# Chapter 14

**New Tools to Assess Nitrogen Management for Conservation of Our Biosphere**

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## INTRODUCTION

Several models can be used to assess the effects of management on nitrogen (N) losses to the environment. Shaffer et al. (2001) discussed the advantages and disadvantages of several of these nitrogen models. Other authors have also evaluated different models and their capabilities of assessing the effects of management on N losses (Cannavo et al., 2008; Beckie et al., 1995). Delgado (2001) reported that computer simulation models are useful tools for assessing the effectiveness of conservation practices (best management practices [BMPs]) and assisting in the challenge of quantifying nitrogen losses. Shaffer and Delgado (2001) proposed that practitioners are more interested in general tools that can be applied quickly to a given situation, while theorists look for detailed, mechanistic tools that can explain a situation comprehensively, using larger numbers of constants, variables, and equations (Figure 1). Shaffer and Delgado (2001) reported that maximizing the probability of selecting the right tool for a project may be achieved by selecting a model of intermediate detail that achieves a balance between the needs of practitioners and theorists (Figure 1). However, depending on the site-specific application, a simpler or more complicated tool may be needed (Shaffer and Delgado, 2001).

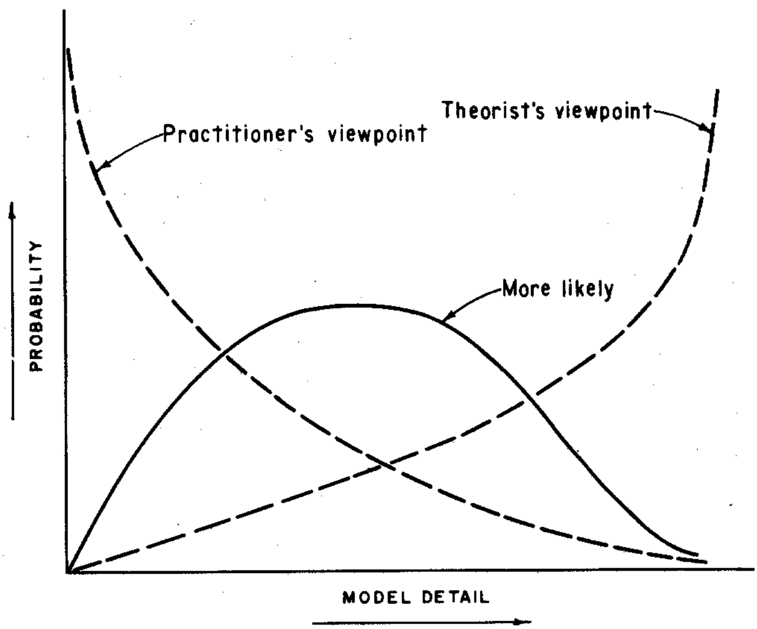



**Figure 1. Selecting the best model for a field project (from Shaffer and Delgado, 2001).**

Selecting a tool that is too simple or complex for a given application may cause problems if the tool's capabilities, applicability, reliability, ease of use, data needs, and/or supplied databases do not fit with the situation that is under assessment (Shaffer and Delgado, 2001). It is therefore advisable to define any problems and goals at the start of a project, before selecting a tool, to avoid wasting energy and resources in efforts that may provide excessive or insufficient information for making correct decisions.

The development of a tiered approach could help users select the right tool for the needs of their project. A tiered approach classifies tools based on the complexity level of the information they process. For example, Tier One defines a level of tools with a simple approach that can use qualitative/quantitative screening for a quick assessment of a field situation, such as the Phosphorus (Lemunyon and Gilbert, 1993; Sharpley et al., 2003) or Nitrogen Index (Delgado et al., 2006, 2008a; Shaffer and Delgado, 2002; Van Es et al., 2002; Van Es and Delgado 2006). Within minutes these tools can analyze a field situation to distinguish the regions with low and very low risk of losing nitrogen from the regions with medium, high, and very high risk of losing nitrogen. Tier Two tools are defined as tools that work at a more complex level, using quantitative analyses to quantify nitrogen dynamics within a daily timeframe, but these tools are still considered relatively simple models; an example of a Tier Two tool is the new Nitrogen Loss and Environmental Assessment Package with geographic information systems (GIS) capabilities (NLEAP GIS 4.2). A Tier Three tool has a larger numbers of constants, variables, and equations, and can be applied to situations that require a highly complex and detailed analysis. Examples of these research models include LEACHEM (Wagenet and Hutson, 1989) and RZWQM (De Coursey et al., 1989).

Beckie et al. (1995) and Khakural and Robert (1993) compared a Tier Two model like NLEAP to more complex Tier Three models such as CERES, EPIC, NTRM, and LEACHM-N. These independent studies found that NLEAP performed similarly to the Crop Estimation through Resource and Environment Synthesis (CERES; Ritchie et al. 1985), the Erosion/Productivity Impact Calculator (EPIC; Williams et al., 1983; 1984), the Nitrogen Tillage Residue Management (NTRM; Shaffer and Larson, 1987), and LEACHM-N (Wagenet and Hutson, 1989). NLEAP can be used to conduct rapid, site-specific evaluations of N management practices (Shaffer et al., 1991; Delgado et al., 1998a, 1998b; Shaffer et al. 2010). Although Tier Three tools are the most complex and detailed of the tools, Tier One and Tier Two tools have also been reported to readily and accurately identify hot spots when using GIS analyses to assess management scenarios with risky landscape combinations. De Paz et al. (2009) showed that Tier One tools (screening analysis with an Annual Nitrogen Index Approach) have a lot of potential for conducting analysis across a Mediterranean region of Spain. Tier Two analyses with GIS have been conducted by Wylie et al. (1994, 1995) for northeastern Colorado, Delgado (2001) and Berry et al. (2005) for south central Colorado, and Delgado and Bausch (2005) for projects using remote sensing and GIS to manage nitrogen application and precision conservation across the landscape.

Although these Tier One and Two tools are simpler, they are built on strong qualitative/quantitative screening approaches and theories that were sufficient to provide predicted values that were positively correlated with observed values (Delgado and Bausch, 2005; Delgado et al., 2006, 2008a; De Paz et al., 2009). The assessment of the effects of management practices on nitrate leaching by these Tier One and Two tools were also positively correlated with observed nitrate levels in underground waters (De Paz et al., 2009; Hall et al., 2001; Wylie et al., 1994, 1995), showing the potential to use these Tier One and Two tools to assess management practices and mitigate the effects of N losses on groundwater.

## NEW NITROGEN LOSS AND ENVIRONMENTAL ASSESSMENT PACKAGE WITH GIS CAPABILITIES

The Nitrogen Loss and Environmental Assessment Package (NLEAP) is an improved and renamed version of the DOS program that was called the Nitrate Leaching and Economic Analysis Package (NLEAP); see Shaffer et al. (2010, Chapter 13) in this book. NLEAP GIS 4.2 is a new, Excel-driven menu that helps users quickly access online databases, convert these databases to a format that is compatible with NLEAP GIS 4.2, and interact with GIS. Users of NLEAP GIS 4.2 may wish to consult the user guide, which provides step-by-step instructions on how to use the model (Delgado et al., 2010a, http://arsagsoftware.ars.usda.gov).

NLEAP GIS 4.2 includes updates and improvements from its predecessor, providing users with newly added functions to help them assess how management practices will affect nitrogen losses to the environment across risky landscape and cropping system combinations. Each of the major components of NLEAP GIS 4.2 is programmed in a different computer language. Shaffer et al. (2010) developed the basic NLEAP GIS 4.2 console in Fortran and C/C++, and the console contains the algorithms that are used to assess the effects of management practices on nitrogen pools and pathways for nitrogen losses; these algorithms are described in Chapter 13 of this book. NLEAP GIS 4.2 includes a new, user-friendly interface that runs the console program within a Microsoft Excel environment. This new interface is highly adaptable and enables users to quickly evaluate multiple practices employed over long periods of time. The NLEAP GIS 4.2 quickly updates database files to be used in multiple GIS software packages, facilitating the analysis and evaluation of management systems across single fields, multiple fields, and regions. Additionally, the new NLEAP GIS 4.2 user interface enables rapid connection to online databases, including current USDA Natural Resources Conservation Service

(NRCS) soil (NASIS and SSURGO) and climate databases. Users can download soil types across several counties and evaluate the effects of BMPs across different regions of the US.

NLEAP GIS 4.2 can quickly provide simulations of surface residue decay and $N_2O$ emissions, multiple simultaneous simulations, and long-term analyses, and return results that can be graphed, displayed in tables, and entered in databases that can be saved for further analyses. The output databases can also quickly export analysis to a GIS format that can be used by managers to identify sensitive areas across the landscape.

NLEAP GIS 4.2 was developed for the Microsoft Office Excel 2003 environment, which can run in a Windows 6 or Windows 7 environment. The upcoming revised NLEAP GIS 4.2, expected to be available in 2010, is currently in development and will work within the Microsoft Excel 2010 environment. We encourage users and other interested persons to review the literature to find guidance in identifying potential applications of NLEAP GIS. Selected potential applications are described in Delgado and Shaffer (2008); other information about the features of NLEAP GIS 4.2 can also be found in Shaffer and Delgado (2001, 2002) and its manual (Delgado et al., 2010a).

**TESTING THE NLEAP GIS MODEL**

The NLEAP model has been widely used and validated in the US, Europe, South America, Canada, and with cooperators from the North China Plain. Given proper input, the model's predicted values for residual soil nitrates and nitrate leaching rates have been shown to be reasonable approximations of actual values over a wide range of circumstances (Shaffer et al., 1995; NCWCD, 1991; Hoffner and Crookston, 1995, 1994; Crookston and Hoffner, 1993, 1992; Walthall et al., 1996; Beckie et al., 1995; Campbell et al., 1993; Follett et al., 1994; Delgado, 1998, 2001, 2000; Wylie et al., 1994, 1995; Stoichev et al., 2001; Lavado et al., 2010). As an example, the combined results for over 200 site-years of validation testing of NLEAP under irrigated and non-irrigated agriculture in the US, Argentina, and China are shown in Figure 2.

Additional details about application of the NLEAP GIS model to field situations and to cases of climatic and spatial variability can be found in Wylie et al. (1994, 1995), Hall et al. (2001), Delgado et al. (1998a, 2000, 2001), Shaffer et al. (1994), Shaffer and Delgado (2001), Delgado and Bausch (2005), and Delgado et al. (2005). These NLEAP analyses were conducted using the old version of NLEAP and manually exporting simulated outputs to GIS software to match a given DOS soil-management scenario simulation, with a given soil polygon-management scenario combination. It took a longer time to conduct these analyses since data management and several other processes were conducted manually and without a friendly interface system that could connect the DOS version with the new GIS software (which uses Windows). The old version of NLEAP was also unable to facilitate the quick modification of GIS databases to export them to the DOS system. Nonetheless, the slower analyses provided very valuable assessments of the effects of nitrogen management practices across the landscape, which were calibrated and validated.

