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Landscape Based Modeling of Nonpoint Source Nitrogen Loading in the Neuse River Basin, North Carolina

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LANDSCAPE BASED MODELING OF NONPOINT SOURCE NITROGEN LOADING IN THE NEUSE RIVER BASIN, NORTH CAROLINA[1,2,3]

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EXECUTIVE SUMMARY

The objective of this research was to arrive at a quantitative and qualitative assessment of nonpoint sources of potential excess N under different land use/land cover (LULC) categories in the Neuse River Basin on a seasonal time scale. This assessment is being supplied to EPA's Landscape Characterization Branch, National Exposure Research Laboratory, in Research Triangle Park, NC, for inclusion in a hydrologic model to predict seasonal fluxes of N from the terrestrial landscape to surface receiving waters and groundwater in the Neuse River Basin.

The analysis was performed in the following five steps: (1) development of a conceptual model to predict potential excess N on land, (2) a literature review to parametrize N fluxes under LULC categories found in the Neuse River Basin, (3) acquisition of high resolution (15-m pixel) LULC data from EPA's Landscape Characterization Branch, National Exposure Research Laboratory, in Research Triangle Park, NC, (4) acquisition of a soil N inventory map for the Neuse River Basin, (5) calculations of potential excess N on a seasonal basis for the entire Neuse River Basin.

In the present model, potential excess N was calculated as the difference between inputs to and outputs from an inorganic N pool. If inputs exceeded outputs, then the difference was assumed to represent potential excess N (X, units are g N m^{-2} per unit time) at risk of loss from the landscape to surface receiving waters and groundwaters:

$$X = (I + F + M) - (U + D),$$

where I is atmospheric N deposition, F is fertilizer N inputs, M is net N mineralization, U is uptake of N by plants, and D is denitrification. Data on the five primary processes that contribute to potential excess N under different LULC categories were obtained from a literature review. In most cases, median values were chosen as the summary statistic best suited to estimate N fluxes. Factors were also estimated to apportion annual N fluxes among different seasons (spring, summer, fall, and winter).

The model was implemented in two versions. In the first version (Model 1), the seasonal estimates of potential excess N were applied to each pixel of the LULC grid. This approach yields a mass-balance model of potential excess N based simply on LULC for each season of the year. In the second version (Model 2), we accounted for the effect that total soil N has on mineralization by utilizing a first-order model for mineralization and

incorporating that value into the mass-balance calculations. Model 2 required creation of an individual grid for each N flux (I, F, M, U, and D) for each season. The grids were generated by applying literature-derived values for each parameter multiplied by seasonal factors to each pixel based on LULC category.

Results from both models indicate large areas of land surrounding the lower reach of the Neuse River as well as pixels bordering streams and tributaries may act as potential "N sinks" because potential N outputs exceed N inputs. Landscape patches that corresponded to potential "N sources" appeared to be influenced primarily by soil N inventories and rates of net soil N mineralization (which is a natural process). The overall flux of N in net soil N mineralization was generally lower in Model 2 than in Model 1. Finally, although there are no field data to validate predictions of potential excess N from Model 1 or 2, we believe predictions from Model 2 are more realistic because of the additional information supplied by estimated stocks of surface soil N across the Neuse River Basin.

Despite many shortcomings, predictions from the model are useful for the original objective of this research: helping to develop a landscape based tool for implementing best management practices to abate N loading to surface receiving waters in the Neuse River Basin through the identification of potential N sources and sinks by LULC category. With output from the model, landscape patterns of potential excess N in the Neuse River Basin can be evaluated in the context of the nutrient storage capabilities of different terrestrial ecosystems, the proximity of terrestrial N sources to streams and rivers, and the likelihood of intercepting N runoff from the landscape as it moves through vegetated riparian buffer zones, wetlands, or soils where removal processes (like denitrification) might help to reduce N loading to aquatic systems. Both Model 1 and Model 2 predicted that there are large land areas in the Neuse River Basin that could be classified as either a N source or a N sink. Such areas are potentially sensitive because future changes in land use, or small alterations in N fluxes, could convert areas that are essentially in balance with respect to N biogeochemistry into the N source or N sink category. In this respect, model predictions indicate that the timing of N inputs and outputs on the landscape can be a critical determinant of potential excess N and the possible export of N from terrestrial to aquatic ecosystems.

