Mitigating and Adapting to Climate Change through

Adaptive Nitrogen and Soil Health Management

Bianca Moebius-Clune, Harold van Es, Jeff Melkonian, Bob Schindelbeck

Department of Crop and Soil Sciences

Introduction

Climate change, greenhouse gases, and energy are current societal challenges. Agriculture emits 8% of the US greenhouse gases (EPA, 2010), while producing only 1.2% of the US Gross Domestic Product. Agriculture is particularly strongly impacted by these issues - both in terms of causes and effects. As the climate is changing growers must mitigate these changes, especially with increasing regulatory pressure, by reducing greenhouse gas (GHG) emissions and energy use associated with crop production. However, they must also adapt to these changes. Soil management can play a key role in addressing these concerns.

Low soil health is often a yield limiting factor for NY crop production and increases the potential for runoff, erosion and other environmental losses, as well as drought. These problems are anticipated to become more severe with climate change. Thus more holistic soil health management will become increasingly necessary as an adaptation and mitigation strategy. N fertilizer is a significant input cost, especially for corn growers, and much money is wasted on over-application in the majority of growing seasons. Conversely, yield potential is lost in some wet seasons. These scenarios result in decreased farm profits and high environmental losses related to GHG impacts, not to mention, ground- and surface water degradation, and estuary hypoxia problems. Improving soil health, carbon and nitrogen management therefore provides win-win opportunities, to increase profits and decrease environmental losses.

Two newly developed tools, the web-based tool *Adapt-N* and the Cornell Soil Health Test framework are receiving national and even international attention. These are now available to enable growers and consultants to better manage nitrogen, carbon, and soil health on the farm. These tools are thus useful for adapting to and mitigating climate change: Adaptive N management with Adapt-N accounts for changes in soil carbon levels and weather influences on nitrogen availability, and thereby maintains yields, while decreasing N-inputs and losses as GHGs. Improved soil health management increases resiliency to weather extremes and increases soil carbon levels, thereby potentially sequestering carbon from the atmosphere into the soil.

Climate Adaptation and Mitigation using these Tools:

Improved soil health, carbon and nitrogen management using these new tools achieves both climate *adaptation* and *mitigation*:

Adaptation to changing weather and increasing weather extremes:

- Increased occurrence of extreme precipitation conditions (dry or wet) increases the variability of crop N fertilizer needs. Depending on early growing season conditions and management factors, sidedress N needs may vary by up to ~ 100 lbs/ac from year to year for the same field and management conditions. *Adapt-N* is a new tool that explicitly accounts for field-specific spring weather influences in calculating crop N fertilizer needs. It thus builds climate change into the recommendation system.

- Improved soil health increases soil infiltration and soil aeration, which reduce the effects of high precipitation on runoff, erosion, and compaction, and thus also reduce denitrification and nitrous oxide losses. Increased soil water retention and rooting depth decrease the soil's susceptibility to drought stress. For example, by increasing the drought-insensitive period from 8 to 12 days, the probability of drought stress in July is decreased from 5% to 1%.

Mitigation of greenhouse gas contributions:

- The use of *Adapt-N* results in (i) more precise management of agricultural nitrogen, (ii) reduced overall N-fertilizer use and the associated CO_2 emissions from the Haber-Bosch process that produces these fertilizers, and (iii) reduced losses of nitrous oxide, which is by far the largest source of greenhouse gas emissions associated with agriculture (EPA, 2010). The current N recommendation systems do not account for site-specific weather factors or changes in soil carbon and therefore often result in inappropriate, generally higher N rates, thereby increasing environmental N losses (also to water resources, another concern).
- Improved soil health management through the use of the Cornell Soil Health Test typically results in better management of soil carbon (organic matter) through reduced tillage, cover cropping, better rotations, or application of organic matter like manure and compost. Better management of carbon biomass and increasing soil carbon levels results in net sequestration of C from the atmosphere to the soil.

Integration of Adaptation and Mitigation:

By linking carbon and nitrogen management in the context of weather conditions, both will be better managed. The Cornell Soil Health Test identifies constraints related to soil health and carbon. When those are addressed, nitrogen management also requires adaptation as soils with higher carbon levels require less N fertilizer and are also less susceptible to losses from leaching and denitrification. *Adapt-N*, unlike other N management tools, accounts for such changes and allows a farmer to take advantage of the investments in soil health and increased carbon levels.