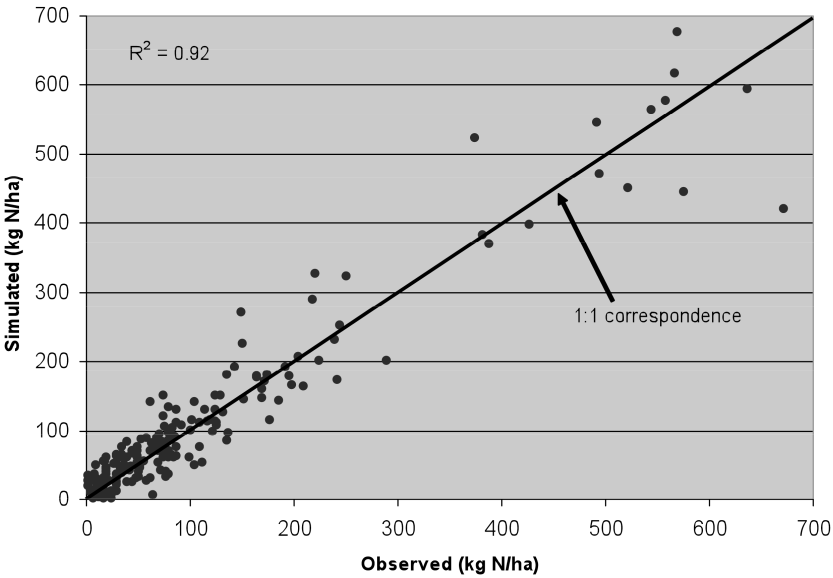



**Figure 2. Combined results for 200 site-years of validation testing of NLEAP under irrigated and non-irrigated agriculture in the US, Argentina, and China (from Delgado et al. 2008a).**

Technological developments such as GPS, GIS software, and remote sensing techniques during the mid-1990s and early 2000s created the potential for studying the effects of management practices on nitrogen losses and the effectiveness of new conservation practices (Berry et al. 2003; 2005; Delgado and Berry, 2008). Using NLEAP with GIS, Wylie et al. (1994, 1995) found that the areas with the higher simulated leaching potential were positively correlated to areas with higher nitrogen inputs and higher underground water nitrate content in parts of northeastern Colorado (Figure 3; Wylie et al., 1994).

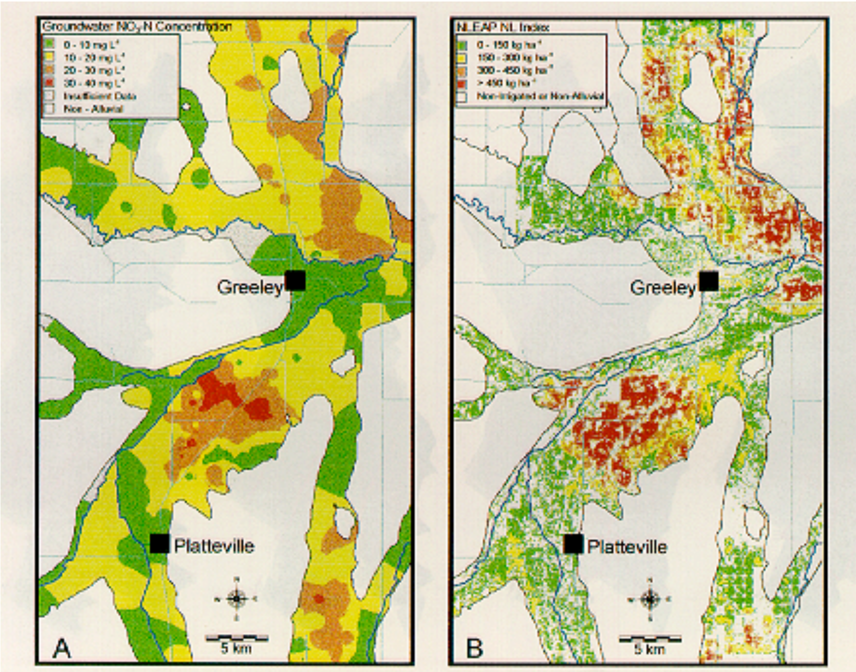



**Figure 3. (A) Average values of actual groundwater $NO_3$-N leached (1989–1991) and (B) average values of NLEAP simulation of $NO_3$-N leached kg N $ha^{-1}$ (from Wylie et al 1994).**

Delgado and Bausch (2005) also used NLEAP and GIS to study nitrogen management in a field from northeastern Colorado and reported that traditional practices that applied excessive amounts of nitrogen in irrigated sandy soils resulted in the leaching of large quantities of nitrates. Delgado and Bausch (2005) validated the capability of the NLEAP GIS approach to simulate the spatial variability of residual soil nitrate by showing that the simulated values correlated with observed residual soil nitrate in the profile. Residual soil nitrate correlated with soil texture, in agreement with similar results from Delgado (2001).

Rupert (2008) showed that for the period from 1988 to 2004 the well network in northeastern Colorado had increasing nitrate concentrations. NLEAP GIS analyses of the effect of management practices on residual soil nitrate have been validated in this region, and predicted nitrate leaching has been correlated to underground nitrate concentration levels in this area. These studies suggest that excessive nitrogen applications may be one of the factors contributing to nitrate levels in underground water (Rupert, 2008; Wylie et al., 1994, 1995; Delgado and Bausch, 2005).

NLEAP GIS analyses can be used to determine whether an alternative practice such as precision farming, remote sensing, and management zones could be used to mitigate nitrate leaching from the root zone. The potential advantages of using these new spatial technologies (e.g., remote sensing, management zones) to reduce nitrate leaching were also studied with NLEAP and GIS (Delgado and Bausch, 2005; Delgado et al., 2005). Remote sensing can be used to improve the synchronization of split N applications with N uptake and reduce nitrogen inputs by 50% without reducing yields (Bausch and Delgado, 2003) and while reducing nitrate leaching by 47% (Delgado and Bausch, 2005). Another approach is to use management zones to improve nutrient management (Fleming et al., 1999). These site-specific management zones (SSMZ) can contribute to increases in nitrogen use efficiencies (Khosla et al., 2002). An analysis of SSMZ showed that they can lead to greater reductions in nitrate leaching compared to traditional practices (Delgado et al., 2005).

In south-central Colorado, NLEAP GIS analyses across the region have shown that new best management practices are contributing to lower nitrate leaching levels. Delgado (2001) and Delgado et al. (2001) also validated the capability of an NLEAP GIS approach to simulate the nitrate dynamics and residual soil nitrate across this region. They found that soil nitrate was correlated with soil texture across fields of south-central Colorado (Delgado, 2001; Delgado et al., 2001) and that rotations of vegetable crops with deeper rooted crops and cover crops, in addition to better synchronization of nitrogen applications with nitrogen uptake requirements, were helping to minimize nitrate leaching across the entire region (Delgado, 1998, 2001; Delgado et al., 2000, 2001, 2007). These results from Delgado (1998) and Delgado et al. (2001, 2007) are in agreement with findings by Rupert (2008) that reported no increases in groundwater nitrate concentrations in the period from 1988 to 2004 in the well network in south-central Colorado. The Delgado (1998) and Delgado et al. (2001, 2007) findings suggest that implementation of conservation practices such as rotations with deeper rooted crops, use of cover crops, and best nitrogen management practices such as accounting for N cycling from cover crops can protect groundwater resources.

Efforts to develop a quicker and more automatic version of NLEAP GIS that could conduct quick regional analyses started with a web prototype developed by Shaffer (2002). An initial GIS prototype system was installed on a laptop to be tested as a stand-alone system (Berry et al., 2005). A new NLEAP GIS 4.2 to conduct simulations of management practices to assess nitrogen losses across the landscape was developed (Delgado et al., 2008c; Figure 4; Shaffer et al., 2010, Chapter 13; Delgado et al., 2010a).

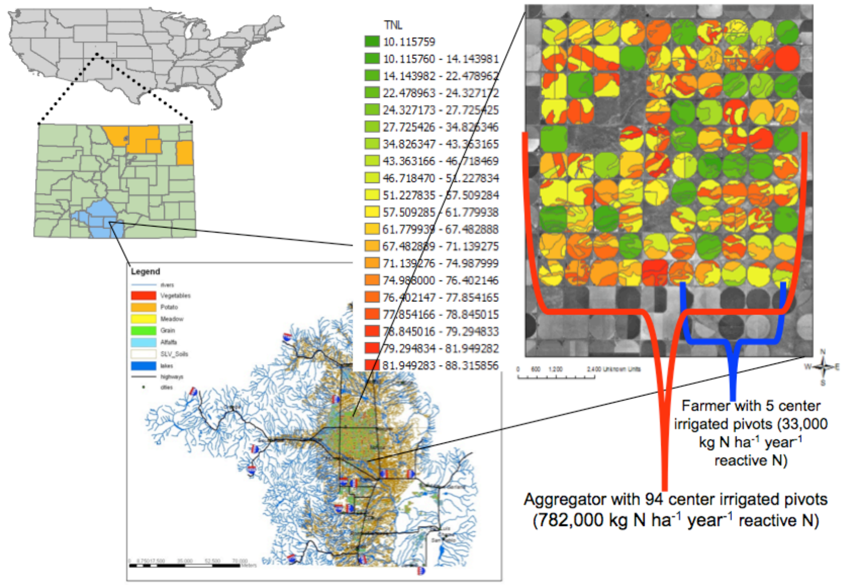



**Figure 4. A stand-alone NTT-GIS prototype can be used to quickly evaluate the effects of management practices on total reactive N losses and the resultant potential to trade across regions (hypothetical example, south-central Colorado) (from Delgado et al., 2008c).**

## APPLICATION OF NLEAP GIS 4.2 TO HELP DECREASE N LOSSES

Nutrient managers need to understand that the different pathways for N loss are controlled by different underlying mechanisms. For example, $NH_3$-N volatilization is related to unincorporated surface applications of ammonia sources (fertilizers and manure), while $NO_3$-N leaching requires residual $NO_3$-N in the soil profile and a significant precipitation or irrigation event, and is affected by soil type (e.g., coarser sandier soils have a higher leaching potential). Management refinements need to target the specific N loss categories that are causing problems on a site-specific basis.