1. INTRODUCTION

Excess nitrogen (N) is an important contributor to the nutrient enrichment of surface waters and the widespread international problem of aquatic eutrophication.[1,2] Elevated nitrate concentration in groundwater is another result of excess soil N in some parts of the United States. For example, nitrate concentrations in unpolluted groundwater[3] are normally <2 mg L^{-1}, but median nitrate concentration in groundwater from the Georgia-Florida coastal plain is 5.8 mg L^{-1} or approximately half the maximum contaminant level for drinking water established by the United States Environmental Protection Agency.[4]

Direct and indirect human health endpoints are potentially associated with elevated N concentrations in surface water and groundwaters. Direct human health effects include infant methemoglobinemia (blue baby syndrome), which is attributed to excessive levels of nitrate in drinking water, and non-Hodgkin's lymphoma.[5] Indirect effects include harmful algal blooms in surface receiving waters and downstream estuaries. Studies indicate a worldwide increase in the prevalence of toxic algae and heterotrophic dinoflagellates[6] that cause various types of shellfish poisoning, including amnesic and paralytic shellfish poisoning. Nutrient exports from the terrestrial landscape to surface receiving waters and estuaries may be one causal factor contributing to the occurrence of harmful algal blooms and hypoxia in coastal waters.[7]

Export coefficients have been used for more than 25 years to predict nutrient losses from the terrestrial landscape to surface receiving waters. Beaulac and Reckhow[8] and later Frink[9] published extensive reviews of export coefficients used to assess terrestrial nonpoint sources of nutrient loading. Export coefficients can be combined with information on land use and land cover to predict terrestrial N export, but precision is poor because the variability in export coefficients is large (Table 1). There are also numerous sources of temporal and spatial variation (e.g., soil type, fertilizer type and amount, crop type, and land management practices) that can not be fully incorporated into export coefficients. Uncertainties in export coefficients are a serious limitation to their use for estimating N loading to surface receiving waters.

Statistical models have been used to improve predictions of N export from the terrestrial landscape by accounting for variation in annual or monthly runoff[10,11] and land use practices.[12,13,14] Empirically derived statistical relationships can be used to reduce some of the uncertainty associated with the selection of export coefficients for different LULC categories. However, export coefficients and other empirically derived statistical models do not convey information about which terrestrial ecosystem processes are potentially important contributors to nonpoint source N loading. Predictive tools that integrate remote sensing and landscape analysis with an understanding of terrestrial N cycling are needed to implement best management practices at the watershed scale with the goal of reducing nonpoint source N pollution to rivers and coastal waters across the United States.

Table 1. Range in mean and median export coefficients for N and P from different LULC categories. The number of literature sources is shown in parenthesis.

	Export coefficient ($g\ m^{-2}\ yr^{-1}$)	
Land cover category	Nitrogen	Phosphorus
Forest	0.01 - 0.8 (12)	0.001 - 0.028 (10)
Cropland	0.32 - 3.3 (15)	0.022 - 0.680 (14)
Grassland/pasture	0.03 - 0.6 (8)	0.032 - 0.082 (7)
Urban	0.50 - 2.8 (13)	0.030 - 0.245 (13)

Source: Frink, C. R. 1991. Estimating nutrient exports to estuaries. Journal of Environmental Quality 20: 717-724.

2. OBJECTIVES

The initial objectives of this study[15] were:

(1) to quantify the potential flux of N and P from terrestrial non-point sources (i.e., contributing sources) in the Neuse River Basin, and

(2) to model the seasonality and potential N and P flux from terrestrial systems to aquatic systems flowing into the Neuse River.

