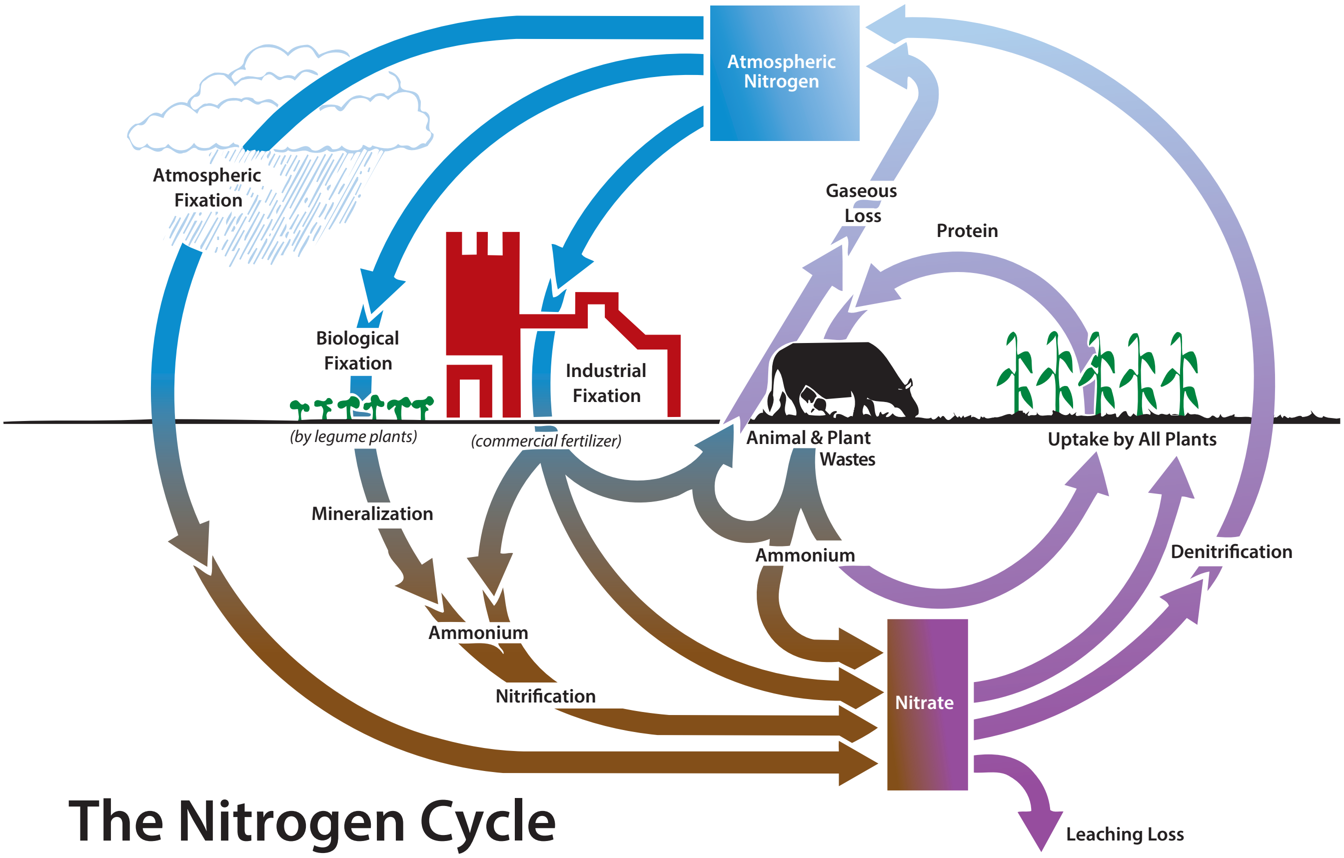
CHAPTER 22

Real-time Simulation Models—A Novel Tool for Farm Nitrogen Management

Derek Hunt, Shabtai Bittman and Ron Fretwell



The Nitrogen Cycle

Adapted with permission from D.M. Ball, C.S. Hoveland and G.D. Lacefield. 1991. *Southern Forages.* Potash and Phosphate Institute and Foundation for Agronomic Research, Norcross, GA.