Nitrogen loss pathways, such as $NO_3$-N leaching from the crop root zone, $NH_3$-N volatilization, gaseous emissions of $N_2O$ and $N_2$ gases, and surface runoff of $NH_4$-N and $NO_3$-N are highly variable in both time and space across agricultural fields. A systematic approach is needed to help identify potential combinations of management, soil, climate, and off-site effects that may contribute to significant N losses and environmental issues and to identify those combinations that have the potential to mitigate N losses and serve as best management practices. In many cases, local conditions and management options create site-specific N loss potentials that require custom management, although some regional generalizations are often possible.

Delgado and Berry (2008) discussed the development of GIS tools to assess the effectiveness of conservation practices across the landscape (precision conservation, also referred to as target conservation). Understanding model capabilities and limitations when using GIS and matching the tool to the specific task in advance will help in the selection of the correct tool for a given analysis. Shaffer and Delgado (2001) and Delgado and Shaffer (2008) and their discussion about capabilities and limitations of the model should be reviewed when users try to assess nitrogen losses from agricultural systems.

A simulation model such as NLEAP GIS 4.2 can quickly provide relatively detailed N loss data for management scenarios and soils across multiple fields and over long periods of time (several climate years/combinations). This makes it possible to identify where and when the risk of N losses is higher and to make comparisons between a baseline scenario and alternative management scenarios that may reduce N losses. The new NLEAP GIS 4.2 includes updates that give users the ability to quickly alternate between the NLEAP simulations and the GIS software, and to conduct a larger number of evaluations and analyses as well. The process has been completely automated so users can quickly do a batch of 5,000+ (site-year) simulations while going back and forth between the NLEAP and GIS software (Delgado et al., 2010a).

If detailed, site-specific analyses are desired, then initially between 5 to 10 years of historical management, crop yield, and climate data should be assembled and run through NLEAP GIS for the specific farm fields of interest. This will provide a detailed look at simulated N loss patterns as a function of time across multiple seasons, crop rotation patterns, detailed N management, and soils. The degree of vulnerability usually becomes apparent for a given site because N losses tend to occur as pulse events driven by combinations of precipitation (or irrigation) and management. The higher loss pulses should be thoroughly examined to help determine the underlying causes and suggest possible management solutions. Management may not be able to completely eliminate $NO_3$-N leaching, but best practices should reduce the magnitude of the more significant pulse events.

The new NLEAP GIS applications minimize the manual inputs that have previously been required of the user, such as manual or semi-automated transfers of soil type (series) identifiers for each farm field from the GIS. The NLEAP GIS outputs are quickly combined with GIS soil properties, producing an appropriate attribute database (*.dbf) file for display in GIS. Many GIS packages (e.g., ArcView, MapInfo, fGIS, and others) can be used. ArcView and MapInfo are examples of commercial packages, while fGIS is open source. We suggest using whichever GIS package is the most familiar to you, provided it has the basic GIS functions (drawing, clipping, and joining) required by NLEAP GIS (review Delgado et al., 2010a).

Soil data in GIS format, suitable for use with NLEAP GIS, can be downloaded from the USDA NRCS Soil Data Mart site (http://soildatamart.nrcs.usda.gov). Soil property (attribute) data in the form of text files are also downloaded along with the soil polygon information, but the attributes need to be converted to NLEAP GIS format before proceeding. See the Delgado et al. (2010a) NLEAP GIS package for Windows XP for instructions on how to handle the soil GIS data. The GIS data can be imported to the NLEAP GIS model. The GIS package can then be used to identify the desired area of the farm to be evaluated.

Step-by-step examples showing users how to conduct an NLEAP GIS analysis are available in Delgado et al. (2010a). Data in NLEAP GIS 4.2 are stored in three tables, which together make up the NLEAP GIS 4.2 database (NLEAP DB). These tables are named SoilLayer, ClimLong, and Events. The SoilLayer table is a collection of soil types, the ClimLong table is a collection of daily weather data (typically several years' worth), and the Events table holds all the events that describe the management scenarios that will be evaluated. Data for the SoilLayer and ClimLong tables are downloaded from Internet databases (NRCS soil SSURGO GIS databases and NRCS climate databases, respectively), whereas data for the Events table can either be input using the Events Creator in NLEAP, or can be imported from a file in Microsoft Excel or Microsoft Access (review Delgado et al., 2010a).

The NLEAP DB outputs each of these three tables into separate Microsoft Excel spreadsheets, which can be accessed from NLEAP GIS 4.2. Using Visual Basic programming, all of the NLEAP GIS data can be entered directly into an Excel spreadsheet and then exported to the NLEAP GIS model. The Driver menu (Figure 5) is used to enter the data. The Driver menu helps users access Internet databases to download soil GIS data (Figure 5). Once the data are downloaded from the NRCS website, the software converts them for use in NLEAP GIS. In a similar manner, the model can help users import weather data from NRCS weather databases and from the new NRCS High-resolution Climate Extractor. The driver will import information from GIS databases and will run the simulations automatically. The outputs are returned to GIS and can be displayed with the GIS software of the user's choice. Other functions of the new NLEAP GIS enable its users to generate graphs (Figure 6) and/or calculate average N losses via different pathways (Figures 6) (review Delgado et al., 2010a).

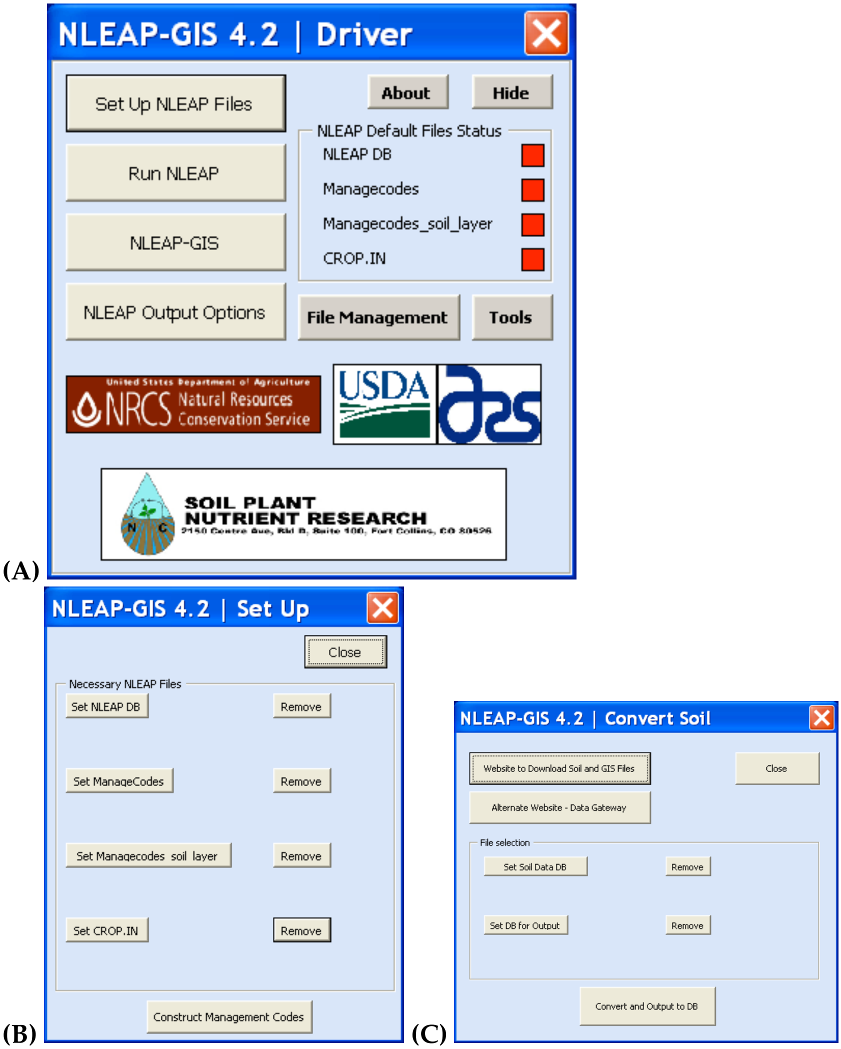
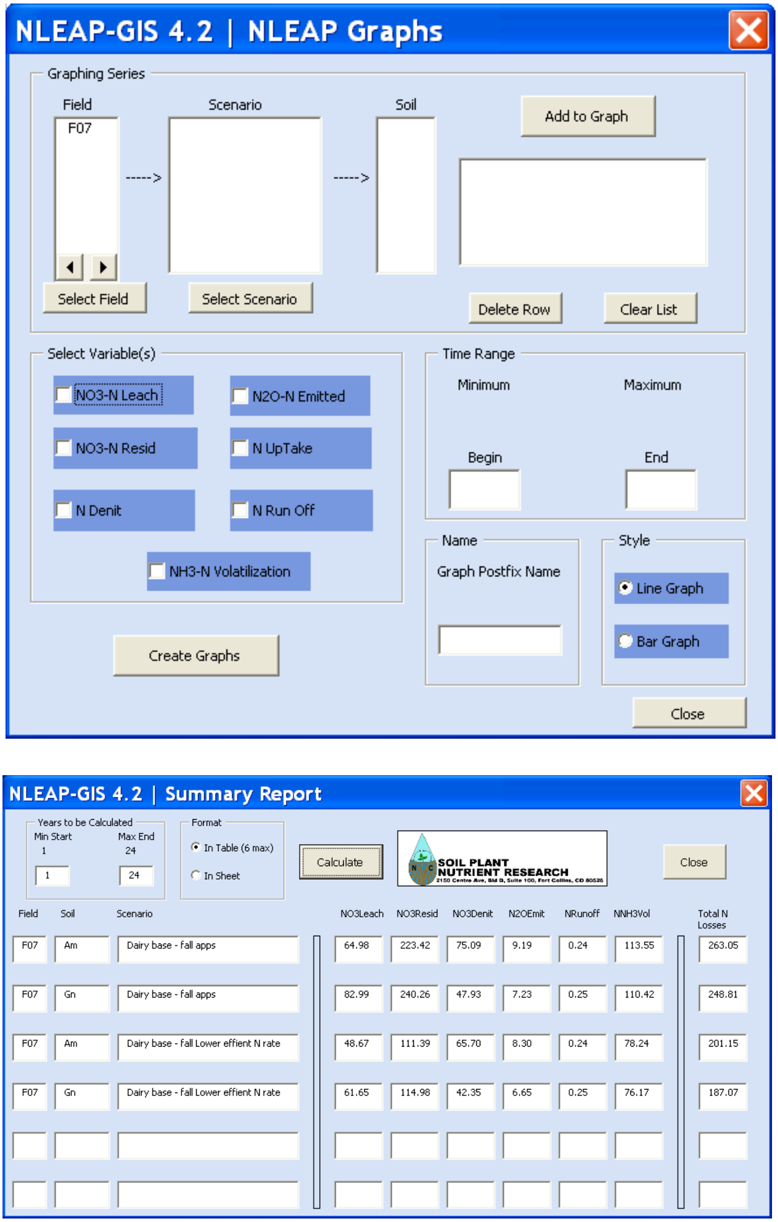



