility, and lack of visibility' – (Adapt-N ATC, 2015)

Nitrogen is a critical input to corn production, and enables farmers to produce crops with higher yields (Ribaudo, et al, 2012). Corn is the most widely planted crop in the United States and the value to the American economy is estimated at $51.9 billion USD in 2014 (National Corn Growers Association, 2015). Increasing demands for international feed grains for human and livestock consumption and biofuel production suggest that corn production is likely to increase in coming years (Ribaudo et al, 2012).

Corn is also the largest consumer of nitrogen in terms of application per acre, total acre areas treated, and total applications. Over 97% of planted corn acres in America receive nitrogen inputs in the form of commercial fertilizers and manure (Ribaudo, et al, 2012).

Figure 1: In some years corn is N deficient, while in another year the same amount of N is sufficient (Adapt-N ATC, 2015)

Corn's nitrogen needs are highly influenced by weather, in particular, early-season rainfall (van Es et al., 2007). Rainfall may lead to large quantities of nitrogen losses from soils, while warmer weather allows for more nitrogen to be mineralized into a crop-accessible form than in cooler weather. Optimal nitrogen applications may range from 0 to 225 lbs per acre, depending on a number of weather and soil factors. In some years, corn is clearly nitrogen deficient, while in others the same amount of fertilizer is adequate (Cornell University, 2015). Currently, nitrogen is inefficiently used in corn production with approximately half of it being lost due to complexities determining crop nutrient needs, inability to optically detect nitrogen, and the mobility of the fertilizer (Adapt-N ATC, 2015).

At the start of the growing season it is not possible for growers to accurately assess how much nitrogen fertilizer will be needed for that year's crop, as the critical processes that affect nitrogen losses (including weather) have not yet occurred. Many growers plan for a worst-case scenario and apply fertilizer in excess of crop needs. Due to the high cost of nitrogen inputs and costs associated with application, this reduces farm profits and poses environmental consequences through leaching of excess nitrogen into groundwater and/or emission as a greenhouse gas to the atmosphere (Moebius-Clune, et al, 2012).

Growers' informational needs

Without data or tools to help farmers determine a crop's nitrogen requirements, nitrogen management is informed by previous practices, general guidelines, and heuristics. This is partially attributed to the fact that excess nitrogen inputs cannot be visually detected. If a corn crop is under-fertilized its leaves will be brown. If the crops leaves have browned it is too late to ameliorate the problem. However, if the crop is adequately fertilized, or over-fertilized, its leaves remain green regardless of additional nitrogen inputs. For this reason, growers need to rely on soil information and localized weather data in order to help them determine the corn's nitrogen needs (Van Es, personal communication, September 21, 2015).

With precise nitrogen inputs, mostly applied at side-dress time (late spring), nitrogen leaching is minimized as most of the applied nitrogen is taken up by the crop and less is lost to the environment (Adapt-N Cornell, 2015).

Side-dress

To fertilize crops when they reach a recommended size/height. Corn has a very specific nitrogen uptake pattern and doesn't require nitrogen until it reaches a certain maturity, and then starts to up-take nitrogen rapidly.

Having recognized the economic and environmental drivers for increasing the efficiency of nitrogen fertilizer use, Cornell University developed the concept of a computational tool called Adapt-N. This was subsequently taken forward as a web-based decision support tool to help growers optimally manage their nitrogen inputs for corn production. The tool uses a computer calibrated crop model that combines high-resolution climate and weather data with growers' own information on soil and crop management, to provide accurate and farm-specific nitrogen recommendations (Moebius-Clune et al, 2012).

Adapt-N was developed over ten years with research led by Cornell University's Department of Crop and Soil Sciences, and many additional collaborators in research and field settings. The tool was first tested in 2008, successfully calibrated through commercial farm trials during 2011-2013, and commercially launched by Agronomic Technology Corporation (ATC) for the 2014 growing season (Adapt-N, Cornell, 2015).

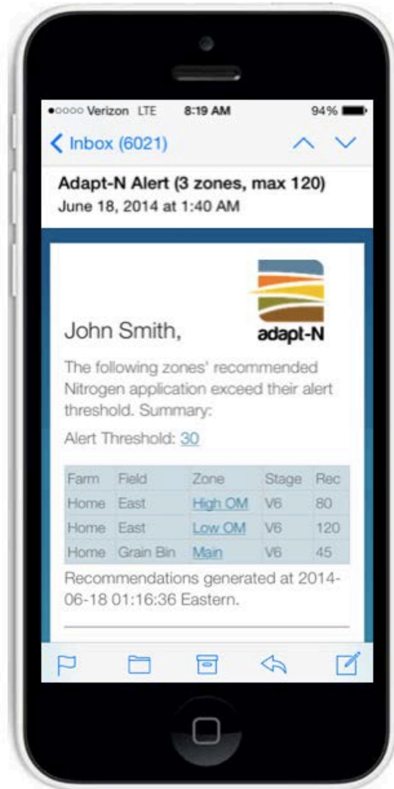

Figure 2: Adapt-N alerts your phone via text message and email when nitrogen inputs are needed. (Source: Adapt-N ATC, 2015)

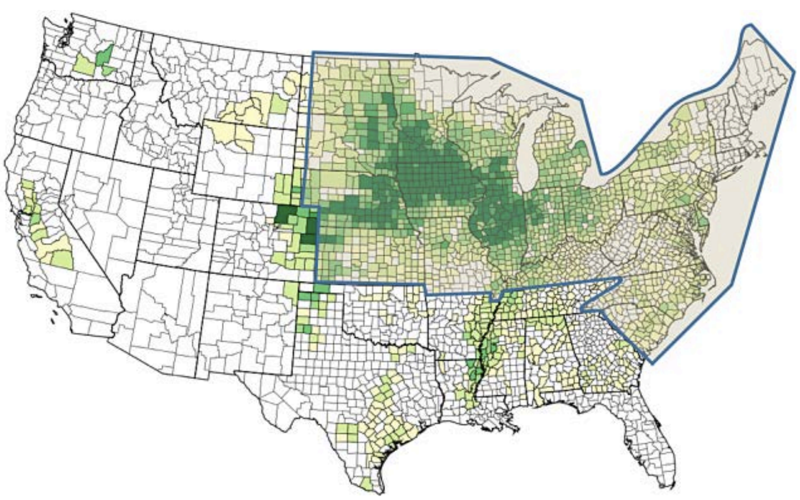

Figure 3: Where can Adapt-N be used?
Adapt-N is currently available in the following states (bounded by the blue line): Connecticut, Delaware, Kansas, Kentucky, Illinois, Indiana, Iowa, Massachusetts, Maine, Maryland, Michigan, Minnesota, Missouri, Nebraska*, New Hampshire, New Jersey, New York, North Carolina, North Dakota*, Ohio, Pennsylvania, Rhode Island, South Carolina, South Dakota*, Vermont, Virginia, West Virginia, Wisconsin [* = Coverage west to 103°]. (Source: Adapt-N ATC, 2015).