Traditionally, farmers have managed nutrients through intuition and experience, with yield and sometimes quality as the target. In essence, the farmers developed mental models of their operation honed with experiential feedback and validation. First-generation nitrogen (N) management technology was based on soil testing and calibration; optimizing N rates through soil chemical analysis allied with information from research on N application rates, timing, placement, various interactions, etc. The models became more quantitative, considering even economics, thus greatly improving precision of N use. Still, precision was lacking partly due to variability in space and time. Second-generation N management technology involves in-crop testing of soil and plants, and spatially variable application rates. The need for more N efficiency is driven by economics, dwindling resources and concerns about environmental impact. However, the success of second-generation methods is hindered by the complexity of the N cycle and inability to accurately predict weather and hence crop response or soil nutrient availability (especially rate of N mineralization).

Mental models for managing N tend to be very simple and qualitative. Computer simulation models help in accounting for many simultaneous soil processes and this helps to make better quantitative decisions for managing the N system. Just as a microscope allows us to see very small objects, simulation models help us to see and understand and ultimately compute the dynamic functions of complex systems.

Models for formulating livestock rations have been used for decades to optimize feed quality using a wide array of product combinations, and contemporary models take into account time factors such the rate of fibre degradation in cattle rumen. These models are widely accepted and used, and although none are perfect, they greatly improve management of livestock feeds.

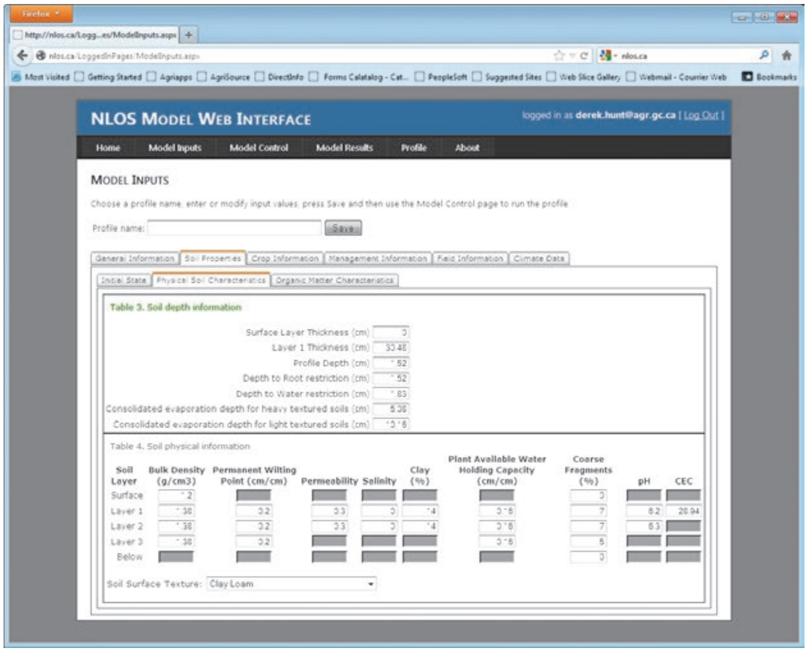


Figure 1. NLOS on the Web: Input table for soil physical characteristics.