**Figure 5. (A) A stand-alone NLEAP GIS 4.2 driver can be used to run NLEAP GIS. The driver has outputs, tools, and management capabilities. (B) A stand-alone NLEAP GIS 4.2 driver can be used to set up databases, management codes, soil layers, crop databases and to construct management codes. (C) A stand-alone NLEAP GIS 4.2 driver can be used to connect to soil GIS databases and to convert those databases into NLEAP GIS format to assess management practices across the landscape.**



(A)

(B)

**Figure 6. A stand-alone NLEAP GIS 4.2 driver can be used (A) to develop graphs and/or (B) to calculate summary reports.**

## THE NITROGEN INDEX

The potential to use a simpler approach to quickly assess the effect of management practices on the risk of nitrogen losses to the environment has been discussed for the last two decades (Follett et al., 1991; Shaffer and Delgado, 2002; Delgado et al., 2006). A review of the advantages and disadvantages of the Nitrogen Index was done by Shaffer and Delgado (2002). One of the simpler approaches was the adaptation of the water leaching index (LI) developed by Williams and Kissel (1991) to nitrate leaching. This simple approach, which was able to perform relatively well in assessing nitrate leaching potential, has been called the N Index and has been used by NRCS personnel to estimate potential $NO_3$-N leaching (Van Es et al., 2002; Van Es and Delgado, 2006).

Other Tier One tool indexes were discussed by Shaffer and Delgado (2002). Shaffer and Delgado (2002) examined the advantages and disadvantages of the Movement Risk Index by Shaffer et al. (1991); the Nitrate Available to Leach Index by Shaffer et al. (1991); the Residual Soil $NO_3$-N Index by Shaffer et al. (1991); the Nitrate Leached Index by Shaffer et al. (1991); the Nitrogen Use Efficiency Index by Bock and Hergert (1991); the Annual Leaching Risk Potential Index by Pierce et al. (1991); and the Aquifer Risk Index by Shaffer et al. (1991) to assess the environmental risk of nitrate leaching. A qualitative/quantitative nitrogen index presented by Delgado et al. (2006, 2008a) includes new and important features that were not available in these other indexes. The Delgado et al. (2006, 2008a) Nitrogen Index is based on annual quantitative N and water balances and the index is available for a Windows Excel environment or a JAVA version. The Nitrogen Index can be connected to P-indexes (Delgado et al., 2006).

The new Delgado et al. (2006, 2008a) indexes are being used to assess the effects of management practices on nitrogen losses. Versions of the California Nitrogen Index and the Mexico Nitrogen Index (English and Spanish versions, Nitrogen Index 4.3) can also be downloaded from the USDA Agricultural Research Service web page: http://arsagsoftware.ars.usda.gov. A prototype of the Caribbean Nitrogen Index was also developed in cooperation with personnel from the USDA NRCS Caribbean Area and University of Puerto Rico (Nitrogen Index 4.3). These nitrogen indexes use qualitative/quantitative rankings to assess the effects of nitrogen management on the risk of nitrogen losses to the environment. The indexes rank the effects of management on nitrogen losses due to leaching, atmospheric, and surface losses, integrating the potential impacts with off-site factors. The risk for nitrogen losses is ranked as very low, low, medium, high, or very high. A new JAVA version of these indexes was developed, which can be applied to site-specific regions, states, and/or countries (http://arsagsoftware.ars.usda.gov). These indexes have already been utilized in a Mediterranean region (De Paz et al., 2009) and Mexico (Figueroa et al., 2009). Nitrogen indexes for Bolivia and Ecuador are in development. The N index for Ecuador and Bolivia includes a prototype of a sustainability index for these regions (Carlos Monar, Luis Escudero, and Ana Saavedra, personal communications).

Other recent nitrogen indexes were developed by Wu et al. (2005) and the Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) developed the Nitrogen Index for the Ontario Region (OMAFRA, 2003; 2005). Wu et al. (2005) developed the Nitrate Leaching Hazard Index, which applied the findings from Delgado (1998, 2001), Shaffer and Delgado (2002), and the concept of using deeper rooted crop rotations as management tools under commercial operations to scavenge $NO_3$-N, minimize $NO_3$-N leaching, and even mine and recover $NO_3$-N from underground irrigation waters. OMAFRA developed the Nitrogen Index for the Ontario Region to assess the effect of management practices on risk of N losses (OMAFRA, 2003, 2005).

## HOW THE NITROGEN INDEX RANKS RISK OF NITROGEN LOSS

The Nitrogen Index assesses the risk of nitrogen losses via different pathways. The following are interpretations of the general risk. These interpretations should also be considered for each individual pathway such as leaching, surface and/or atmospheric loss. Even if the general risk (the risk across all pathways) is ranked as medium or low, one of the pathways may still show a high risk, so practices that reduce the risk of losses to specific pathways should be considered.

In addition even if the individual pathway such as leaching, surface and/or atmospheric loss is ranked as medium, users should check the Estimated Potential Nitrate Available to Leach (Residual Soil Nitrate Risk) value to see how much risk there is of high residual soil nitrate, irrespective of the general risk ranking and the estimated amount of nitrate leached. For example, it is important to check this risk value because even if the general risk of nitrate leaching into the environment is ranked as medium for soils with low permeability and hydrology class D, there may be management scenarios that still have great risk of having high levels of residual soil nitrate when excessive amounts of N fertilizer or excessive amounts of manure are applied. This red flag of a high risk of residual soil nitrate available to leach will show—especially under low precipitation and/or no irrigation. This specific condition will be indicated by a large value for Estimated Potential Nitrate Leaching in the N Index (Delgado et al., 2006, 2008a). Although soils with these conditions may have a low general risk of nitrogen movement (low leaching), they will still be susceptible to N losses if they have a high residual soil nitrate and unpredictable high storm event occurs. In cases of medium nitrate leaching potential, the Nitrogen Index will still show a great risk of having a very high residual soil nitrate; the Nitrogen Index may still show the need to improve nitrogen management practices to reduce the risk of having large quantities of residual soil nitrate available to leach.

The following descriptions of general risk are an excerpt (with some adaptations and revisions) from the "Interpretations of Rankings" passage available in the Nitrogen Index:

***Very High and High Risk***

We suggest that those fields with very high and high risk rankings have their N management practices reevaluated by farmers/managers. N budgets ($N_{min}$) should be used as a basis for practice modification; N budgets will reduce the N inputs, which increase the risk of N losses to the environment. A very high or high risk assessment suggests that N is being over-applied and/or that the potential for reactive N losses to the environment is of concern. Nutrient managers should conduct N management practices following university and state recommendations. It is recommended that inputs of organic and inorganic N be reduced and/or managed to better synchronize N applications with N uptake by the crop. Users of the N Index should talk with technical service providers, extension agents, and NRCS personnel to develop nutrient management and conservation plans. These new plans may include any of the following BMPs, though the list is not exhaustive: soil testing, analysis of irrigation water, analysis of fertilizer input (organic, inorganic or both), crop rotation, use of scavenger crops, an N budget that accounts for any other sources of N, such as background N in groundwater, and residual N in soil and green manure. In the case of forage systems, nutrient managers should consider intensifying cropping systems to two and three forage crops, if possible, to increase synchronization of N uptake and sink.

***Medium Risk***

We suggest that those fields with medium risk for nitrogen losses are being managed adequately, perhaps using current BMPs. A medium risk assessment suggests the potential for reactive N losses to the environment is of minor concern. However, at a medium risk there may still be potential for N loss reduction and improvement of N use efficiencies (e.g., example describe above with high risk of high residual nitrate). We recommend that nutrient managers consider evaluating their practices to further improve N use efficiencies following university and state recommendations to minimize losses.

***Low and Very Low Risk***

We suggest that those fields with low and very low risk of nitrogen loss are being managed very well, probably using current BMPs. If anything, nutrient managers should evaluate the N budget to determine if there are any N deficiencies (if not a leguminous crop). The assessment suggests that these systems may be able to receive additional N inputs, improving crop performance without increasing potential for high and very high N losses to the environment.

## NITROGEN INDEX INPUTS

The new Tier One Nitrogen Index has a combination of qualitative/quantitative inputs that are used to assess nitrogen management (Figure 7; Table 1). The Nitrogen Index is user-friendly software that includes several dropdown menus to facilitate the quick entry of information. There are also several help screens and an easy-to-read instruction manual. It takes approximately three to five minutes to enter each case. The first case may take a few extra minutes to set up, but the following cases can be done much faster if the user simply needs to make modifications to variables such as rate, methods, or soil types. A comparison table can be used to quickly compare the different Nitrogen Index evaluations. For a detailed description of the data inputs for the Nitrogen Index, review Delgado et al. (2008a) and manuals.