3 Data inputs to Adapt-N

3.1 The underlying models in Adapt-N

Adapt-N's engine is the Precision Nitrogen Management (PNM) model that was developed from two re-coded and integrated models:

- **LEACHN soil model** (Hutson & Wagenet, 2003) which uses information on weather and soil properties to simulate the following root zone mechanisms:
    - Water storage, drainage and evaporation.
    - Nitrogen losses (leaching, ammonia volatilization, and denitrification)
    - Biological and chemical nitrogen transformations
    - Redistribution of water and nitrogen as affected by each rain event and soil characteristics (Hutson & Wagenet, 2003)

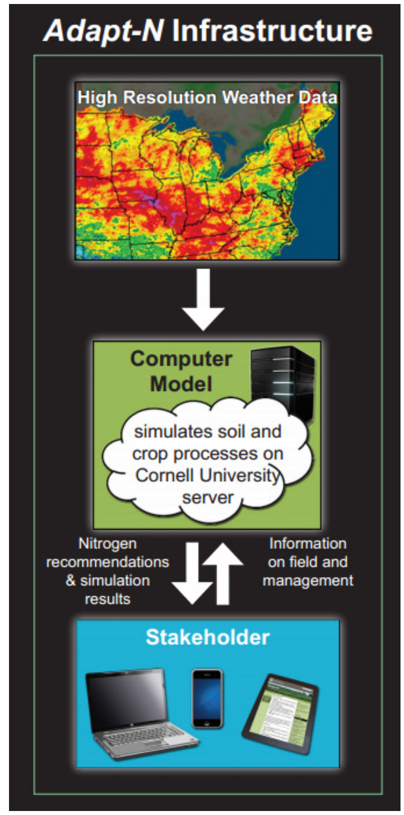

Figure 4: Adapt-N infrastructure (Source: Adapt-N Cornell, 2015)

- **Corn Uptake Growth and Yield Model** (Sinclair & Muchow, 1995) which uses temperature, precipitation and solar radiation data to simulate:
    - Growth, development and yield of the corn crop
    - Concurrent uptake of nitrogen and water

3.2 Meteorological data inputs to Adapt-N

The temperature and precipitation data that inform the PNM model are derived from NCEI's Global Historical Climatology Network-Daily (GHCN-D) database. These data inputs are critically important features as they allow for location-specific and timely nitrogen application recommendations (Moebius-Clune, et al, 2014). Adapt-N uses the most recently observed temperature and precipitation data by collecting all morning observations released from GHCN-D stations.

The Northeast Regional Climate Center (NRCC) supplies Adapt-N with the NCEI data that serves as the meteorological and climatological input to the software. The inputs include high-resolution daily maximum and minimum temperature and precipitation data derived from GHCN-D, and solar radiation data that are modelled based on real-time Automated Surface Observing System (ASOS) observations provided by NOAA's National Weather Service.

Meteorological inputs to Adapt-N

- GHCN Daily min & max temperature
- GHCN Daily rainfall
- Solar radiation

3.2.1 Global Historical Climatology Network-Daily data

GHCN-D is a global land-based (in-situ) database that collects observations from a number of different observing networks (DeGaetano, personal communication, August 18, 2015). The database was developed for a wide variety of potential applications, including climate analysis and monitoring studies that require data at a daily time scale (Lawrimore, et al, 2011). As the National Climatic Data Center (NCDC)[1] Climate Products and Services Market Analysis shows, sectors that rely on GHCN-D data in their operations include agriculture, construction, insurance, electric and gas utilities, energy management companies and retailers among others (Adams, 2014).

GHCN-D contains records from over 80,000 stations in over 180 countries and territories, and is the most comprehensive daily global dataset available. Variables commonly include maximum and minimum temperature, total daily precipitation, snowfall and snow-depth. Data for the US is reported once daily (usually in the mornings) from stations across the country (Lawrimore, et al, 2011).

[1] In 2015 NCDC merged with NOAA's National Coastal Data Development Center, National Oceanographic Data Center and National Geophysical Data Center to form NCEI

Interpolating GHCN-D data

There are approximately 10,000 rain gauges located across the conterminous United States[2]. Statistical methods have been developed to interpolate gauge rainfall to finer resolutions that can be used for applied purposes (DeGaetano & Wilks, 2009). For deriving monthly rainfall accumulations, NCEI provides a monthly GHCN (GHCN-M) gridded data set on a 5° by 5° (approximately 200,000 km^2)[3] resolution (72 longitude by 36 latitude grid boxes) (DeGaetano, personal communication, August 6 2015). This data set is derived by correcting and interpolating anomalies from 2,592 gridded data points across the globe.

There are several thousand GHCN-D stations across the continental US that report daily maximum and minimum temperature. Like precipitation estimates, the uneven and relatively sparse distribution of these stations has created the impetus to develop interpolation methods that deliver temperature values on a more localized scale. NCEI also produces a global gridded GHCN *monthly* dataset for temperature (temperature overview-GHCN).

Operating at the field level, Adapt-N requires highly localized precipitation and temperature values in order to make accurate nitrogen recommendations. As the GHCN-D station density is not high enough to offer such localized precipitation and temperature values, Adapt-N relies on two models, the Multi-Sensor Precipitation Estimate (MPE) for precipitation, and the Rapid Fresh Model (RAP) for temperature, to interpolate GHCN temperature and precipitation to a downscaled, 4km by 4km, resolution (DeGaetano, personal communication, August 24, 2015). This is explained in more detail in the following sections.

3.2.2 Rapid Refresh Models (RAP)

The RAP model provides temperature estimates on a 13-km horizontal grid resolution. NRCC further downscales this model to a 4 km by 4 km resolution (at mid latitudes) through two interpolation processes. The first process involves taking the RAP model values and verifying

[2] Grouped together, these rain gauges would cover an area slightly larger than a tennis court
[3] This figure was calculated based on the global average grid size

them against the temperature values provided by GHCN stations[4]. The GHCN value is used to correct any errors or biases that may be associated with the model values. For example, if a GHCN station reports a maximum daily temperature in Ithaca, New York, of 15°C, and the RAP model reports the temperature value in Ithaca of 13°C, then an error of 2°C is assigned to this location. Subsequently the RAP model value at the grid near Ithaca would be adjusted (by 2°C) to match the GHCN station value. The errors between each GHCN-D station and the corresponding RAP model value are then interpolated to all RAP grid points in areas between the stations using a statistical technique known as multi-quadratic interpolation. Through this process, the temperature at each RAP grid point is adjusted based on the temperatures observed at the closest GHCN stations (DeGaetano, personal communication, August 24, 2015).

The second process involves vertical interpolation to account for elevation differences between the 13 km RAP grids and the GHCN-D stations. Vertical interpolation is also used to account for elevation differences between the RAP grid and the 4 km grid points used by Adapt-N. As the GHCN stations are in diverse locations across the country, (for example, on mountains, hills, in valleys, next to bodies of water), the RAP model is used to identify how temperature varies with elevation on any given day. This model-derived change in temperature with elevation is known as a lapse rate. By knowing the model lapse rate and the elevation of each GHCN station (or 4 km grid point), the RAP temperatures can be adjusted to account for the topographical features of the landscape between stations (DeGaetano, personal communication, August 24, 2015).

If the RAP data are not available on a given day due to server or transmission errors, Adapt-N relies on the Nomads archive[5] to source these data and import them into the tool

[4] In the scientific community land based stations (in-situ) are considered to provide the true value when compared against modelled products. While GHCN stations are subject to their own biases or errors, such as changes in instrumentation and shielding, time of observation inconsistencies, station moves affecting sensor exposure, and human error in data collection, they are subject to a series of quality controls and are considered to be the most accurate source of climate and weather information (Leeper, et al, 2015).

[5] NOMADS: 'NOAA National Operational Model Archive and Distribution System is a web-services based project providing both real-time and retrospective format independent access to climate and weather model data' (NOAA, 2014)

retrospectively. The NCEI data archives are an important backup for Adapt-N (DeGaetano, personal communication, August 24, 2015).

3.2.3 Multi-sensor Precipitation Estimates (MPE)

The MPE data are derived from the network of National Weather Service Doppler Radars that report rainfall amount estimates on a 4 km grid. Under those radar pixels that are located in the same spot as GHCN stations, the radar precipitation amount is compared against the rain gauge amount. If there is a discrepancy between the two values, the GHCN value is considered to be the true value. An error amount is computed for each Doppler Radar point that is accompanied by a rain gauge. For MPE grid locations where there are no rain gauges, the errors are interpolated from nearby GHCN stations to derive an adjusted radar precipitation value that is consistent with the GHCN-D station gauges (DeGaetano, personal communication, August 31, 2015).