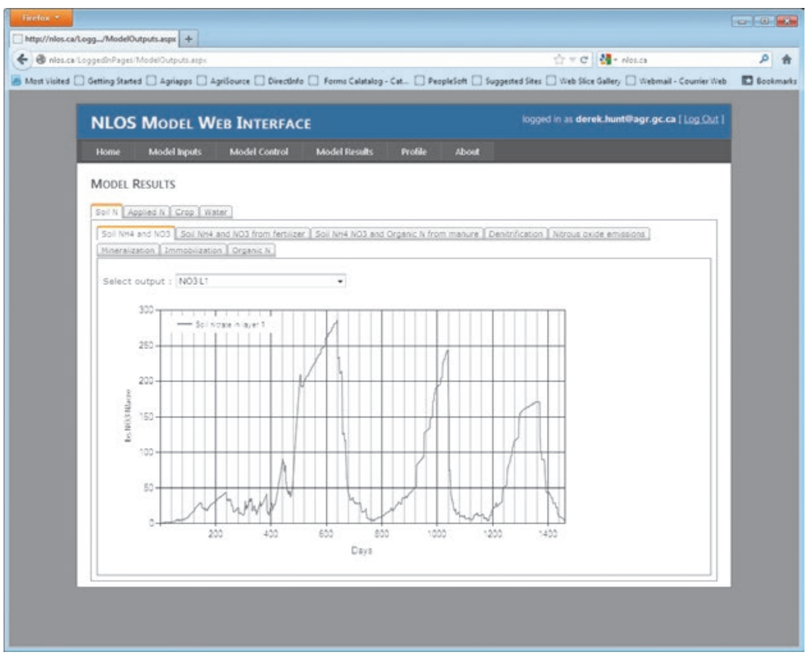


Figure 2. NLOS on the Web: Output graph of soil nitrate-N in soil layer 1 (typically 0-30 cm or 0-12 in) over 4 years.

The dynamic behaviour of N in the soil is not intuitive; it cannot be seen and is not easily measured. At any moment, we cannot tell what is happening to N-containing compounds in the soil: where do they go? How are they transformed? Where are they lost? The human mind cannot carry out such complex simultaneous calculations, made even more intricate by feedbacks and time lags that may range from minutes to years. Mechanistic N models such as ANIMO (Kroes and Roelsma 1998; Rijtema and Kroes 1991) from The Netherlands and SOIL-N (Eckersten and Jansson 1991; Eckersten et al. 1994) from Scandinavia simulate all the main soil processes at regular time intervals, typically a day. They process information based on soil parameters, farm management practices and daily weather data. Mechanistic models are used for guiding management expert systems like Manner from the U.K. (Chambers et al. 1999) and the PNM tool from Cornell, U.S.A. (Melkonian et al. 2005).

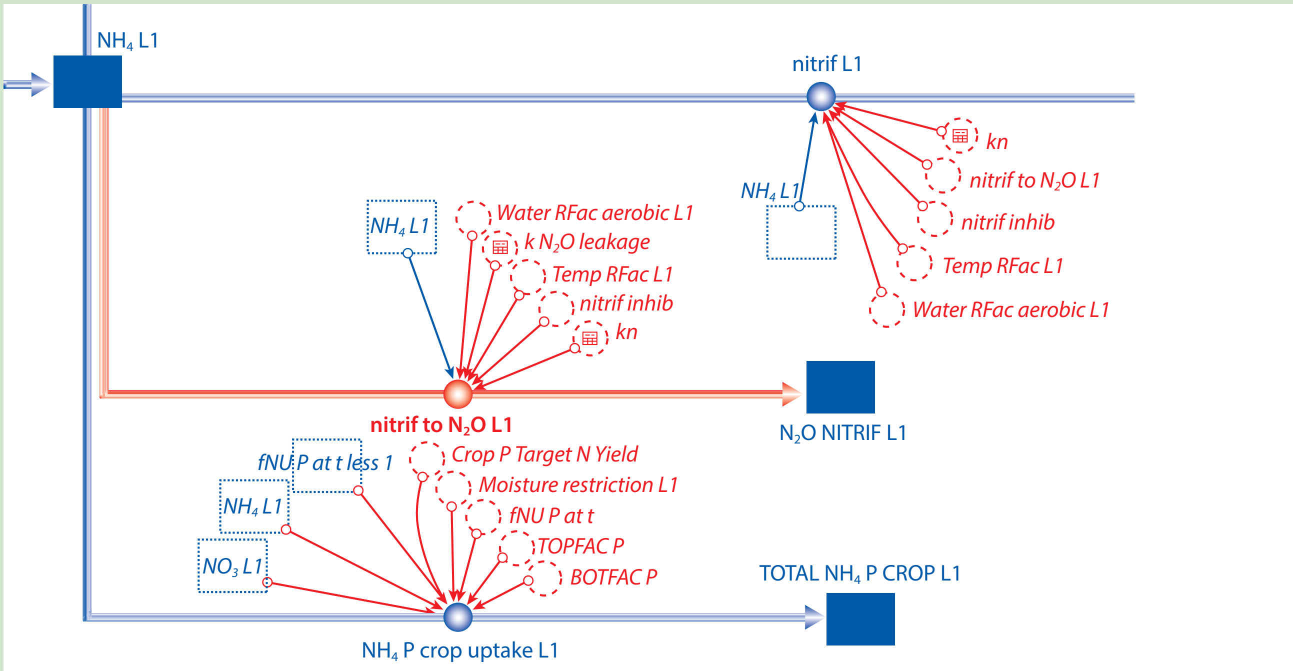
It is now possible for non-experts to run dynamic soil N models automatically in 'real-time' using the World Wide Web (WEB). Real-time models help reveal the soil N situation as it is on a given day, helping guide timely decisions and demonstrating the effects of past decisions. As these models provide current information, they may narrow end-of-season predictions. Real-time models are currently in use at a just a few locations (Van Es 2010; Clark 2004; Herrmann et al. 2005).