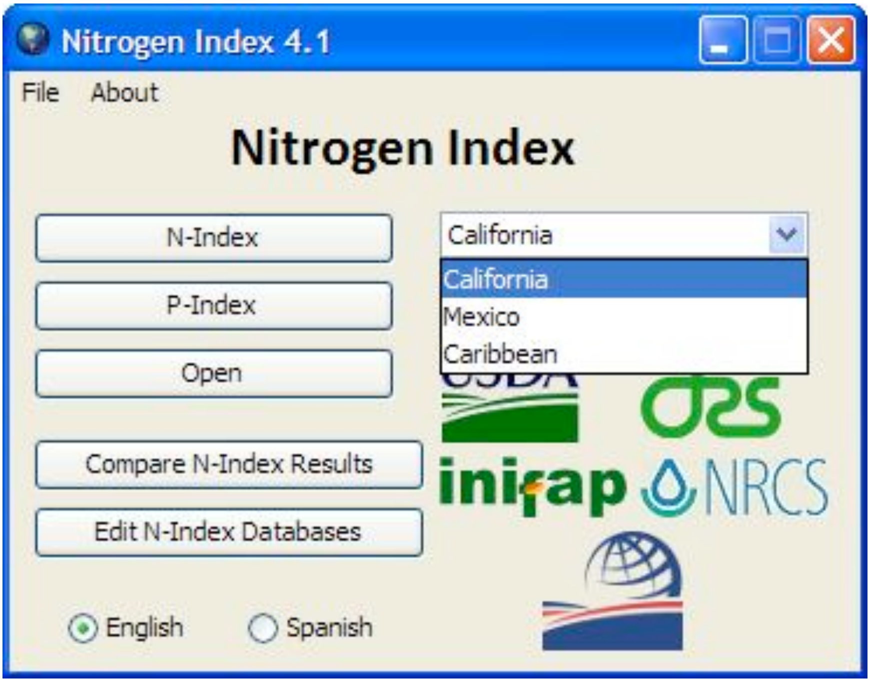



**Figure 7. JAVA version of the Nitrogen Index. The Nitrogen Index has a dropdown menu that can be used to select a region (such as California) and its accompanying data. Users can alternate between English and Spanish versions of the menu simply by clicking the desired language.**

## Table 1. Nitrogen Index Tier One (from Delgado et al., 2006, 2008a).

| Site characteristics | **Nitrogen Index rating** | | | | | Nitrate leaching | Surface transport | Air quality |
|---|---|---|---|---|---|---|---|---|
| | **None/very low 0** | **Low 2** | **Medium 4** | **High 6** | **Very high 8** | | | |
| N susceptible volatization method | None applied | Placed with planter deeper than 5 cm | Incorporated < 2 days after application or irrigation immediately after application | Incorporated or irrigation > 7 days after application | Surface application without irrigation | | | |
| Column factor | 0 | 2 | 4 | 6 | 8 | | | X |
| Proximity of nearest field edge to named stream or lake | Very low >305 m | Low 152-305 m | Medium 61-152 m | High 9-61 m | Very high >9 | | | |
| Column factor | 0 | 2 | 4 | 6 | 8 | | X | |
| Rooting depths and crop rotation | 1.5 m and deeper rooted crop rotation | 0.9-1.5 m deeper crop and rotation with shallower crops | 0.9-1.5 m | <0.45 m and rotation with deep rooted crop | <0.45 m and no deep rooted crops in rotation | | | |
| Column factor | 0 | 2 | 4 | 6 | 8 | | X | |
| Aquifier leaching potential risk (ALPR) | Very low | Low | Medium | High | Very high | | | |
| Column factor | 0 | 2 | 4 | 6 | 8 | X | | |
| Tile drainage | No tile drainage | Mitigate with pumping wetland, wood chips, and >3,048 m to water body | Same as low but >305 m to water body | Same as low but <305 m to water body | Drains to ditch, creek, or stream and no mitigation | | | |
| Column factor | 0 | 2 | 4 | 6 | 8 | X | | |
| $NH_3$ volatization | Very low $NH_3$ volatization <22.4 kg N $ha^{-1}$ | Low $NH_3$ volatization >22.4-33.6 kg N $ha^{-1}$ | Medium $NH_3$ volatization >33.6-56 kg N $ha^{-1}$ | High $NH_3$ volatization >56-84 kg N $ha^{-1}$ | Very high $NH_3$ volatization >84 kg N $ha^{-1}$ | | | |
| Column factor | 0 | 2 | 4 | 6 | 8 | | | X |
| Denitrification | Very low denitrification <28 kg N $ha^{-1}$ | Low denitrification 28-56 kg N $ha^{-1}$ | Medium denitrification 56-84 kg N $ha^{-1}$ | High denitrification 84-112 kg N $ha^{-1}$ | Very high denitrification >112 kg N $ha^{-1}$ | | | |
| Column factor | 0 | 2 | 4 | 6 | 8 | | | X |
| Soil erosion (wind and water) | Very low <2.2 Mg $ha^{-1}$ | Low 2.2-6.7 Mg $ha^{-1}$ | Medium 6.7-11.2 Mg $ha^{-1}$ | High 11.2-33.6 Mg $ha^{-1}$ | Very high >33.6 Mg $ha^{-1}$ | | | |
| Column factor | 0 | 2 | 4 | 6 | 8 | | X | |
| Runoff class (runoff class table 2) | Very low or negligible | Low | Medium | High | Very high | | | |
| Column factor | 0 | 2 | 4 | 6 | 8 | | X | |
| Irrigation erosion (see QS note) | Not irrigated or furrow irrigated | Tailwater recovery or QS < 6 for very erodible soils or QS < 10 for resistant soils | QS > 10 for erosion resistant soils | QS > 10 for erodible soils | QS > 6 for very erodible soils | | | |
| Column factor | 0 | 2 | 4 | 6 | 8 | | X | |
| Vegetative buffer | >30.5 m wide | 19.8-30.5 m wide | 6.1-19.8 m wide | < 6.1 m wide | No buffer | | | |
| Column factor | 0 | 2 | 4 | 6 | 8 | | X | |
| Subtotal nitrate leaching component | 0-10 | >10-22 | >22-33 | >33-45 | >45-56 | | | |
| Subtotal surface transport component | 0.7 | >7-15 | >15-28 | >28-34 | >34-40 | | | |
| Subtotal air atmospheric component | 0.7 | >7-15 | >15-22 | >22-28 | >28-32 | | | |
| Total index points | 0-24 | >24-52 | >52-83 | >83-107 | >107-128 | | | |
| N hazard class | None or very low | Low | Medium | High | Very high | | | |

## NITROGEN INDEX ALGORITHMS FOR SOURCES AND PATHWAYS (QUANTITATIVE FACTORS)

The new Tier One Nitrogen Index qualitatively ranks management practices and landscape combinations and categorizes the level of risk of nitrogen loss for a given combination as very low, low, medium, high, or very high risk (Delgado et al., 2006). The Nitrogen Index conducts a quick quantitative N balance, tracking sources of pathways, similar to the annual Nitrogen Index of Pierce et al. (1991) that was included in the DOS version of NLEAP (Shaffer et al., 1991). This new Nitrogen Index has expanded/combined information, quantitative and qualitative rankings, assessment of risk for leaching, surface and atmospheric pathways, international input, and the ease of use (Delgado et al., 2006). The new Nitrogen Index also considers and integrates management, rotations, and off-site factors when ranking the risk of nitrogen losses to the environment. Additionally, the Nitrogen Index can be connected to the Phosphorous Index to conduct simultaneous analyses. New Macronutrient and Micronutrient Indexes and a new $N_2O$ emissions index are in development. For detailed information on Nitrogen Index algorithms, calculations, qualitative rankings, off-site factors, or how algorithms work with soil profile depths, the user should review Delgado et al. (2006, 2008a, Manual: http://arsagsoftware.ars.usda.gov).

The Nitrogen Index also has internal databases and coefficients that are based on values reported in the literature, but users could adjust these to the site-specific values for their region or their country. For example, default organic soil matter N mineralization is 45 kg N $ha^{-1}$ per 1% soil organic matter (Vigil et al., 2002), but users can enter the site-specific rate. The databases of the Nitrogen Index have values from different studies from California, Mexico, and the US. For example, nitrogen content values of different types of manures in the US and Midwest are used (Davis et al., 2002). The default values for N release from types of manures were obtained from Eghball et al. (2002). Users can always enter their site-specific nitrogen content values and mineralization rates. The default coefficients for ammonia volatilization losses and denitrification losses were adapted from Meisinger and Randall (1991, Tables 2 and 3), but users could enter their site-specific rates. The default values used for N content per unit of harvest crop are from Meisinger and Randall (1991) and Delgado et al. (1998a); however users could also enter their site-specific values for crops and/or crop varieties.

**Table 2. Nitrogen Index Tier One matrix for ammonia volatilization coefficients due to climate, fertilizer type, and management of N fertilizer applied (Delgado et al., 2006, 2008a).**

| Type of fertilizer | Management of Fertilizer | Climate | | |
|---|---|---|---|---|
| | | Humid | Sub-humid | Dry |
| Urea | Surface applied | 10 | 15 | 25 |
| Urea | Incorporated | 2 | 3 | 5 |
| $(NH_4)_2SO_4$ | Surface applied | 4 | 8 | 15 |
| $(NH_4)_2SO_4$ | Incorporated | 1 | 1 | 2 |
| $NH_4NO_3$ | Surface applied | 2 | 4 | 10 |
| $NH_4NO_3$ | Incorporated | 0 | 5 | 1 |
| Anhydrous-$NH_3$ | Incorporated | 1 | 2 | 3 |

Source: Adapted from Meisinger and Randall, 1991.

Notes: Fertilizer N can be entered using the drop-down menu to select from several types of fertilizers (urea, $(NH_4)_2SO_4$, $NH_4NO_3$ and others). For each fertilizer event, you can use the "Rain/Irrigation" drop-down menu (below the fertilizer type) to select the precipitation or irrigation conditions that follow the fertilizer application. Notice that when you select the rain/irrigation conditions, the ammonia volatilization coefficient (AVC) is populated with a value corresponding to both fertilizer type and rain/irrigation after application. The AVC is also affected by whether the fertilizer is incorporated or surface applied, which is also selected in the "Source of N and Method of Application" drop-down menu.

**Table 3. Nitrogen Index Tier One matrix for denitrification coefficients due to drainage and soil organic matter content (SOM).**

| SOM % | Drainage group | | | | |
|---|---|---|---|---|---|
| | Excessively well drained | Well drained | Moderately well drained | Somewhat poorly drained | Poorly drained |
| <2 | 2 | 3 | 6 | 10 | 20 |
| 2-5 | 4 | 4 | 8 | 15 | 25 |
| >5 | 6 | 6 | 12 | 20 | 30 |

Source: Adapted from Meisinger and Randall, 1991.

Denitrification coefficient: The California N Index uses the denitrification rates published by Delgado et al. (2008a), which were adapted from Meisinger and Randall (1991). The denitrification coefficient is affected by soil organic matter content, hydrology characteristics, manure applications, tile drainage, precipitation and irrigation. For sites with tile drainage, if a field has tile drainage, selecting "Yes for Tile Drainage" will divide the denitrification rate by two. For a dry climate *without* irrigation, the denitrification rate is divided by two. If manure is applied under any of the previous scenarios, the denitrification rate is doubled. If you enter a custom denitrification coefficient, the above interaction is bypassed, and you must account for these factors by adjusting your own coefficient.