3.2.4 Solar Radiation

Solar radiation data is the third climatological input that is important to crop growth. Adapt-N uses a solar radiation product developed by the NRCC based on ASOS from the National Weather Service. The model estimates solar radiation based on hourly airport observations from 883 stations across the US. Meteorological variables necessary for input into the solar radiation model include dew point temperature, surface pressure, cloud layer coverage, cloud layer heights, ceiling heights and visibility and present weather, such as fog.

The model receives a measurement from the closest station and uses this value for the grid locations surrounding the station (Belcher & DeGaetano, 2007). The interpolation processes that are undertaken for temperature and precipitation are not necessary for solar radiation, as the crop growth model is less sensitive to variations in this data input (DeGaetano, personal communication, August 31, 2015).

4 Benefits and limitations of using NCEI data

The GHCN-D data that lies at the core of the meteorological inputs to Adapt-N is fundamental to the successful operation of the tool. Weather is the key source of variability that Adapt-N tries to manage and without temperature and precipitation estimations, accurate nitrogen recommendations could not be made. After the GHCN-D temperature and precipitation values are downscaled, they are input on demand into the Adapt-N model that simulates soil and crop processes at the farm level and determines how much nitrogen is available to the crop, and how much more nitrogen is needed for the crop to reach its full yield. Adapt-N is then able to provide specific nitrogen recommendations based on localized weather data to agronomists and farmers in various locations across the US.

4.1 Benefits of using GHCN-D data from NCEI

Daily data product

A key benefit of sourcing GHCN-D data from NCEI is that observations are reported on a daily basis. Adapt-N requires daily temperature and precipitation data throughout the growing season for regions across the nation. The GHCN-D dataset is the best option for Adapt-N as it meets these fundamental criteria[6].

Reliability

"It's really the convergence of expertise that made Adapt-N a success" – Harold van Es, Adapt-N team leader

As Adapt-N is now a commercial tool and has users in 28 states, ATC depends on a constant and reliable stream of data. As GHCN-D observations are made available daily, the company is assured knowing that they are continuously and programmatically connected to the weather and climate data source required for the successful operation of the tool. On occasions when there have been missing data value, or error data values, the NRCC team has been quick to address these problems. Further, the data network behind the NRCC's service has built-in redundancy to

[6] Melkonian, personal communication, August 25, 2015. Van Es, personal communication, August 26, 2015. Levow, personal communication, September 2, 2015

ensure that an isolated technical issue does not prevent Adapt-N from accessing the service at large[7].

Quality & trust

In recent years there has been a big focus on the need for the private sector to be more engaged in the provision of weather and climate services, data and tools (Biagini & Miller, 2013). ATC is approached on a monthly basis by a new weather service provider offering its services to Adapt-N. Greg Levow of ATC commented, "we have had weather companies make claims of offering precipitation data on a 200-acre resolution, or temperature on a 1 km by 1 km grid. We have not gone through the process of validating these claims, but these companies are likely using the same GHCN-D data source as we are, perhaps in combination with other data sources and/or different interpolation algorithms, and downscaling it to a finer resolution" *(personal communication, September 3, 2015).*

"We get pitched a new weather service each month from a different commercial weather service provider" – Greg Levow, CEO, ATC

"When we have questions about climatology issues, or have to assess claims that other weather service providers are making about their data source, we view the NRCC as a knowledgeable, academic and unbiased source of information". - Greg Levow, CEO, ATC

The process of further interpolating data does not necessarily make it any more accurate beyond a certain resolution (Art DeGaetano, personal communication, August 24, 2015). ATC is assured knowing that they are receiving good quality data from a trusted government source, and that their data interpolation processes are carried out by NRCC, an academic and government affiliated institution that is neutral and impartial[8].

[7] Degaetano, personal communication, August 24, 2015. Melkonian, personal communication, August 25, 2015. Van Es, personal communication, August 26, 2015. Levow, personal communication, September 2, 2015

[8] Degaetano, personal communication, August 24, 2015. Melkonian, personal communication, August 25, 2015. Van Es, personal communication, August 26, 2015. Levow, personal communication, September 2, 2015.

4.2 Support from the Northeast Regional Climate Center

While the GHCN-D data itself is essential to Adapt-N, the data infrastructure that NOAA has developed through its Regional Climate Centers (RCC), together with the expertise of their staff, has played a key role in the success of Adapt-N[9]. The mission of the RCCs is to facilitate regional engagement with NCEI's climate and weather data and products. Adapt-N provides an excellent example of how the NRCC facilitated NCEI's climate and weather data to help support decision-making in the agricultural community, a vital part of the US economy with a disproportionate environmental footprint.

There was a natural connection between the original developers of Adapt-N and the NRCC and they started collaborating on the needs for high-resolution temperature and precipitation data as part of a federal grant on Computational Agriculture. As the original Adapt-N developers were based in the Soil and Crop Sciences Department at Cornell, they in turn required additional expertise in meteorology and climatology to help them develop the tool (van Es, personal communication, August 26, 2015). Further, as the developers wanted to make their tool operational on a farm level they required additional data products that were not readily available at the localized spatial scale. The NRCC took on the operational role of providing NCEI data, and the staff developed a daily 4km gridded dataset for temperature based on GHCN-D data to meet Adapt-N's spatial requirements.

A further advantage of the NRCC to Adapt-N is that the center provides the data through the NRCC web services, allowing Adapt-N to dynamically link with the database rather than downloading the data from the NCEI archive. This has allowed ATC to live-feed data into the Adapt-N tool (DeGaetano, personal communication, August 24, 2015).

While ATC has capitalized on the research of Cornell, and the services provided by the NRCC, in return they have offered insight into commercial agricultural applications. The initial tool

[9] Melkonian, personal communication, August 25, 2015. Van Es, personal communication, August 26, 2015. Levow, personal communication, September 2, 2015.

prototype that ATC licensed from Cornell was not well designed for the commercial end user. Equipped with their knowledge of end user needs, ATC was able to bring functionality and marketing to Adapt-N that allowed it to become a commercially viable product (Levow, personal communication, September 3, 2015).

4.3 Data limitations

In the absence of the GHCN-D data, Adapt-N would not have been developed. The tool's academic and commercial developers consider there to be no other national daily dataset of the same quality as GHCN-D. Prior to Adapt-N, the Cornell's department of Soil and Crop Sciences sent out a weekly notice to each climate region within New York State and provided a general recommendation for each region for three representative soil types. This information could be used to provide a general guideline, however, it was not detailed enough to provide agronomists with a site-specific recommendation. It was not until the NRCC provided downscaled versions of GHCN-D for temperature data that Adapt-N was equipped with the spatial scale that was required[10].

ATC does however have certain data requirements that it would like to meet that currently are not comprehensively provided by either a public nor private entity. Ideally, Adapt-N would like to offer its end users data on a 1km by 1km resolution for both temperature and precipitation. This type of resolution could presently be achieved through a dense network of on-farm stations. DTN, a weather service company, provides farmers with a personal weather station and an annual maintenance service (DTN, 2015). The farmers' data is in turn shared with the entire network to build up a proprietary weather grid from on-farm observations. While this has provided an alluring consideration, these services currently do not provide a geographic density that meets the requirements of Adapt-N (Levow, personal communication, September 2, 2015).

[10] Melkonian, personal communication, August 25, 2015. Van Es, personal communication, August 26, 2015.