We have recently developed a new real-time N model called 'NLOS On the Web' (NOW), which can be accessed by anyone at www.NLOS.ca. This model will tell you on any day, on any field where all the forms of N are located, how much there is of each form in each part of the system and what functions such as leaching and mineralization are occurring — all in estimated values. To run, the model needs basic soil information (which is stored for future use), farm practices information (e.g. planting and N applications), and daily weather data, which the model obtains automatically from a user-chosen weather station.

Figure 1 shows a portion of a data input table (for soil parameters). Figure 2 shows a four-year output graph of soil nitrate-N in soil layer 1, but the model can be activated on any day to give current status for any of the soil N, soil water and crop N parameters for any field on the farm.

The tool shows the rates of N movements, transformations and losses on a daily basis, or cumulatively to the current day. For example, on any day the user will observe the accumulation, movements and depletion of applied fertilizer and manure N on fields with contrasting soils and crop management (e.g. corn vs. grass, or cover cropping) in relation to crop uptake. And for those wishing a deeper understanding, the model calculates chemical and microbial N transformations. Each day the user can access information on the effects of immediate and long term practices on crop utilization, or conversely, losses.

NLOS on the WEB (www.nlos.ca)



Portion of NLOS model built with STELLA® modelling software.

Unique aspects

- Coupling in real-time of on-farm weather data, soil temperature and soil moisture with a complete soil N-plant-water simulation model.
- Capability of users to enter their own soil data and management information and see in real-time (i.e. day by day) the consequences of their management decisions.
- On-farm testing can be conducted for validating predictions for a particular field. Simulations from the real-time management tool can then be compared with on-site soil, water and plant samples. This will allow for validation of the underlying soil N-plant-water model as well as providing information for model improvement and adaptation.
- "What if" scenario analyses can be performed in real-time allowing for in season changes to management practices.

Benefits

- Improve management and planning to better utilize N from fertilizer and manure, thereby reducing nitrate leaching to ground water and runoff to surface waters.
- Real-time, internet based information provides immediate feedback for management decisions and will improve the development and use of environmental farm plans which help reduce nutrient loading to the environment.
- Real-time information will help forecast harvesting date and residual soil N which may suggest urgency of mitigating practices.
- The real-time internet format allows for the most recent extension and research information to be incorporated and provided to farmers for adoption in best management practices.
- Better utilization of N from fertilizer and manure will reduce greenhouse gas emissions and improve environmental performance.
- Improve N use efficiency and lower environmental impact of crop production.

With help of professional advisors, this on-farm tool will help farmers and managers self-assess and develop better N management skills.

Are the model predictions dependable?

This cannot be easily answered. In fact, the validity of estimates needs to be tested against local knowledge and experience and key measurements. Figure 3 shows how nitrate levels in a silage corn field (top 30 cm or 12 in) change over a two year period. Weekly field measurements (circles) are compared to an un-calibrated NLOS model output (black line) for the same field. Even without local calibration, the simulated data compares reasonably well with field measurements, but it is by no means a perfect match. The model over-predicted the drop in soil nitrate in the first year but under-predicted it in the second year. The model also predicted a later peak in nitrate values in the first year, but was reasonably close to measured values in the second year. Why the differences?

An important consideration when comparing observed field data with model simulations is that field data often shows considerable spatial variation which is shown in the black vertical error passing through the circles. The variability of field measurements is likely due to soil variability across the corn field; even though it looks quite uniform, there are differences both at the surface and below the surface which affect the nitrate concentrations.