The total nitrogen inputs into the system are summarized in the following equation:

$$S_{NI} = (N_f + N_{in} + N_{min} + N_{atm} + N_{ma1} + N_{ma2} + N_{cr} + N_{irb} + N_{iro}) , \quad (1)$$

where $S_{NI}$ = total system nitrogen inputs (kg N ha$^{-1}$ y$^{-1}$); $N_f$ = N applied as fertilizer (kg N ha$^{-1}$); $N_{in}$ = root zone initial inorganic N before planting (0 to 1.5 m depth or 0 – depth of the deepest rooted crop – kg $NH_4$-N + $NO_3$-N ha$^{-1}$); $N_{min}$ = mineralization of N from soil organic matter (0 to 0.3 m depth – kg N ha$^{-1}$ y$^{-1}$); $N_{atm}$ = atmospheric N deposition (kg N ha$^{-1}$ y$^{-1}$); $N_{ma1}$ = initial $NH_4$-N + N mineralization from manure kg N ha$^{-1}$ y$^{-1}$; $N_{ma2}$ = N mineralization from manure applied last year kg N ha$^{-1}$ y$^{-1}$; $N_{cr}$ = crop residue N mineralization (kg N ha$^{-1}$); $N_{irb}$ = background $NO_3$-N applied in irrigation water (kg $NO_3$-N ha$^{-1}$); $N_{iro}$ = available organic N applied in irrigation water (kg N ha$^{-1}$).

The $NH_3$-N volatilization losses are calculated using Equation 2 and ranked qualitatively as very low, low, medium, high, and very high risk (see Delgado et al., 2006):

$$N_v = (N_{fsv} \bullet N_{vcf}) + (N_{msv} \bullet N_{vcm}) \,, \tag{2}$$

where $N_v$ = N ammonia volatilization (kg $NH_3$-N ha$^{-1}$); $N_{fsv}$ = N fertilizer susceptible to $NH_3$-N volatilization (kg N ha$^{-1}$); $N_{msv}$= $NH_4$-N from organic inputs susceptible to $NH_3$-N volatilization (kg N ha$^{-1}$); $N_{vcf}$ = N ammonia volatilization coefficient fertilizer; $N_{vcm}$ = N ammonia volatilization coefficient manure.

The denitrification losses are calculated using Equation 3 and are also ranked qualitatively as very low, low, medium, high, and very high risk (see Delgado et al., 2006, 2008a):

$$N_d = (N_f + N_{iNO3\text{-}N} + N_{mi} - N_v) \bullet (N_{dc}) \,, \tag{3}$$

where $N_d$ = N denitrification (kg N ha$^{-1}$); $N_f$ = N applied as fertilizer (kg N ha$^{-1}$); $N_{iNO3\text{-}N}$ = surface 0–0.3 m initial kg $NO_3$-N ha$^{-1}$; $N_{mi}$ = inorganic N added with organic inputs (kg N ha$^{-1}$); $N_v$ = N ammonia volatilization (kg $NH_3$-N ha$^{-1}$; Equation 2); $N_{dc}$ = N denitrification coefficient.

The user also needs to rank the total erosion (wind and water) at the site and the qualitative rankings used to calculate the N losses due to erosion with the following equation:

$$N_{er} = SOM \div 100 \bullet ER \bullet 0.58 \bullet 0.125 \,, \tag{4}$$

where $N_{er}$ = N erosion (kg N ha$^{-1}$); $SOM$ = soil organic matter *(%)*; $ER$ = erosion rate (kg ha$^{-1}$).

A follow-up calculation will be estimated for the available N that was lost to erosion with the following equation:

$$N_{erav} = N_{erav} \bullet k_{er} \,, \tag{5}$$

where $N_{erav}$ = available N erosion (kg N ha$^{-1}$); $N_{er}$ = N erosion (kg N ha$^{-1}$); $k_{er}$ = erosion N available constant.

The nitrogen removal is calculated with the following equation:

$$S_{NR} = (N_c + N_d + N_v + N_{erav}) \,, \tag{6}$$

where $S_{NR}$ = cropping system N pathways for removal (kg N ha$^{-1}$ y$^{-1}$); $N_c$ = N uptake by crops (kg N ha$^{-1}$); $N_d$ = N denitrification (kg N ha$^{-1}$, Equation 3); $N_v$ = N ammonia volatilization (kg $NH_3$-N ha$^{-1}$, Equation 2); $N_{erav}$ = N erosion (kg N ha$^{-1}$, Equation 5).

The nitrogen available to leach is calculated with Equation 7 and ranked qualitatively as very low, low, medium, high, and very high risk (see Delgado et al., 2006, 2008a):

$$NAL = S_{NI} - S_{NR} \,, \tag{7}$$

where $NAL$ = $NO_3$-N available to leach (kg $NO_3$-N ha$^{-1}$); $S_{NI}$ = cropping system nitrogen inputs (kg N ha$^{-1}$ y$^{-1}$, Equation 1); $S_{NR}$ = cropping system N pathways for removal (kg N ha$^{-1}$ y$^{-1}$, Equation 6).

The Nitrogen Index also calculates the leaching index from Williams and Kissel (1991) (equation not shown). The LI is ranked qualitatively as very low, low, medium, high, and very high risk (see Delgado et al., 2006, 2008a). Irrigation inputs are added to precipitation. The nitrate leaching losses are calculated with Equation 8 (Pierce et al., 1991), and the results are ranked qualitatively as very low, low, medium, high, and very high risk (see Delgado et al., 2006, 2008a):

$$NL = NAL * (1.0 - \exp^{(-k*WAL/POR)}) \,, \tag{8}$$

where $NL$ = $NO_3$-N leaching (kg $NO_3$-N ha$^{-1}$ y$^{-1}$) at specific depth (e.g., root zone); $NAL$ = $NO_3$-N available to leach (kg $NO_3$-N ha$^{-1}$ y$^{-1}$, Equation 7); $K$ = is a coefficient (1.2); $WAL$ = water available for leaching (it can be the LI for an annual NAL); $POR$ = soil porosity [(1 – (bulk density ÷ particle density)) * (leaching depth * unit area)].

The total nitrogen removal is calculated with the following equation:

$$S_{TNR} = (S_{NR} + NL) \,, \tag{9}$$

where $S_{TNR}$ = cropping system total N pathways for removal (kg N ha$^{-1}$ y$^{-1}$); $S_{NR}$ = cropping system N pathways for removal (kg N ha$^{-1}$ y$^{-1}$, Equation 6); $NL$ = $NO_3$-N leaching (kg N ha$^{-1}$ y$^{-1}$, Equation 8).

The residual soil nitrate is calculated with the following equation:

$$RN_{NO3\text{-}N} = S_{NI} - S_{TNR} \,, \tag{10}$$

where $RN_{NO3\text{-}N}$ = residual soil $NO_3$-N (kg $NO_3$-N ha$^{-1}$ y$^{-1}$); $S_{NI}$ = total system nitrogen inputs (kg N ha$^{-1}$ y$^{-1}$, Equation 1); $S_{TNR}$ = cropping system total N pathways for removal (kg N ha$^{-1}$ y$^{-1}$, Equation 9).

The nitrogen efficiency for the cropping system is calculated with the following equation:

$$S_{NUE} = ( N_c \div S_{NI} ) \bullet 100 \, , \qquad (11)$$

where $S_{NUE}$ = cropping system N use efficiency (%); $N_c$ = N uptake by crop (kg N ha$^{-1}$ y$^{-1}$); $S_{NI}$ = total system nitrogen inputs (kg N ha$^{-1}$ y$^{-1}$, Equation 1).

For the California Nitrogen Index the ratio of inputs to nitrogen removal by the crop is calculated with Equation 12. This ratio only accounts for the total N applied in manure, applied in fertilizer and in background water. In this example the system assumes that it is in steady state and that all of the applied N in manure will be available. The N index is flexible enough that it can be adapted to reflect any ratio as defined or required by the given state or country (for an example, note the differences between the California N Index [Equation 12] and Mexico Nitrogen Index [Equation 13].

$$S_{RARca} = (N_f + N_m + N_{ir} ) \div N_c \, , \qquad (12)$$

where $N_f$ = N applied as fertilizer (kg N ha$^{-1}$); $N_m$ = total N in manure kg N ha$^{-1}$ y$^{-1}$; $N_{ir}$ = total N in irrigation water (kg N ha$^{-1}$); $N_c$ = N uptake by crop (kg N ha$^{-1}$ y$^{-1}$).

For the Mexico Nitrogen Index the ratio of inputs to nitrogen removal by the crop is calculated with Equation 13. This ratio accounts for the total system nitrogen inputs:

$$S_{RARmx} = S_{NI} \div N_c \, , \qquad (13)$$

where $S_{NI}$ = total system nitrogen inputs (kg N ha$^{-1}$ y$^{-1}$); $N_c$ = N uptake by crop (kg N ha$^{-1}$ y$^{-1}$).

There is an advantage in using a robust new Nitrogen Index based on quantitative/qualitative entries: using a Windows- or JAVA-based Nitrogen Index, users could take five to ten minutes to set up an evaluation. If more than one scenario is going to be evaluated, several scenarios could be built with an average of less than five minutes per scenario. Users could assess the effect of practices and separate the practices with medium, high and very high risk from those that have the very low and low risk.

The N index tool has been compared with experimental field data across different regions and countries and has been found to have comparable accuracy (Delgado et al., 2008a; De Paz et al., 2009), calculated residual soil nitrate, and nitrate leaching correlated with observed values (Delgado et al., 2006; De Paz et al., 2009). This new Nitrogen Index tool was developed with international cooperation from several countries (Delgado et al., 2006, 2008a). The Nitrogen Index has been calibrated and validated using data from the US, Argentina, and China. Recent evaluations conducted in a Mediterranean region, Mexico, and the Caribbean have also validated this Tier One approach (David

Sotomayor, personal communication). The use of site-specific regional and/or state values such as crop, soils, and manures appears to improve the accuracy of this Tier One tool to assess the risk of management on N losses.

## NITROGEN TRADING TOOL PROTOTYPES: NEW APPROACHES TO NITROGEN MANAGEMENT DECISION MAKING

A new concept of receiving environmental quality market credits to account for reductions of agricultural N losses and prevention of their transport into water bodies has been proposed (Greenhalch and Sauer, 2003; Ribaudo et al., 2005; Glebe, 2006; Hey, 2002; Hey et al., 2005; Delgado et al., 2008; Lal et al., 2009). However, since quantification of N losses is so complex, and the pathways for losses of nitrogen are so numerous, it is difficult to determine how management practices can reduce the losses of nitrogen by a given amount (Delgado, 2002) and how much can be traded in a given water and air quality market without the use of a robust tool (Delgado et al., 2008a).