5 The success of Adapt-N

Studies at Cornell University have shown that Adapt-N has the ability to significantly increase grower profits while decreasing environmental losses.

The success of Adapt-N has been qualified into two principal categories; economic cost savings for farmers and environmental benefits, which in turn result in societal benefits. Additional benefits can also be observed such as regulatory compliance, and spurring innovation and competition in precision agricultural management.

5.1 Economic savings and profits for farmers

Profit gains as a result of using Adapt-N, versus not using Adapt-N, have been quantified through strip trials and average approximately $30 per acre (Sela, et al., 2015; in review). Profit gains were mostly attributed to fertilizer cost saving due to lower nitrogen input recommendations, without causing significant yield losses. In some instances, Adapt-N recommended higher nitrogen rates, which led to larger crop yields and increased net profits. Overall, Adapt-N recommended rates resulted in average nitrogen input reductions of 45 lbs per acre (Sela, et al., 2015; in review).

What are strip trials?

Comparing two practices of farm management within the same field. Usually the grower's regular management is compared with a new practice (On-farm network, 2007)

In the growing seasons of 2011 through 2014, Cornell's Department of Soil and Crop Sciences conducted a total of 115 strip trials on commercial and research farms in the Northeast and Midwest to evaluate how well Adapt-N predicted the nitrogen needs of corn at side-dress (in-season application) time**.** The strip-trials compared the grower's conventional nitrogen management practice, with the recommendations provided by Adapt-N in side-by-side locations. The market prices of both corn and nitrogen were used to inform the profit analysis. Adapt-N rates resulted in average nitrogen input reductions of 53 lbs per acre in NY, 30 lbs per acre in Iowa, and 45 lbs per acre overall. Yields were actually 2 bushel per acre higher, demonstrating that Adapt-N's reduced nitrogen recommendations were generally justified. Even on trials where Adapt-N advised farmers to reduce nitrogen inputs and this resulted in reduced yields, the net profits were on average still greater owing to costs saved on nitrogen inputs. In a few cases did the Adapt-N recommendation result in a profit loss, owing largely to an unexpected late season drought that resulted in substantial yield reductions to both treatment fields (Adapt-N and conventional, Moebius-Clune, et al, 2014).

State-Year	NY2011	NY2012	NY2013	NY2014	IA2011	IA2012	IA2013	Mean
N input diff (lbs/ac)	**-62.7**	**-66**	**19.1**	**-32.6**	**-16.7**	**-27.6**	**-19.3**	**-29.4**
Yield diff (bu/ac)	**-0.05**	**-1.85**	**20.60**	**-3.20**	**1.90**	**-0.45**	**0.50**	**2.49**
Profit diff ($/ac)	**$34.1**	**$23.93**	**$93.63**	**$0.95**	**$21.6**	**$14.35**	**$12.2**	**$28.68**

Table 1: Shows the environmental and economic assessment of Adapt-N performance over the 2011-2014 strip trials (Sela, et al., 2015).

As decreased nitrogen inputs *did not* result in yield losses (on average), this suggested that nitrogen is being excessively used in corn production. Adapt-N also allowed for simulation of environmental losses from the treatments in the strip trials. This indicated how much nitrogen was not taken up by the crop, and consequently lost to the environment. The findings show that by the end of the growing season, simulated nitrogen leaching losses were decreased by an average of 14 lbs of nitrogen per acre (35%), and gaseous losses by an average of 13 lbs of nitrogen per acre (35%; Sela et al., 2015, in review).

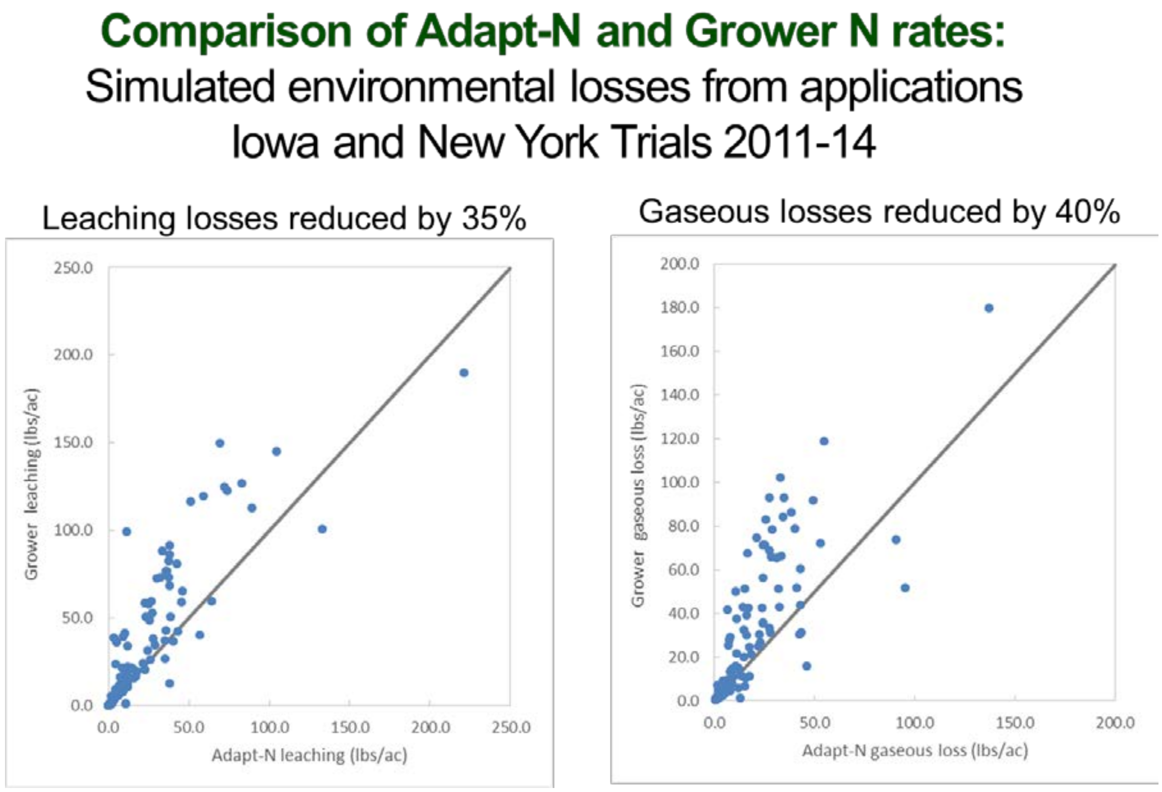

Figure 5: Simulated environmental losses from trials in Iowa and New York (Sela et al., 2015). Grower N rates refer to the conventional nitrogen management practice of the corn grower.

Did you know?

There are approximately 90 million acres of corn grown in the US (National Corn Growers Association, 2015). This is roughly the same size as the entire state of Montana!

Assuming the average savings of $30 per acre, if Adapt-N was used across all 90 million acres, this could save corn growers a total of $2.7 billion!

Farm focus: Donald & Sons Farm

Figure 6: Donald and Sons farm in Monrovia, NYC (Moebius-Clune, et al, 2013)

Donald and Sons Farm, located in Moravia, New York grows approximately 1,300 acres of corn and soybean per year. Until 2011, the farm relied on N recommendations provided by a commercial Midwest nutrient analysis laboratory that based recommendations on soil tests. Recommendations ranged from 195 to 260 lbs of N per acre. In 2011, the farm spent $107,000 for N fertilizer – four times higher than what they had spent in 2010, owing to increased N prices and a shift towards ever-higher recommended N inputs.