There are no simple explanations, but local knowledge and experience can be used to adapt the model so that it does a better job at predicting N status in the soil which is essential if the model is to be trusted for farm decisions. Real-time presentation of soil N processes allows the farmer to better interpret results of soil testing such as the Pre-Plant N Test (PPNT; Bundy et al. 1995) or the pre-side dress nitrate test (PSNT; Blackmer et al. 1989) used in corn production. In addition, better interpretation can be made from crop N status monitored with chlorophyll leaf sensors and canopy reflectance measurements monitored to provide vegetation indices (NDVI, SRI etc.).

The NLOS model (Bittman et al. 2001) is useful for predicting the effects of different management choices. In Figure 3 the green line (Scenario 1) shows simulated soil nitrate levels if pre-plant mineral fertilizer is replaced with whole dairy manure at an equivalent rate (based on mineral N). The pattern of soil nitrate levels is similar for fertilizer and manure until about mid-July where nitrate levels from manure are higher due to mineralization of organic N from the manure. The blue line (Scenario 2) shows what would happen if manure was applied after corn harvest at about 270 kg N/ha (240 lb N/ac). Initially soil nitrate levels increase sharply but peak at much lower levels than with spring application and then decline sharply. This is caused by ample fall rains, typical for the region.

The NOW software has some special attributes. It is built so that it can be more easily locally validated and calibrated. The functional NLOS model itself is depicted pictorially (see image on page 94), and changes can be made using images from a pull down menu. Thus, no modelling expertise is needed.

An extremely powerful aspect of NLOS on the WEB that is currently being developed is to incorporate full editing capability available in the PC version of NLOS version. Model constants and equations will be available for editing and adjusting to advanced users through instrument panels. This will allow for model modification, on-line and in real-time, so that advanced users can adapt the model for their own local conditions. For example, if a user is seeing crop growth being under predicted by the model, then growth rate parameters can be adjusted so the model better simulates what is seen in the field.

References available online at www.farmwest.com

Derek Hunt Agriculture and Agri-Food Canada, Agassiz, BC, Canada | derek.hunt@agr.gc.ca

Shabtai Bittman Agriculture and Agri-Food Canada, Agassiz, BC, Canada

Ron Fretwell RHF Systems, Kelowna, BC

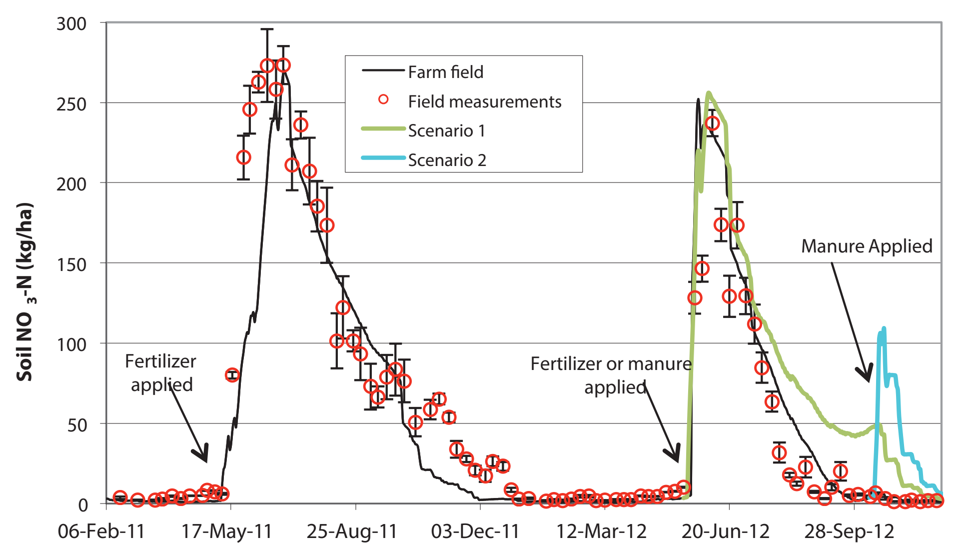


Figure 3. Simulated and measured soil nitrate-N (kg N/ha) for 0-30 cm (0-12 in) from a corn crop at Agassiz, BC, 2011-2012 with NLOS.