Use of $^{15}N$ isotopic research and modeling may shed some light on how we can quantify the benefits of best management practices. Delgado et al. (2010b) used advanced $^{15}N$ techniques and modeling to account for N losses to the environment from crop residues and inorganic N fertilizers. Accounting for nitrogen cycling from crop residues and their incorporation could contribute to reductions in $N_2O$ emissions and nitrate leaching losses. These modeling approaches showed that the total losses of nitrogen were lower from crop residue and a $^{15}N$ isotopic method verified that the nitrogen losses were lower (Delgado et al. 2010b). The disadvantage to using $^{15}N$ methods is that they are very expensive and time consuming; modeling tools, however, could provide an inexpensive quick approach to assessing these N losses.

The concept of using environmental quality market credits to account for reductions of N losses with robust models could potentially contribute to improved management practices at a field level (Delgado et al., 2008b). Since N dynamics are so complex and the quantification of nitrogen losses is difficult to achieve under so many crop-soil-weather-management combinations, assessors of the reduction in nitrogen losses to be traded in environmental quality markets may wish to consider the use of nitrogen trading tools to assist them in this process (Delgado et al., 2008b, 2010c). The potential to use a Nitrogen Trading Tool to reduce the nitrogen losses to the environment has been described by Delgado et al. (2008b) and Gross et al. (2008). A prototype of the Nitrogen Trading Tool has already been completed that can conduct assessment of management practices on losses of reactive N and their potential to be traded as credits (Delgado et al., 2008b, 2010c) and the potential to trade direct and indirect carbon sequestration equivalents due to reduction in nitrogen losses (Delgado et al., 2008b, 2010c) that could potentially contribute to the conservation of our biosphere (Delgado, 2010).

Delgado et al. (2008b) defined the new concept of the Nitrogen Trading Tool (NTT) within the context of the N cycle and considered a nitrogen mass balance approach for the cropping systems to ensure that today's nitrogen management practices will not create problems later on. The tool can quickly compare any given baseline scenario to a new management scenario. They define this trading tool as an economic balance between the new management scenario and the baseline scenario, a balance that functions similarly to a banking operation. A positive balance (NTT-$DNL_{reac}$) means that a new N management practice increases the savings in reactive N, while a negative number clearly shows that there are no savings in reactive N to trade. Phrased in terms of the bank metaphor, a positive number means that there is "money" (nitrogen) in the bank for trade, while a negative number indicates an empty or overdrawn "account," and thus no potential for trading.

Prototypes of the NTT were developed in cooperation between the NRCS and Agriculture Research Service Soil Plant Nutrient Research Unit (Gross et al., 2008; Delgado et al., 2008b). These prototypes (web-based and stand-alone) can quickly determine how many potential N credits their farming operations can generate. A ratio or factor can be applied to the nitrogen available to trade (Delgado et al., 2008b; Lal et al., 2009). Potential exists to further develop such tools and have them available as stand-alone versions and/or on the Internet so that conservationists, field managers, aggregators, sellers, and traders can have access to the same datasets and/or established rules. Lal et al. (2009) reviewed trading programs in the US and reported that the rules for trading nitrogen may be need to be evaluated by region. A screen for the web-based prototype of the Nitrogen Trading Tool using NLEAP is shown in Figures 8 and 9, showing how the NTT can be used to capture the soils from the NRCS soil web survey (Figure 8) and pasted to conduct in a Web NTT GIS analysis (Figure 9).

The stand-alone NTT GIS can be used to assess the potential benefits of reducing N losses across a region (Figure 4; Delgado et al., 2010c). Additional information about the stand-alone version can be viewed in Delgado et al. (2008b) and Gross et al. (2008). The stand-alone NLEAP GIS NTT can be used for different sites across the US to assess the effects of management practices at a given field (Delgado et al., 2010c).

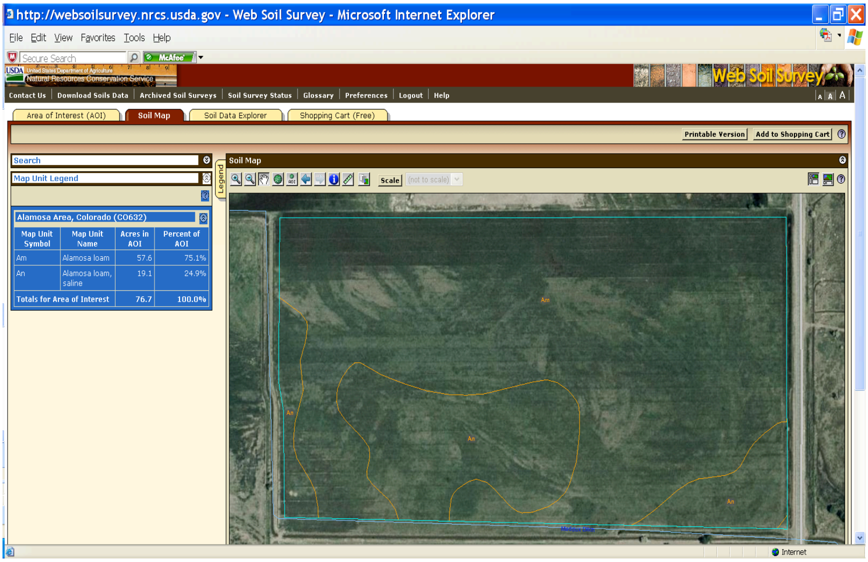



**Figure 8.** Web prototype of the NLEAP NTT can use the web soil survey to identify a given farm or field from an available database. The highlighted soil information is copied and pasted into the web NTT prototype and the NLEAP GIS run is conducted for the two soils identified at the field site and the management practices to be evaluated.

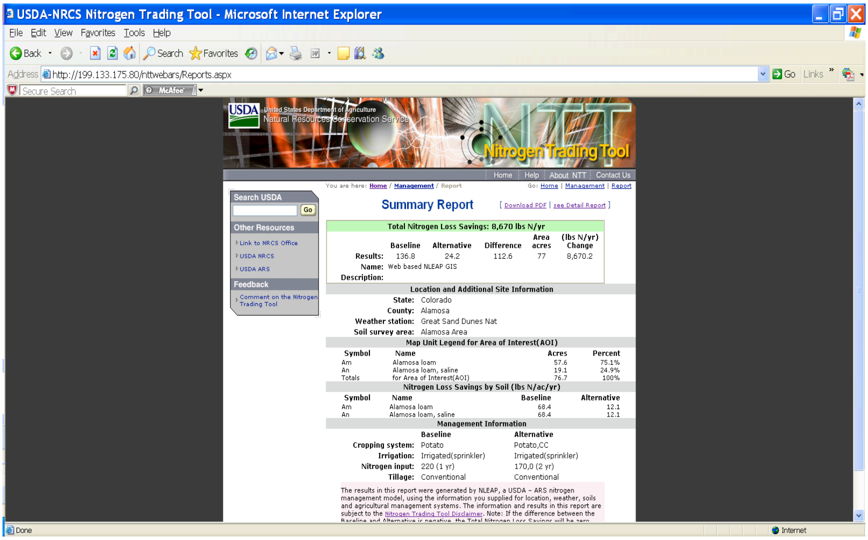



**Figure 9.** Web prototype of the NLEAP NTT can use the soils sites and areas identified using the web soil survey to run the NTT and generate an NTT GIS evaluation for a given farm.

In addition to the NLEAP NTT GIS web prototype that we presented in this chapter and the 2010 stand-alone NLEAP GIS 4.2 and NLEAP GIS NTT tools (http://arsagsoftware.ars.usda.gov/agsoftware/), NLEAP capabilities were added also to the new AgroEcoSystem model (Figure 10). New trading tools to assess ecosystem services trading, similar to the concepts and methods described by Delgado et al. (2008b, 2010c) will be available in the near future. Some of these new prototypes were presented at the Carbon trading workshop conducted by the Soil and Water Conservation Society at their 2010 annual meeting. Web tools such as Ecosystem Interface, which includes COMET-VR (which uses Century-DAYCENT) and the Nutrient Trading Tool (NTT, which uses SWAT-APEX) will be capable of simulating effects of management practices on carbon, phosphorous, erosion, and nitrogen dynamics for ecosystem services trading (McKinney, 2010; Saleh, 2010). McKinney (2010) reported that tools such as the web prototype version of NLEAP NTT (Figures 8 and 9) contributed to the foundations of modeling systems approaches (such as the Ecosystem Interface web tool) that can provide information to be used for nutrient management at the farm level, watershed planning, and nutrient trading for environmental conservation.

Another new tool is the new AgroEcosystem–Nitrogen Loss and Environmental Assessment Package (AgES-NLEAP) NTT prototype that has also been developed for geospatial assessment of N management effects across fields and management units (based on soil type) within a field. AgES-NLEAP is a Java-based application with an embedded open source GIS platform linked to the WorldWind web service data specification from NASA. The vision of the AgES-NLEAP effort is the creation of a geospatial N management system that enables the scientific modeling process to be closer to a "real world" experience through GIS mapping and analysis coupling. Current features of the prototype include (1) interactive geospatial editing of all NLEAP input parameters required for model execution; (2) geospatial visualization of NLEAP model responses across fields and soil types within a field for both time series (daily, monthly, and yearly) and summary (simulation average) output over multiple scenarios; (3) "on-the-fly" dynamic color ramping of NLEAP output over a selected time period or the entire simulation period; and (4) geospatial querying of NLEAP output across selected fields and management units. Features 2–4 listed above are illustrated in Figure 10. Some of the advancements offered by AgES-NLEAP over traditional modeling approaches include querying and mapping of available NLEAP input and output data for GIS-based web services, embedded execution of the NLEAP model and direct mapping of state variables into a GIS-based world view, and simply the mapping of spatial/temporal NLEAP simulation results in a realistic manner that has previously not been possible.