The large expenditures that the farm was spending on N motivated them to seek out new tools to optimize application rates. In 2011, the Donalds decided to join the New York State wide Adapt-N beta-testing effort. After a dry spring, the Adapt-N recommendation for their trial field was only 80 lbs per acre, nearly a third less than their standard recommendation of 220 lbs per acre. There was no consequent yield loss from reducing the nitrogen rate by 140 lbs per acre. In the state-wide trials, 86% of trials showed higher profits using the Adapt-N rate, with an average increased profit of $35 per acre.

Farm focus: Hallpine Farm

Figure 7: Dale Hallings owner of Hallpine farm

Dale Hallings is the owner and operator of Hallpine farm in Penn Yan, New York, a 750 acre corn and bean farm of which 300 acres are corn. With increased precipitation and rainfall in the region, Dale was having difficulty determining how much nitrogen to apply to his cornfields, alongside his regular practice of applying chicken litter manure. Dale signed up for Adapt-N in the 2014 growing season after learning about it from his agronomist.

Due to the heavy rains and subsequent flooding of his cornfields, Adapt-N recommended higher nitrogen applications, as high quantities had been lost to denitrification and leaching. Following the recommended Adapt-N rate, Dale's yields increased by 14 bushels per acre, which amounted to net profits of approximately $17 per acre*. After profiting over $5000 across his 300 corn acres, Dale was very pleased with his earnings.

Dale is excited to see the results of the 2015 growing season. He has a higher yield goal than what he would conventionally expect, and has applied 30 units less of nitrogen per acre when compared to his previous nitrogen management practices, thanks to the recommendations provided by Adapt-N (Dale Hallings, personal communication, September 3, 2015).

* Considers cost of nitrogen inputs, costs of applying N and cost of Adapt-N software

5.2 Reducing losses to the environment

Corn crops (as well as other crop systems) are naturally nitrogen-deficient, making nitrogen inputs necessary to achieve proper yields. Gaseous nitrogen (N_2) is abundant in the atmosphere, however must be converted into a reactive form ('reactive nitrogen') to be used in agricultural applications. The use of reactive nitrogen in agriculture has environmental implications that are linked to the following problems:

"Nitrogen is a critical nutrient to crop growth and productivity, but 50% of it is wasted due to its complexity, mobility and lack of visibility. That leads to economic loss and environmental degradation through greenhouse gas emissions and hypoxia". Adapt-N ATC, 2015

- Global climate change
- Depletion of strategic ozone
- Nitrate leaching into ground water systems and drinking water aquifers
- Hypoxia (oxygen depletion) and eutrophication in coastal and lake ecosystems (this is further explored below in a case study relating to the Gulf of Mexico).
- Harmful algal blooms
- Biodiversity loss in aquatic and terrestrial ecosystems
- Acidification and eutrophication effects on freshwater aquatic ecosystems, soils and forests
- Regional haze

(Ribaudo, et al, 2011)

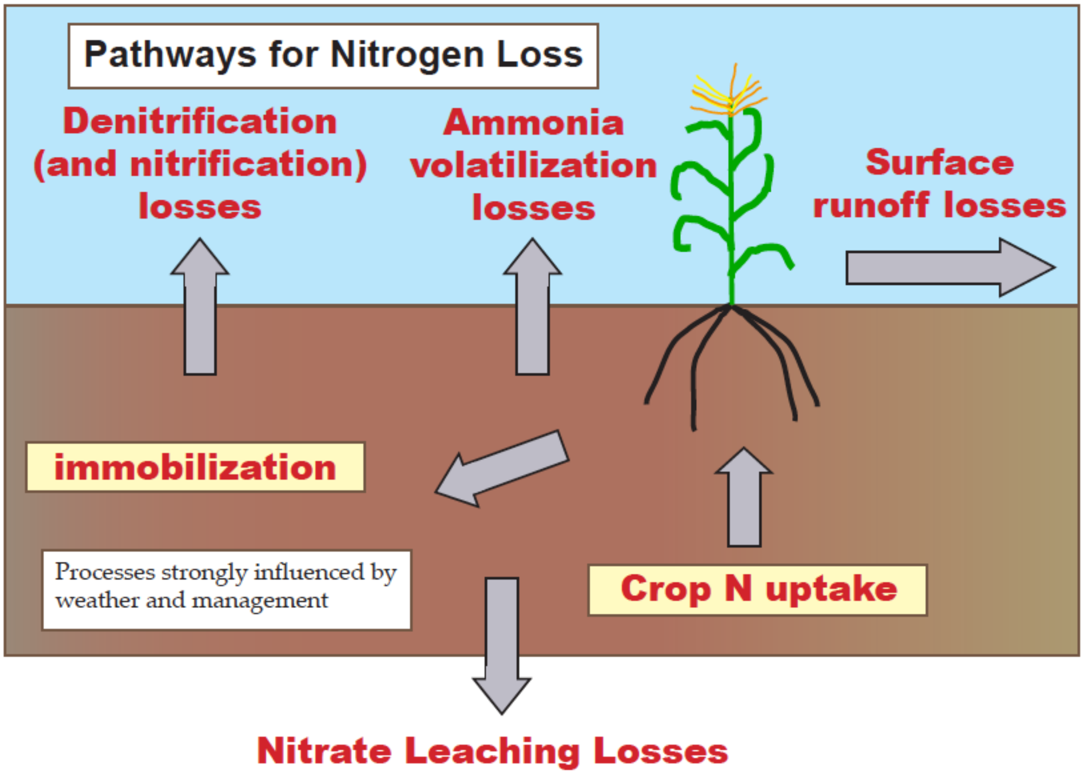

Figure 8: Pathways for Nitrogen Loss. This figure illustrates the various processes by which nitrogen is gained by the crop, or lost to the environment (Moebius-Clune, et al, 2014).

Pathways for nitrogen loss

Nitrate leaching: nitrogen leaching occurs when sufficient irrigation or rain exceeds the soils water-holding capacity and dissolvable nitrate travels downwards through the soil profile. The nitrate eventually ends up in underground aquifers or in surface waters. Nitrogen concentrations in estuaries can cause hypoxia (low oxygen content), algae blooms, human health problems, loss of biodiversity, and even collapse of estuary ecosystems (Ribaudo, et al, 2011).

Denitrification (and nitrification): nitrous oxide (N_2O) is a powerful greenhouse gas. When soils have low oxygen levels, some microorganisms, known as denitrifiers convert NO_3 to nitrous oxide (N_2O) and nitrogen (N_2) both of which are gases emitted to the atmosphere. While Nitrogen (N_2) is not harmful to the environment, nitrous oxide is a potent greenhouse gas that contributes to climate change (Ribaudo, et al, 2011).

Surface runoff: runoff occurs when manure or fertilizers are applied to the surface of the crop field and rain washes out the nitrogen before it is absorbed into the soil (Ribaudo, et al, 2011).

Ammonia volatilization: if manure or urea is applied to the soil surface and is not immediately incorporated into the soil, significant amounts of nitrogen can be lost to the atmosphere through the conversion of ammonium to ammonia gas (NH_3). Volatilization losses are more likely to occur in hot and windy conditions (Ribaudo, et al 2011).

Immobilization: the process by which nitrogen inputs are taken up by other soil organisms and are therefore unavailable to the crops (Johnson, et al, 2005).

Crop uptake: the ultimate goal of nitrogen management is for the nitrogen inputs to be taken up by the crop, rather than lost to other processes. Nitrogen is most likely to be absorbed by the crop when it is applied at the time when the crop is actively absorbing it (Johnson, et al, 2005).

Environmental Focus – Hypoxia in the Northern Gulf of Mexico

Hypoxia occurs when the concentration of dissolved oxygen in the water column decreases to a level that can no longer support living aquatic life – generally defined as levels below 2 mg/l (or ppm) (NOAA, 2015b).