Background on the Tools:

Soil Health Management

Intensive production of field crops frequently results in soil degradation through loss of organic matter and erosion. Lower productivity, increased production inputs and greater environmental impacts result. In addition, degraded soils are less resilient to the effects of climate change, especially to the greater occurrence of periods of excess and deficient precipitation. Soil health has emerged as an important focus for soil and water management in New York. It integrates physical, chemical and biological components and processes and the interactions among them. Soil-impacting practices such as tillage, traffic, plant cover systems, and organic and inorganic inputs strongly influence all components of soil quality and, thus, ecological functioning. We developed a laboratory soil test that provides an integrated assessment of the triad of soil health domains - physical, biological and chemical (Fig.1, for more information, see http://soilhealth.cals.cornell.edu/). The Cornell Soil Health Test (CSHT) employs soil quality indicators that represent processes relevant to soil functions and also provides information that is useful for practical soil management (Idowu et al, 2008; Gugino et al, 2009). Unlike the standard approach that focuses of soil chemical amendments like fertilizers, soil health management needs to be approached from a holistic perspective within the context of the constraints of the soil and the farm (attitude to change, equipment availability, cropping system, availability of organic sources, etc.). We have offered the Cornell Soil Health Test since 2006 and analyzed approximately 5000 soil samples from the Northeast. The aggregate data show that fields in vegetables and field crops tend to be constrained by low aggregation, available water capacity, organic matter and biological activity, and by frequent compaction problems.

CORNELL SOIL HEALTH TEST REPORT (COMPREHENSIVE)

Name of Farmer: Beth Gugino	Sample ID: E231
Location: Plant Pathology, 630 W. North St. Geneva NY 14456	Agent: George Abawi
Field/Treatment: Gates 72	Agent's Email: 0
Tillage: 9+ INCHES	Given Soil Texture: LOAMY
Crops Grown: CLE/SWC/BNS	Date Sampled: 5/4/2007

	Indicators	Value	Rating	Constraint
PHYSICAL	Aggregate Stability (%)	26	32	
	Available Water Capacity (m/m)	0.13	29	water retention
	Surface Hardness (psi)	167	53	
	Subsurface Hardness (psi)	300	46	
BIOLOGICAL	Organic Matter (%)	2.3	18	energy storage, C sequestration, water retention
	Active Carbon (ppm) [Permanganate Oxidizable]	554	38	
	Potentially Mineralizable Nitrogen (μgN/ gdwsoil/week)	7.9	10	N Supply Capacity
	Root Health Rating (1-9)	4.3	63	
CHEMICAL	*pH	7.4	78	
	*Extractable Phosphorus (ppm) [Value <3.5 or >21.5 are downscored]	10.0	100	
	*Extractable Potassium (ppm)	50	72	
	*Minor Elements		100	
	OVERALL QUALITY SCORE (OUT OF 100):		53.3	Low

Measured Soil Textural Class:==> silt loam

SAND (%): 44.0 *SILT (%): 50.0* *CLAY (%): 6.0*

Location (GPS): Latitude=> 42.866667 Longitude=> -77.05

* See Cornell Nutrient Analysis Laboratory report for recommendations

Fig. 1. Example soil health test report.

Managing for enhanced soil health also provides societal benefits by reducing runoff and erosion and chemical losses. The use of the CSHT provides information on existing soil constraints and provides a framework for enhancing soil health. For example, a CSHT report of a degraded soil may show low aggregate stability, high soil strength (compaction), low organic matter and active carbon contents, and high potential for disease pressure. This soil would therefore have high potential for runoff and erosion (due to low aggregate stability and poor crop establishment from compaction), limited carbon sequestered, and may need higher levels of pesticides to control diseases. In addition, the low organic matter contents affect the nitrogen dynamics and will require higher N fertilizer rates. With changing climate, we expect greater occurrence of extreme weather events and therefore higher potential for runoff, erosion, water logging, N leaching and denitrification losses, pesticide runoff and leaching, compaction damage and disease pressure with excess rainfall. Conversely, higher temperatures and more severe droughts will cause greater drought stress, root restriction, and yield losses. Better soil health management can thus make the soil and crop system more resilient and mitigate these climate change effects.

Adaptive N Management

The most recent EPA report lists agricultural N management is the fifth largest source of greenhouse gas emissions in the US due to the large nitrous oxide losses (216 Tg CO_2 eq). The total global warming potential of agricultural N management is larger than that from the entire US aviation industry (EPA, 2010). Corn production accounts for a large fraction of these losses because of its large acreage, high N use, and low N use efficiency. The high N fertilizer use in corn also implies that this cropping system is very energy intensive (N fertilizer manufacture requires a lot of natural gas and thus additionally produces high carbon dioxide losses).

High precipitation variability increases the uncertainty in predicting N fertilizer needs for corn production as high short-term N losses may occur through leaching and denitrification from spring and summer rainfall. Conversely, little losses occur in dryer growing seasons. This uncertainty results in the general practice of using high "insurance fertilizer" applications which results in over-fertilization during normal and dry years. Conversely, in extremely wet springs like 2009, N rates actually need to be adjusted upward. Until recently, the limited ability to estimate N fertilizer needs for corn based on weather conditions was a constraint for developing precise N recommendations.