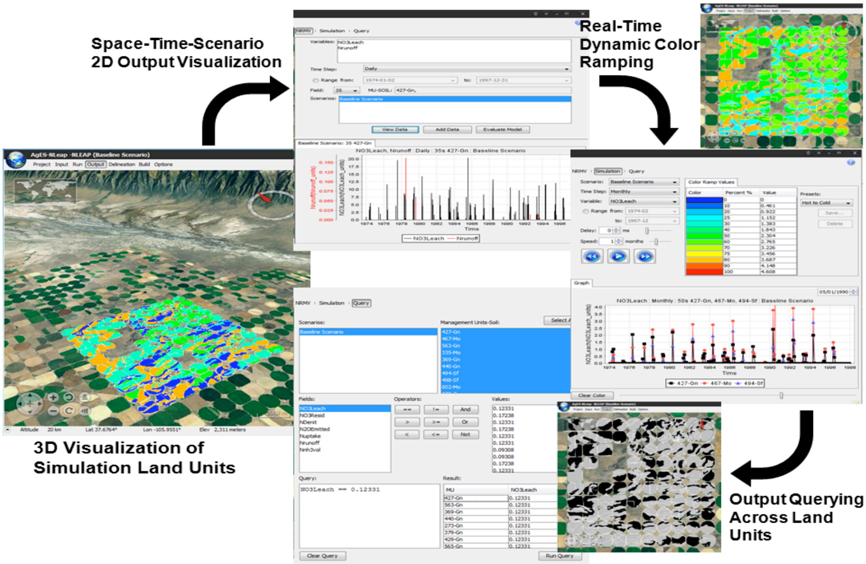



**Figure 10. The AgroEcoSystem-NLEAP (AgES-NLEAP) NTT prototype for geospatial assessment of N management effects across fields and management units (south-central Colorado) with illustration of AgES-NLEAP capabilities for space-time-scenario output visualization, dynamic color ramping, and geospatial querying.**

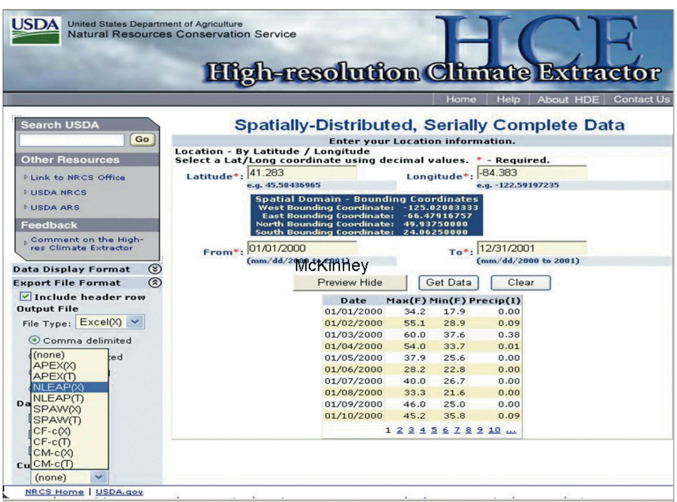



**Figure 11. Spatially distributed data from the NRCS High-resolution Climate Extractor (HCE) can be exported in Excel (X) or text (T) format from all areas of the continental US for use with NLEAP GIS 4.2.**

The NRCS High-resolution Climate Extractor (HCE), an online data tool, provides serially complete daily precipitation and maximum and minimum temperature data for all sections of the continental US. The data period is 1960–2001, and the spatial resolution is 4 km (Eischeid et al., 2000; Daly et al., 2008; DiLuzio et al., 2008). Users can select the Get HCE data button to automatically extract these data from the HCE. Locational and temporal options for specifying latitude, longitude and the time period desired are available. These data will be useful in providing computer models with a continuous stream of actual climate information, and enabling quick assessments of nitrogen management practices and their potential to be used for conservation of our biosphere (Figure 11).

Delgado et al. (2008b) developed the following equations to calculate reactive N losses, which include nitrate leaching ($\Delta$ $NO_3$-N, Equation 14), nitrous oxide losses ($\Delta$ $N_2O$-N, Equation 15), ammonia volatilization ($\Delta$ $NH_3$-N, Equation 16), surface N transport not connected to soil erosion ($\Delta$ $N_{st}$, Equation 17), surface N transport caused by soil erosion, ($\Delta$ $N_{er}$, Equation 18) and NTT difference in reactive N losses ($NTT\text{-}DNL_{reac}$, Equation 19):

$$\Delta\ NO_3\text{-}N = NO_3\text{-}N_{bms} - NO_3\text{-}N_{nms} \tag{14}$$

$$\Delta\ N_2O\text{-}N = N_2O\text{-}N_{bms} - N_2O\text{-}N_{nms} \tag{15}$$

$$\Delta\ NH_3\text{-}N = NH_3\text{-}N_{bms} - NH_3\text{-}N_{nms} \tag{16}$$

$$\Delta\ N_{st}\text{-}N = N_{st}\text{-}N_{bms} - N_{st}\text{-}N_{nms} \tag{17}$$

$$\Delta\ N_{er} = N_{er}\text{-}N_{bms} - N_{er}\text{-}N_{nms} \tag{18}$$

$$NTT\text{-}DNL_{reac} = \Delta\ NO_3\text{-}N + \Delta\ N_2O\text{-}N + \Delta\ NH_3\text{-}N + \Delta\ N_{st} + \Delta\ N_{er} \tag{19}$$

Delgado et al. (2008b) considered that nutrient managers may also be interested in total nitrogen losses. Although management of denitrification is a good approach to reducing $NO_3$-N losses to water bodies (Hunter 2001; Mosier et al. 2002, Hey, 2002; Hey et al., 2005), nutrient managers may be able to reduce N inputs if the losses due to denitrification are reduced and nitrogen use efficiencies are increased (Mosier et al., 2002). The NTT calculates $N_2$-N denitrification ($\Delta$ $N_2$-N) and total N losses ($NTT\text{-}DNL_{tot}$) with Equation 21 and 22, respectively. For Equations 14 through 21, *bms* refers to the base management scenario, and *nms* refers to the new management scenario:

$$\Delta\ N_2\text{-}N = N_2\text{-}N_{bms} - N_2\text{-}N_{nms} \tag{20}$$

$$NTT\text{-}DNL_{tot} = NTT\text{-}DNL_{reac} + \Delta\ N_2\text{-}N \tag{21}$$

Delgado et al. (2008b, 2010c) reported that the stand-alone prototype can calculate the direct and indirect carbon sequestration equivalents due to improvements in nitrogen management that reduce the N losses to the environment. The direct carbon sequestration equivalents calculated with the NTT are achieved with reductions in direct emissions of $N_2O$. Indirect carbon sequestration equivalents can also be calculated with the NTT, and they reflect the reductions of reactive nitrogen that can contribute to indirect emissions of $N_2O$ (Delgado et al., 2010c). Delgado et al. (2010c) reported that indirect carbon sequestration equivalents due to reduction in nitrogen losses can be calculated using the IPCC coefficients (Eggleston et al., 2006). However, Delgado et al. (2010b) recommended that some of these IPCC $N_2O$ emissions coefficients be revised.

The potential to trade carbon sequestration equivalents generated by practices that reduce the direct emissions of $N_2O$ losses are estimated with the following equation:

$$\Delta\ DCO_2\text{-}C_{se}N_2O = \Delta\ N_2O\text{-}N \cdot 310 \cdot 0.2727 \cdot 1.571 \qquad (22)$$

Delgado et al. (2008b, 2010c) calculated the savings in carbon sequestration equivalents due to the reduction in indirect $N_2O$ losses using the following equation (Delgado et al., 2010c):

$$\Delta\ ICO_2\text{-}C_{se}N_2O = [((\Delta\ NO_3\text{-}N + \Delta\ N_{st}\text{-}N + \Delta\ N_{er}) \cdot 0.0075 \cdot 310 \cdot 1.571) + (\Delta\ NH_3\text{-}N \cdot 0.01 \cdot 310 \cdot 1.571)] \cdot 0.2727 \qquad (23)$$

The total savings in carbon sequestration equivalents due to the reduction in indirect and direct $N_2O$ losses is estimated with the following equation:

$$\Delta\ TCO_2\text{-}C_{se}N_2O = \Delta\ DCO_2\text{-}C_{se}N_2O + \Delta\ ICO_2\text{-}C_{se}N_2O \qquad (24)$$

Another point to be considered by nutrient managers in the connection between carbon and nitrogen is management of crop residue and cycling. Al Sheikh et al. (2005) reported that management practices that use cover crops and small grains, returning all crop residue to the soil, could increase nitrogen sequestration. Long-term $^{15}N$ studies have found that crop residue organic N will stay around cycling for a long time (Delgado et al., 1996, 2010b). Delgado and Follett (2002) reported that carbon management should be part of nutrient management practices and that carbon sequestration reduces the nitrogen losses to the environment when nitrogen cycling is accounted for, reducing nitrogen inputs. Nitrogen trading tools could consider nitrogen cycling and sequestration with soil organic matter as potential long-term strategies to reduce nitrogen losses and enable the trade of nitrogen savings (Delgado et al., 2008b, 2010c).

## SUMMARY

The identification of potential problems with N losses quickly leads to a list of potential solutions in terms of BMPs. Local cooperative extensions and NRCS have identified practices shown to be of value in each region. This list should be used as a starting point, and any potential BMPs should be individually evaluated for the site-specific conditions.

Some common practices for controlling $NO_3$-N leaching include multiple fertilizer applications, the use of fall cover crops to recover residual soil $NO_3$-N, adjustment of fertilizer and manure rates to account for other sources of N, precision application of fertilizers across a field, use of management zones, crop rotations with deeper rooted crops and legumes, avoidance of off-season fertilizer applications, use of fertigation with drip irrigation and/or center pivot irrigation, incorporation of N fertilizers, and use of tissue analysis. The relative effectiveness of each method will depend on site-specific conditions and can be evaluated by comparing simulated N loss results with corresponding results using the historical data.

NLEAP GIS, Nitrogen Index, and Nitrogen Trading Tools with or without GIS have been used to evaluate BMPs across several different regions, agroecosystems, and climates. The NLEAP GIS model uses national database resources for data on soils, climate, and management, which allows for the potential application of the model to the field. Users of the tool should be aware that the effectiveness of the tool can increase with calibration and validation, and also by using site-specific information. We emphasize that the users and staff should visit the site; talk to local producers, the NRCS, and extension personnel; and take some samples if possible to improve the accuracy of Tier One, Two, and Three tools. Users should review Shaffer and Delgado (2001) and Delgado and Shaffer (2008) and their recommendation of a tiered approach to management. If more detailed results are needed, users should move to a Tier Three approach supported by research at the local site and use some of the other models already listed in this chapter or look for other new alternatives. Depending on the project, Tier One and Tier Two tools could be suitable for assessing the effects of management practices on the risk of nitrogen losses to the environment. These tools have been tested and when provided with valid information, they have been able to assess the risk of management practices on N losses. Users could use this information in cooperation with consultants, service providers NRCS, and extension personnel to develop management practices that improve N use efficiencies to reduce the risk of N losses to the atmosphere and water bodies, and to help conserve our biosphere.

## DISCLAIMER

Mention of trade names or commercial products in this book is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA.

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