A Research Agenda for Managing Crop Nitrogen for Weather

By Tom Bruulsema

Weather strongly influences N: its supply in and loss from the soil, and its crop-growth-driven demand. A recent soil science symposium identified opportunities for research leading to improvement of current crop N recommendation systems. The proceedings, titled Managing Crop Nitrogen for Weather (IPNI, 2007), describes several approaches to application of process-based models that hold promise for achieving this goal.

Farming has always depended on the weather. Since the dawn of agriculture, producers have had to adapt to it. While today's technologies allow a single producer to control a larger area of cropland than ever before, adapting to weather is just as important as it ever was. Weather impacts N dynamics at least as much as crop performance; arguably more, since it influences processes of N supply and loss from soils as well.

Decades of research into improved N management for crops have proven that there is no simple soil test that – on its own – can predict an optimum rate of N. Nevertheless, producers have improved their management of the nutrient. Between 1964 and 2006, partial factor productivity for N use in corn production in North America has increased from 42 to over 60 kg of corn per kg of N fertilizer applied (calculated using the method of Fixen and West, 2002). However, the current partial nutrient balance indicates an average recovery efficiency of less than 80% – that is, the N in grain harvested from the field amounts to 80% of the N in the applied fertilizers and manures – indicating considerable room for further improvement.

The reason many efforts to improve prediction of optimum rates have failed is that they have focused only on one specific tool at a time, be it a soil test, a plant indicator, or a weather-based predictor. The research effort that is needed must integrate these tools. Single-factor approaches do not lead to improved recommendations, because the factors determining N requirement are multiple.

Any approach that aims to come closer to optimum than current systems must account in a robust manner for the multiple factors affecting the demand for and supply of N (Stanford, 1973). Nitrogen demand associated with a specific crop yield potential is one of the three main components. The second is the supply function, most of which is directly influenced by management (applications of manure or fertilizer), but a substantial part is governed by biological mineralization and immobilization from native soil organic matter, and biological N fixation. The third component is the loss function, governed by weather processes that control water accumulating in and moving through soil, and the specific timing of these events interacting with the amount of N in the mobile nitrate form on any given day.

Few studies systematically partition variability in crop N response into the three components described above: crop N demand, soil N supply and soil N losses. Each of these three has both spatial and temporal components. Spatially, variability both within and among fields may be important. The main variation of interest is year-to-year or interannual. The two may interact with each other and thus be difficult to partition.

Managing crop N for weather requires site-specific approaches and flexible decision-making.

Process-based models that estimate mineralization, leaching, volatilization, and denitrification along with crop growth and development could contribute enormously to the rate decision at the critical point just prior to when crop N uptake begins. Agrometeorological information needs to be integrated into the decision-making process. The uptake of N for most crops, including corn, does not become rapid until several weeks after planting. By that time, probabilistic scenarios for that season's yield prospect can be better defined than they could have been prior to planting. A focused effort is required to develop prediction tools operating from process-based models that incorporate both past data and future probability scenarios.

Delaying applications until the last possible moment helps adapt N management to weather by reducing the time between application and crop uptake. Effectively, it transforms weather forecast probabilities into realities. Both probabilities and current realities need to be dealt with in adapting N management to weather.

However, a "just-in-time" approach to N management also needs to consider the probability of inclement field conditions preventing the timely application of a side-dress dose. Certain soil textures, particularly poorly-drained clay soils, may be most susceptible. The choice then becomes pre-plant with a controlled-release source (or an inhibitor to control transformation to nitrate), versus side-dress or split application, and that choice may be governed by soil texture. Sandier soils are accessible quite rapidly after wetting, so are more amenable

Abbreviations and notes for this article: N = nitrogen.

Table 1. Examples of crop and soil water models with potential application to weather-based N recommendations. More detail is available in IPNI (2007).

Example	Crop N demand	Soil N supply	Soil N loss
HERMES (Kersebaum)	SUCROS (daily timestep; van Keulen et al., 1982)	Two-pool first order soil N mineralization	Soil water capacity model; Denitrification; Leaching
PMN (Melkonian and van Es)	Maize N model (daily timestep; Sinclair and Muchow, 1995)	Two-coefficient model of soil N mineralization	Soil water capacity model; Denitrification; Leaching
LEACHM-N (Hutson and Wagenet, 1992)	Non-interactive with weather	Single-coefficient model of soil N mineralization	Richards soil water flux + convection-dispersion for solute transport
DSSAT-CERES (Singh)	Crop growth and N uptake (maize and wheat; daily timestep)	Godwin & Singh, 1998	Leaching; Denitrification; Ammonia volatilization
SUNDIAL (Dailey)	Crop N uptake, soil N mineralization and losses (weekly timestep)	Soil N mineralization; Crop residue N	Leaching; Denitrification
Dryland wheat (Pan; Karamanos)	Growth based on soil water and anticipated rainfall (empirical)	Mineralization; Immobilization; Residual N	Leaching; Denitrification

to multiple applications, while the slower-drying clay soils are more likely to be better served with a controlled-release strategy. Decision support systems must consider not only the physiological needs of the crop, but also the practical realities of possibilities for management operations including soil conditions supporting application equipment.