Several studies discussed in van Es et al. (2007) have demonstrated the significance of early-season weather conditions on the seasonal corn N needs: spring weather appears to be the strongest determinant for N availability. This is largely explained by the water and temperature dynamics during that period. During the late spring, when the corn crop is still small, high quantities of soil mineral N (mostly nitrate from SOM and also early N applications) reside in the soil profile. If excessive rainfall occurs during this critical time, significant N losses may occur from leaching or denitrification. Soil nitrate accumulation is higher for soils high in SOM and fields that received high early fertilizer application. This may result in very significant N losses with high rainfall. Greenhouse gas emissions from a single 50 mm (2") rainfall event may then be as high as 2600 kg CO_2e ha^{-1} as a result of N_2O losses (Tan et al., 2009). As a result, required supplemental N fertilizer rates vary greatly depending on weather conditions during the early season.

When maize N fertilizer recommendations are based on average crop response using methods like the static mass balance approach (Stanford et al., 1973) or Maximum Return to N (Sawyer et al., 2006), this will generally result in excessive fertilization in years with dry springs, and inadequate fertilization in wet years with high early season N losses. In many cases, farmers opt to use higher rates (insurance fertilizer) in case of a wet early season. In the majority of years this results in excessive fertilizer application, unnecessary expense, increased environmental losses, and high GHG impacts (Sogbedji et al. 2000; van Es et al., 2007). Organic N (manure, etc.) applications result in even higher soil nitrate accumulations in the late spring and a greater potential for loss from excessive soil wetness. Livestock farmers then often face the challenge to decide on applying expensive supplemental sidedress N.

The above concerns have increased with the documented effects of climate change, including the greater occurrence of high-rainfall events in the early growing season in the Midwestern and Northeastern US over the past 30 years. Therefore, climate change adaptation should strongly focus on efforts to better incorporate weather effects into N management. This will increase the precision of N fertilizer management and provide incentives for better timing of N applications (sidedress vs. preplant).

The *Adapt-N* tool (Melkonian et al., 2007) is an excellent adaptation strategy to climate change, because it explicitly accounts for weather conditions, by building on new advances in Web technology, fast database access, new high-resolution climate data, and a well-calibrated computer model. *Adapt-N* is a web-based decision tool (http://adapt-n.eas.cornell.edu/) developed at Cornell University that uses a dynamic simulation model and links to the high resolution weather data (3x3 mile grid) stored at the Cornell Center for Advanced Computing. Model users can thus apply the model to individual fields or farms and receive a recommended sidedress N rate from computer simulations based on field-specific crop and soil inputs and high-resolution weather data. *Adapt-N* can be used in both manured and non-manured corn productions systems (grain, silage and sweet corn), for different years within rotations, and for at-planting or sidedress N applications. It can also be used for retrospective evaluation and what-if scenario-testing at the end of the growing season, allowing the user to improve their understanding of the system and adapt their management strategy. The tool is based on extensive research efforts and has been validated in experiments.

The *Adapt-N* approach uses computer simulation of soil and crop processes to provide precise N fertilizer recommendations. It accounts for the field-specific effects of weather, as well as localized conditions, including soil type (texture, soil carbon levels, etc.), soil management practices (tillage, fertilizer and organic matter applications, etc.), crop management (date of planting, maturity class, expected yield, population, etc.). It thus allows for incorporation of the effects of soil change as a result of long-term management practices (e.g. higher N mineralization on fields that received long term manure application vs. those on cash grain farms without manure). It also allows for adaptation to the impacts of conversion to no-tillage or increased occurrence of extreme weather events from climate change on soil N supply.

Therefore, *Adapt-N* has advantages by <u>adapting</u> to climate change by explicitly accounting for weather conditions, as well as <u>mitigating</u> global warming by reducing nitrous oxide losses through more precise N management.

Adapt-N's web-based interface (Figure 2) is user friendly, and we are working with field specialists in New York and Iowa in 2011 & 2012 to test the tool on farms. It also allows for in-field access using mobile computing technology, and thus users can run the model on the Cornell computer servers even while being in the field (Figure 3). Currently, this tool appears to be the most promising and cost effective method for precise N management in corn.

Figure 3. Crop consultant running the Adapt-N model on Cornell computers from a corn field using a smart phone.

Conclusion

Soil health management provides a holistic approach with economic and environmental benefits through better soil functioning in the context of climate change adaptation. It may reduce runoff, erosion, leaching, denitrification, pesticide use, etc., while increasing C sequestration and N use efficiency. *Adapt-N* addresses climate change issues by allowing N management adaptation to changed weather patterns and enabling more precise N use that will reduce losses of nitrate and N_2O.

Note: Key References are provided on the websites for each tool. Two factsheets with further information about *Adapt-N* are included in this booklet.