"The overwhelming scientific evidence indicates that excess nitrogen from the Mississippi River drainage basin coupled with hydrologic and climatic factors drives the onset and duration of hypoxia in the northern Gulf of Mexico" – (NOAA, 2015a).

The northern Gulf of Mexico, on the Louisiana/Texas continental shelf, is the largest hypoxia zone in the entire western Atlantic Ocean, and in U.S coastal waters. As indicated by figure 8, the Mississippi river system is the dominant source of freshwater to the northern Gulf of Mexico (Lumcon, 2015)

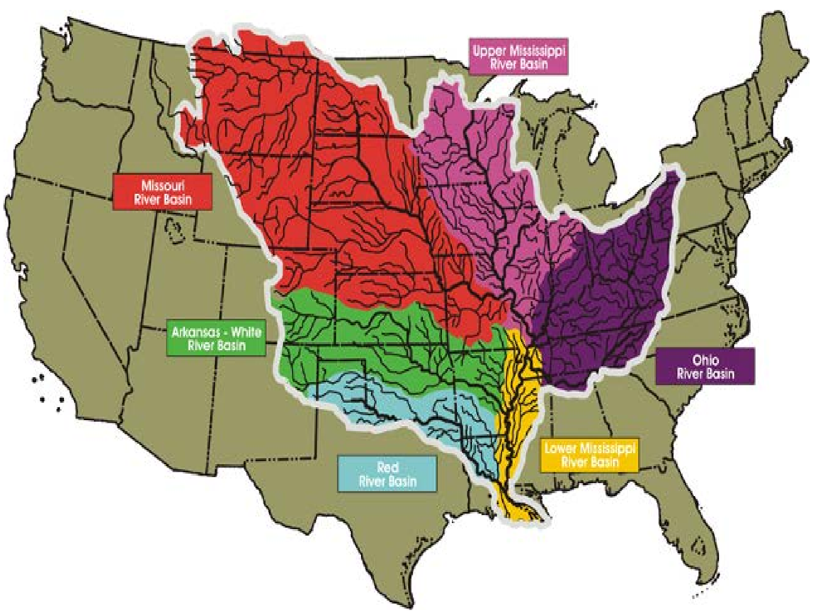

Figure 9: sourced from Lumcom, 2015. The Mississippi River basin is the dominant source of freshwater to the Northern Gulf of Mexico. Crop nitrogen inputs that leach into the river system may flow into the Gulf waters via the Lower Mississippi or Atchafalaya River drainage basin (Lumcon, 2015)

In recent decades there has been a marked increase in the concentrations of N and phosphorous in the Lower Mississippi River, which feeds into the Gulf of Mexico. The increases have been attributed to increased use of N and phosphorus fertilizers for agricultural purposes and N fixation by leguminous crops, and atmospheric deposits of oxidized N from fossil fuel combustion (Lumcon, 2015).

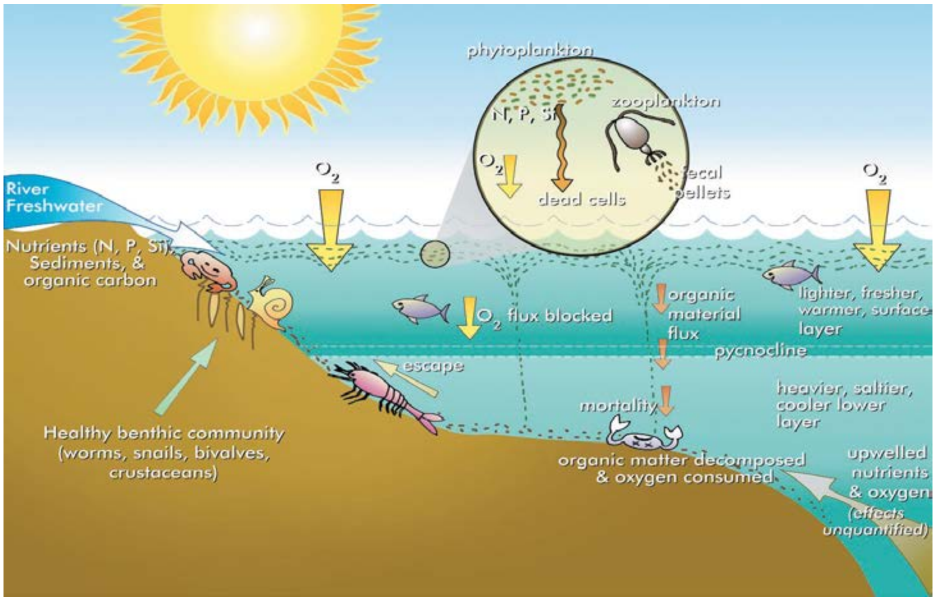

Figure 10: The Eutrophication Process (NOAA 2015a) Eutrophication can cause hypoxia when decaying organic matter on the ocean floor, such as phytoplankton depletes oxygen and the renewal of oxygen is prevented by stratification.

In the same way that nitrogen and phosphorous fertilize land based crops, they also fertilize ocean plants (Lumcon, 2015). When ocean systems are over-enriched with nutrients, the process of Eutrophication occurs, resulting in significant increases of algae in marine ecosystems. Nitrogen is the most significant nutrient causing algal growth in coastal waters (NOAA, 2015a).

Algal blooms initiate a large growth of phytoplankton on the water's surface, in quantities well beyond the capacity of its predators' consumption. After its short life span, the phytoplankton sinks down to bottom waters where it will be decomposed by bacteria. When the bacteria decompose the abundant carbon in the phytoplankton, oxygen is consumed. Due to water column stratification, oxygen is consumed faster than it can be replaced, resulting in hypoxia or dead zones. Decades of scientific research shows that oxygen stress is the primary result of excess nutrient delivery to Gulf waters from the Mississippi and Atchafalaya River drainage basin, in combination with the stratification of Gulf waters (NOAA, 2015a).

Stratification is also necessary for the development of hypoxia in the bottom layer of water. In most saltwater systems, the water lies in horizontal layers, with warmer and/or fresher water at the surface, and colder and/or saltier water on the ocean floor. This layering separates lower waters from the atmosphere and prevents the replenishing of oxygen supply when it is consumed by the decomposing organic matter (NOAA, 2015a).

Aquatic life capable of swimming (crabs, shrimp, fish), may evacuate the area, however less mobile aquatic life experience stress or death. The potential increase of hypoxia could lead to the decline of commercially and ecologically important species. The fishery resources in the Gulf are one of the most valuable in the United States, generating $2.8 billion annually (NOAA, 2015b).

As Adapt-N recommends only as much nitrogen as is needed by the crop, it reduces the amount of nitrogen leached into waterways. The use of Adapt-N has the potential to minimize the formation of harmful algae blooms that lead to hypoxia in the Gulf of Mexico.

Climate Focus – Heavy Precipitation in the Northeast

As indicated in the third National Climate Assessment, climate change is expected to lead to increased precipitation in most areas across the US, and in particular the Northeast region (USGCRP, 2014). This could mean greater costs for nitrogen inputs for farmers in the northeast region, as well as greater environmental losses. Tools such as Adapt-N can provide important guidance in a changing climate.