Current recommendation systems for N application to corn are based mainly on factors that do not reflect weather. Several states and provinces have made recent advances in developing recommendation systems based on identified databases of crop response trials. The regional N rate guidelines for midwestern states including Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio and Wisconsin are based on factors including the price ratio between harvested corn and N fertilizer, previous crop, and to some extent the productivity of the soil, and are specific to each state. The Maximum Return to N (MRTN) is determined from quadratic-plateau response curves fitted to recent state-specific crop response data (Sawyer et al., 2006). In Ontario, a large database comprising over 600 site-years of corn N response trials was used in a similar manner to develop a set of recommendations comprising six factors: price ratio, yield goal, soil texture, previous crop, site heat unit rating, and application timing (www.gocorn.net). It is difficult, however, to adapt current local weather information to make further adjustments to these recommendations. For example, the pre-sidedress soil nitrate test (a soil test with some weather dependence) is advocated in some of these regions, but the producer is left with little guidance as to how to interpret the nitrate result in the context of the full set of other factors.

Computer models of crop growth predict growth and development of crops as a function of their soil and air environment. The primary driving variables are solar radiation, temperature, and water. The function of a model is to predict the outcome of numerous complex processes underlying a main process of interest. In the case of agronomy, the main interest is often the yield outcome. When variables under management control are included, the model can also serve to predict optimum input levels of such variables.

Moving the recommendation approach from single to multiple factors is likely to require some form of computer model to assist with the integration. **Table 1** lists some of the crop models referred to in the proceedings publication, *Managing Crop Nitrogen for Weather* (IPNI, 2007), and briefly describes the methods used for modeling each of the three fundamental process categories. There are many more models that could be implemented. Supplying accurate input data is a constant challenge with a modeling approach. When models are applied, it is important to critically evaluate each component to ensure a balanced representation of the important processes, and rigorously validate with data from on-farm research.

A research agenda to further the development of integrated model-based N recommendations should include:

- Participatory research with producers and advisers to test feasibility of integrated N management tools, using on-farm weather monitoring;
- Development of models that address the weather's impact on crop growth, soil N supply, and soil N losses;
- Further exploration of datasets of past response research, assembling the necessary soil and weather data to run models to estimate the movement and transformation of soil N;
- Increased use of real-time remote-sensed data to detect N status of plants and gauge need for additional N application;
- Development of simplified means to characterize soil physical properties that impact water and nutrient movement in soil for practical management, using principles from the sciences of soil physics and agro-meteorology;
- Spatial analysis and description of nitrate transport and transformation within agricultural fields;
- Identifying genetic traits influencing the physiology of crop growth, to select genotypes that capture more of the nutrients made available through the season by mineralization.
- Field validation of soil-crop-water-nutrient models.

- Increased accessibility of real-time weather data.

Spatial and temporal variation need to be addressed together. The complex interactions that stand out in several of the studies reported in IPNI (2007) show that spatial variations in soil properties affect optimal N rates in a complex manner. It can be postulated that a highly site-specific approach to managing N will not be effective without an eye to the weather, and that attempts to make weather-specific recommendations will also fail if there is no eye to the soil and its spatial variability.

Managing crop N for weather requires site-specific approaches and flexible decision-making. These aspects are difficult to accommodate in regulatory approaches to nutrient management, and indeed are a limitation in nutrient management plans established on cycles of several years. While nutrient management plans have value in tactical planning, it is important that they allow flexibility in day-to-day implementation to suit changing weather conditions. Nutrient management must adapt more closely to changeable weather. Systems allowing producers to make data-driven decisions more rapidly may have advantages over regulatory approaches in improving the efficient use of N.

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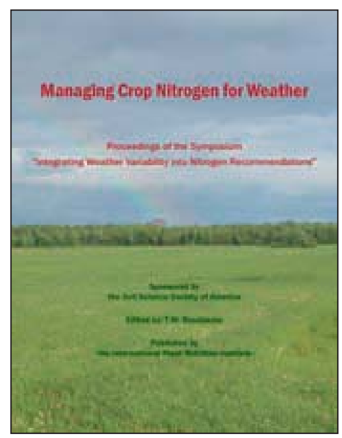
Proceedings of the Symposium "Integrating Weather Variability into Nitrogen Recommendations"



The weather controls a great deal of the crop response to N. The contents of a new publication titled *Managing Crop Nitrogen for Weather*, based on the proceedings of a symposium at the 2006 meeting of the Soil Science Society of America (SSSA), provide details of experimental data and experiences of those engaged in efforts to improve prediction of crop N needs in response to weather conditions.

The papers contained in this new 132-page publication were originally presented at the Symposium "Integrating Weather Variability into Nitrogen Recommendations." Thirteen of the original presentations from the Symposium are contained in the publication, plus abstracts of others. The authors are from several different countries and are recognized scientific authorities on their topics. The International Plant Nutrition Institute (IPNI) published the proceedings.

The publication is paper-bound, 8½ x 11 in., and contains some color. It is available for purchase from IPNI for US$50.00 plus shipping/handling.

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