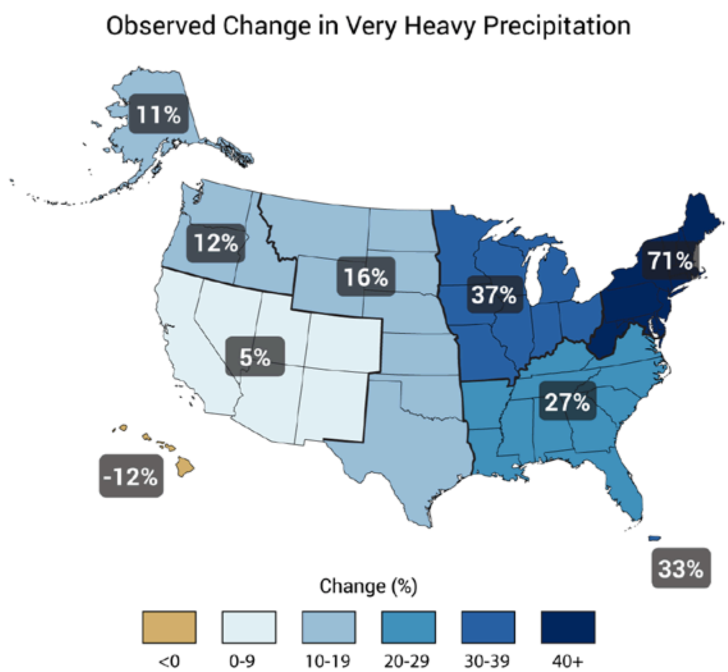

Figure 11: Observed change in very heavy precipitation. Source: Third National Climate Assessment (USGCRP, 2014)

By making nitrogen application more adaptive and targeted to the immediate needs of a crop on a field-by-field basis, Adapt-N can make a positive contribution to minimizing nitrogen losses to the environment, ultimately helping to reduce the associated wider-scale impacts described above.

At first glance it might also seem that the $100 billion nitrogen fertilizer industry (global) would be detrimentally impacted by Adapt-N, in particular in the context of decreased nitrogen sale to farmers using the tool. As the Cornell strip trials showed, in general, Adapt-N recommends decreased nitrogen inputs when compared to growers' traditional nitrogen management practice (Adapt-N, 2015). However, ATC and the Cornell researchers believe that the nitrogen industry has far less to lose from decreased sales and far more to lose from regulation. There is currently a fear amongst the fertilizer industry and growers that the government will start mandating limits on nitrogen applications in coming years (Levow, personal communication, September 3, 2015).

There are currently no hard regulations in place in the US that limit nitrogen inputs, however the Environmental Protection Agency (EPA) has promoted responsible nitrogen management and undertaken several efforts to combat nitrogen and phosphorus pollution problems, including working with:

- State and federal partners on the Mississippi River/Gulf of Mexico Watershed Nutrient Taskforce to reduce hypoxia in the Northern Gulf of Mexico
- States to identify water that contains nitrogen and phosphorus pollution, and to develop total maximum daily loads to determine allowable nutrient input and restore waters (EPA, 2015)

There was strong agreement amongst the interviewees that tools like Adapt-N that promote responsible nutrient management will lessen the need for regulation and therefore associated economic and practical-use restrictions.

5.3 Corporate endorsement

Adapt-N has also been endorsed by Walmart's sustainability program. As a part of its sustainability efforts, Walmart has committed to eliminating 20 million metric tons of greenhouse gas emissions associated with its global supply chain by the end of 2015. Of this amount, 40% is to come from fertilizer use optimization. The Environmental Defense Fund has been working with Walmart to identify tools, such as Adapt-N, that will help Walmart achieve its sustainability objectives (Burgess, 2014). Walmart ranked Adapt-N in the top tier of tools as a part of its sustainability toolkit for suppliers.

6 Going forward

Adapt-N has many goals to improve and expand its service. This includes incorporating a forecast component in the tool, diversifying to other crops, and expanding internationally.

Adapt-N currently does not include a forecast weather component. The tool provides recommendations based on daily weather, and climate, but does not project the weather for the coming days. This is partially due to the fact that crop nutrient needs cannot be accurately predicted at the start of the growing season, as the critical processes that affect nitrogen uptake and losses have not yet occurred (Moebius-Clune, et al, 2012). Despite this, a forecast component would be an asset to the tool; in particular as it pertains to rainfall conditions, as this is the most important variable for corn growth (DeGateano, personal communication, August 24, 2015).

With partial funding from General Mills, ATC is currently in the process of developing a wheat version of Adapt-N with beta-testing beginning next year. Wheat requires less nitrogen inputs than corn, however as a staple US crop commodity, it still relies on considerable amounts of nitrogen and would demonstrate both economic and environmental benefits from optimal management (Van Es, personal communication, August 26, 2015).

As Adapt-N has only been operational commercially for two years, it is currently focused on national expansion in the United States. The product is widely available in the eastern half of the nation; however expansion has been limited to the east of the Rockies. Adapt-N's long term plans are to scale the service to an international level, however there are many obstacles to doing so in many countries, in particular developing countries, since Adapt-N requires reliable meteorological data access. Although GHCN monthly is a global database, it does not provide data at the required temporal frequency, and station density is much more limited in certain parts of the world such as South America and Africa (Lawrimore, et al, 2011). In other countries that do offer weather services, they may not be freely available, and the cost of serving high-resolution data may be prohibitive. As high-resolution climate and weather data is a fundamental component of Adapt-N, any plans of expansion first must address reliable access to weather and climate data. The use of satellite data could potentially be used to expand Adapt-N to countries where land based data is sparse or unavailable. Countries in Western Europe, as well as Australia and New Zealand, offer potential markets where expansion would presently be feasible (Levow, personal communication, September 2, 2015).

There are also other logistical considerations that limit the expansion of Adapt-N. For example, if a country does not have an adequate fertilizer supply and demand market or adequate technologies for application, Adapt-N may not have a suitable market in that region (Levow, personal communication, September 2, 2015).

7 Conclusions

Adapt-N is the product of collaboration between academia, government and private sector expertise. It was developed through a convergence of expertise in several disciplines; soil science, climate science, and an understanding of the needs of corn growers and the direction of the precision agriculture market. None of these entities alone could have produced Adapt-N.

Responsible nitrogen management is a win-win for the environment and the economy. Based on decades of research, and four years of strip trials, Adapt-N has emerged as the flagship tool that helps corn growers save money through decreased nitrogen inputs and increased yields, and lessens environmental impacts by recommending only as much fertilizer as the crop needs. Its value to the corn industry, the environment, and by extension society at large cannot be understated.

NCEI's high-resolution climate and weather data is a fundamental input to this tool and it allows growers to obtain localized recommendations based on weather conditions – the key source of variability that corn growers are trying to manage. Without a national weather and climate database of temperature and precipitation, as provided by GHCN-D, and without the know-how of the NRCC to downscale the data to the required spatial resolution, Adapt-N would not exist.

While this success story is specific to the agricultural sector, NCEI climate and weather data have a fundamental role to play in decision making across all sectors. This success story is intended to share one company's process of leveraging NCEI's climate and weather data to develop a decision making tool, and will hopefully encourage and inspire other companies in other sectors to do the same.

References

Adams, P. (2014). NCDC Climate Products and Services Market Analysis. *Global Science & Technology Inc*.

Adapt-N ATC. (2015). Accessed July 15, from <www.Adapt-N.com>.

Adapt-N Cornell. (2015). Accessed July 15, from < http://adapt-n.cals.cornell.edu/>.

Belcher, B, N. & DeGaetano, A, T. (2007). A revised empirical model to estimate solar radiation using automated surface weather observations. *Solar Energy*, *81*(3), 329-345.

Biagini, B. & Miller, A. (2013). Engaging the Private Sector in Adaptation to Climate Change in Developing Countries: Importance, Status, and Challenges. Climate and Development, Vol. 5, Issue 3, 2013. Pages 242-252.

Burgess, K. (2014). New technology helps farmers conserve fertilizer and protect their crops. The Guardian. Retrieved Sept 8, from <http://www.theguardian.com/sustainable-business/2014/aug/20/adapt-n-harnessing-nitrogen-technology-farming-future>.

Cornell University (2015). 'Adapt-N, A tool for adaptive nitrogen management in corn'. Retrieved July 22 2015, from <http://adapt-n.cals.cornell.edu/about/index.html>.

DeGaetano, A, T., & Belcher, B, N. (2007). Spatial interpolation of daily maximum and minimum air temperature based on meteorological model analyses and independent observations. *Journal of Applied Meteorology and Climatology*, *46*(11), 1981-1992.

DeGaetano, A. T., & Wilks, D. S. (2009). Radar-guided interpolation of climatological precipitation data. *International Journal of Climatology*, *29*(2), 185-196.

DTN (2015). DTN Ag Weather Stations. Retrieved Sept 8, from <http://www.dtn.com/ag/producer/ag_weather_station/index.cfm>.

EPA, Environmental Protection Agency (2015). 'Nutrient and Policy Data: what EPA is doing'. Retrieved Sept 7, from <http://www2.epa.gov/nutrient-policy-data/what-epa-doing>.

Hutson, J, L., & Wagenet, R, J. (2003). Leaching Estimation And Chemistry Model: a process based model of water and solute movement, transformations, plant uptake, and chemical reactions in the unsaturated zone. Version 4. *Dept of Crop and Soil Sciences*. Research Series No. R03-1. Cornell University, Ithaca, NY, USA.

Johnson, C., Albrecht, G., Ketterings, Q., Beckman, J., & Stockin, K. (2005). Nitrogen Basics - The Nitrogen Cycle. Agronomy Fact Sheet Series – Fact Sheet 2. *Cornell University Cooperative Extension Program*.

Lawrimore, J, H., Menne, M., Gleason, B., Williams, C., Wuertz, D., Vose, R., & Rennie, J. (2011). An overview of the Global Historical Climatology Network monthly mean temperature data set, version 3. *Journal of Geophysical Research*, Vol. 116, 1-18.

Leeper, R., Rennie, J., & Palecki, M. (2015) Observational Perspectives from U.S. Climate Reference Network (USCRN) and Cooperative Observer Program (COOP) Network: Temperature and Precipitation Comparison. *J Atmos. Oceanic Technol*.

LUMCON, Louisiana Universities Marine Consortium (2015). 'Hypoxia in the Northern Gulf of Mexico – What is Hypoxia?' Retrieved September, 7 from <http://www.gulfhypoxia.net/Overview/>.

Moebius-Clune, B, N., Carlson, M., van Es, H, M., Melkonian, J, J., DeGaetano, A, T., & Joseph, L. (2014). Adapt-N Training Manual: A tool for precision management in Corn. *Cornell University: College of Agriculture and Life Sciences*.

Moebius-Clune, B, N., Carlson, M., van Es, H, M., & Melkonian, J, J. (2013). 'What's Cropping Up? Adapt-N Proves Economic and Environmental Benefits in Two Years of Strip Trial Testing in New York and Iowa. *Nutrient Management*. Vol.21 No.5, 57-60.

Moebius-Clune, B, N., van Es, H, M., & Melkonian, J, J. (2012). 'Adapt-N Increased Grower Profits and Decreased Environmental N Losses in 201 Strip Trials'. *Cornell University: College of Agriculture and Life Sciences*.

National Corn Growers Association. (2015). 2015 World of Corn. Retrieved July 23 2015 from, <http://www.worldofcorn.com/#/>.

NOAA's National Centers for Environmental Information (2015a). 'The Causes of Hypoxia in the Northern Gulf of Mexico. Retrieved September 7, from <http://www.ncddc.noaa.gov/hypoxia/>.

NOAA's National Centers for Environmental Information (2015b).'The Problem of Hypoxia in the Northern Gulf of Mexico.' Retrieved September 7, from <http://www.ncddc.noaa.gov/hypoxia/>.

NOAA's National Centers for Environmental Information (2014). NOAA National Operational Model Archive and Distribution System. Retrieved September 29, from <nomads.ncdc.noaa.gov>.

Ribaudo, M., Livingston, M., & Williamson, J. (2012). Nitrogen Management in Corn Production Appears to be Improving. USDA, Economic Research Service. Retrieved July 23 2015, from <http://www.ers.usda.gov/amber-waves/2012-december/nitrogen-management-in-corn-production-appears-to-be-improving.aspx#.VbER-IuINRB>.

Ribaudo, M., Delgado, J., Hansen, L., Livingston, M., Mosheim, R., & Williamson, J. (2011). Nitrogen in Agricultural Systems: Implications For Conservation Policy. Err-127. *U.S Dept. of Agriculture, Econ. Res. Serv*.

Sela, S., van Es, H, M., Moebius-Clune, B, N., Marjerison, R., Melkonian, J, J., Moebius-Clune, D., Schindelback, R., & Gomes, S. (2015). Adapt-N Recommendations for Maize Nitrogen Management Increase Grower Profits and Reduce Environmental Losses on Northeast and Midwest USA Farms. *Soil Science Soc. America J*. (in review).

Sinclair, T, R., Bennett, J, M., & Muchow, R, C. (1990). Relative sensitivity of grain-yield and biomass accumulation to drought in field-grown maize. Crop Sci. 30, 690-693.

USGCRP. (2014). "Climate change impacts in the United States: the third national climate assessment (NCA3)." *US Global change research program* 841.

Van Es, H, M., & Melkonian, J, J. (2007). Nitrogen Management Under Maize in Humid Regions: Case for a Dynamic Approach. In: T. Bruulsema (ed.) Managing Crop Nutrition for Weather. Intern. Plant Nutrition Institute Publ. pp. 6-13.

Appendix 1: Adapt-N research and development team

Dr. Harold Van Es, Professor and Chair of Soil Science at Cornell University. Harold is the team leader and one of the initial developers of Adapt-N and began his initial research on the tool in the 1990's.

Dr. Art DeGaetano, Professor of Atmospheric Science at Cornell University, and Director of the Northeast Regional Climate Center.

Dr. Jeff Melkonian, Senior Research Associate in the Department of Soil and Crop Science. Jeff is one of the original Adapt-N researchers.

Greg Levow, Co-founder and President of Agronomic Technology Corporation (ATC), the firm that commercialized the Adapt-N Tool.

Adapt-N Farmers

Robert Donald, co-owner of Donald and Sons Farm, located in Moravia New York, grows approximately 1,300 acres of corn and soybeans per year. The Donald's first began using Adapt-N during the Cornell beta testing efforts in the 2011 growing season.

Dale Hallings, owner of Hallpine Farm in Penn Yan, New York, owns a 750 acre farm, 300 acres of which are corn. He signed on for Adapt-N in the 2014 growing season after learning about it from his agronomist.

Appendix 2: Rationale for case study selection

This case study topic was chosen to highlight user engagement with NCEI's Center for Weather and Climate data for three primary reasons:

Firstly, at the core of the high-resolution climate and weather data that inform Adapt-N crop models are the Global Historical Climatology Network-Daily (GHCN-D) data. This foundational NCEI data product is an in-situ (land-based) database, meeting the requirement for the first of three data products (in-situ, satellite, radar) that will inform the NCEI case studies.

Secondly, agriculture was a sector of interest as identified in early inception meetings with Global Science & Technology, Inc (GST). As this case study focuses on corn production, the principal crop commodity of the US economy, and the fertilizer industry, a highly lucrative enterprise with a considerable environmental footprint, this presents a topical focus that is of prime importance to the US economy.

Thirdly, this use-case provides access to three tiers of weather data end users; Cornell University Department of Soil Sciences that initially developed the concept for Adapt-N, Agronomic Technology Corporation (ATC), the firm that leveraged the Cornell research to commercialize Adapt-N, and agronomists that have been using the tool for the last three growing seasons. Access to three tiers of end users has allowed for a robust analysis of how NCEI's climate and weather data has contributed to responsible nitrogen management.