As the research progressed, the objectives were amended. Tasks related to P export were omitted and the project was directed entirely to developing a landscape based model for predicting potential excess N.

The research was redirected to N for the following reasons:

(1) export coefficients for N are much more variable than those for P and this uncertainty indicates a greater need to study factors affecting N export from different LULC types to surface receiving waters,

(2) data on P biogeochemistry under different LULC categories are far more limited than for N which greatly increases the uncertainties associated with modeling potential excess P under different land covers,

(3) N is critical stimulus for coastal eutrophication and harmful algal blooms in N-limited estuaries and shallow coastal waters,[16] and

(4) finally, long-term monitoring data suggest that P loadings to the Neuse Estuary are declining while N loadings are increasing.[17]

The modified objective was to arrive at a quantitative and qualitative assessment of nonpoint sources of potential excess N under different LULC categories in the Neuse River Basin on a seasonal time scale. This assessment is being supplied to EPA's Landscape Characterization Branch, National Exposure Research Laboratory, Research Triangle Park, NC, for inclusion in a hydrologic model to predict seasonal fluxes of N from the terrestrial landscape to surface receiving waters and groundwater in the Neuse River Basin.

3. STUDY PLAN

The analysis was performed in the following five steps:

(1) development of a conceptual mass balance model to predict potential excess N on land,

(2) a literature review to parametrize N fluxes under LULC categories found in the Neuse River Basin,

(3) acquisition of high resolution (15-m pixel) LULC data from EPA's National Exposure Research Laboratory, in Research Triangle Park, NC,

(4) acquisition of a soil N inventory map for the Neuse River Basin,

(5) GIS calculations of potential excess N on a seasonal basis for the entire Neuse River Basin.

The technical approach outlined in this report can be used to assess the effect of changes in terrestrial N fluxes on potential excess N and how best management practices might be implemented on the landscape to mitigate the likelihood of nonpoint source N pollution.

4. CONCEPTUAL MODEL

A "long-term concept" for N mass balance on agricultural land was described more than 25 years ago by Fried[18] and subsequently modified by Tanji et al.[19] Since those precedents, numerous studies have employed a mass balance approach to estimating N losses from terrestrial landscapes.[20,21,22 23,24,25,26,27,28]

In the present model, potential excess N was calculated as the difference between inputs to and outputs from an inorganic N pool. Generally, inorganic N does not accumulate in soils, thus the difference between inputs and outputs was assumed to be excess N subject to loss through surface runoff and leaching below the root zone.

Even though nitrate is more readily leached than ammonium, no distinction was made between ammonium- and nitrate-N as potential contributors to N leaching. For this reason, the calculations of N export are "conservative" and may overestimate potential N losses. Like other mass balance calculations of this kind, it was assumed that the soil-plant system is at steady state with respect to the soil N inventory.

Potential excess N (X) for a particular LULC category was calculated according the following mass balance equation (units are g N m^{-2} per unit time):

$$X = (I + F + M) - (U + D),$$

where I is atmospheric N deposition, F is fertilizer N inputs, M is net N mineralization, U is uptake of N by plants, and D is denitrification.

The difference between N inputs and outputs (X) is called "potential excess N" for the following reasons:

1. atmospheric N deposition will be highly dependent on local conditions (e.g., the proximity to localized N sources) and is largely controlled by precipitation which can exhibit significant spatial and temporal variation, therefore the actual N deposition to a given pixel may vary widely from

the regional average used in the model,

2. in many cases, fertilizer N inputs are not precisely known and are approximated on the basis of best available information,

3. net N mineralization was summarized as a potential annual rate which may or may not be realized depending on variations in soil properties and climate,

4. plant uptake of available inorganic N is based only on estimates of aboveground biomass production (measurements of belowground biomass production are rare in terrestrial ecosystems and, consequently, this flux is usually unknown), and

5. estimated annual losses of soil N through denitrification for each LULC category are approximate because this process is highly episodic and is strongly affected by the timing of precipitation events.

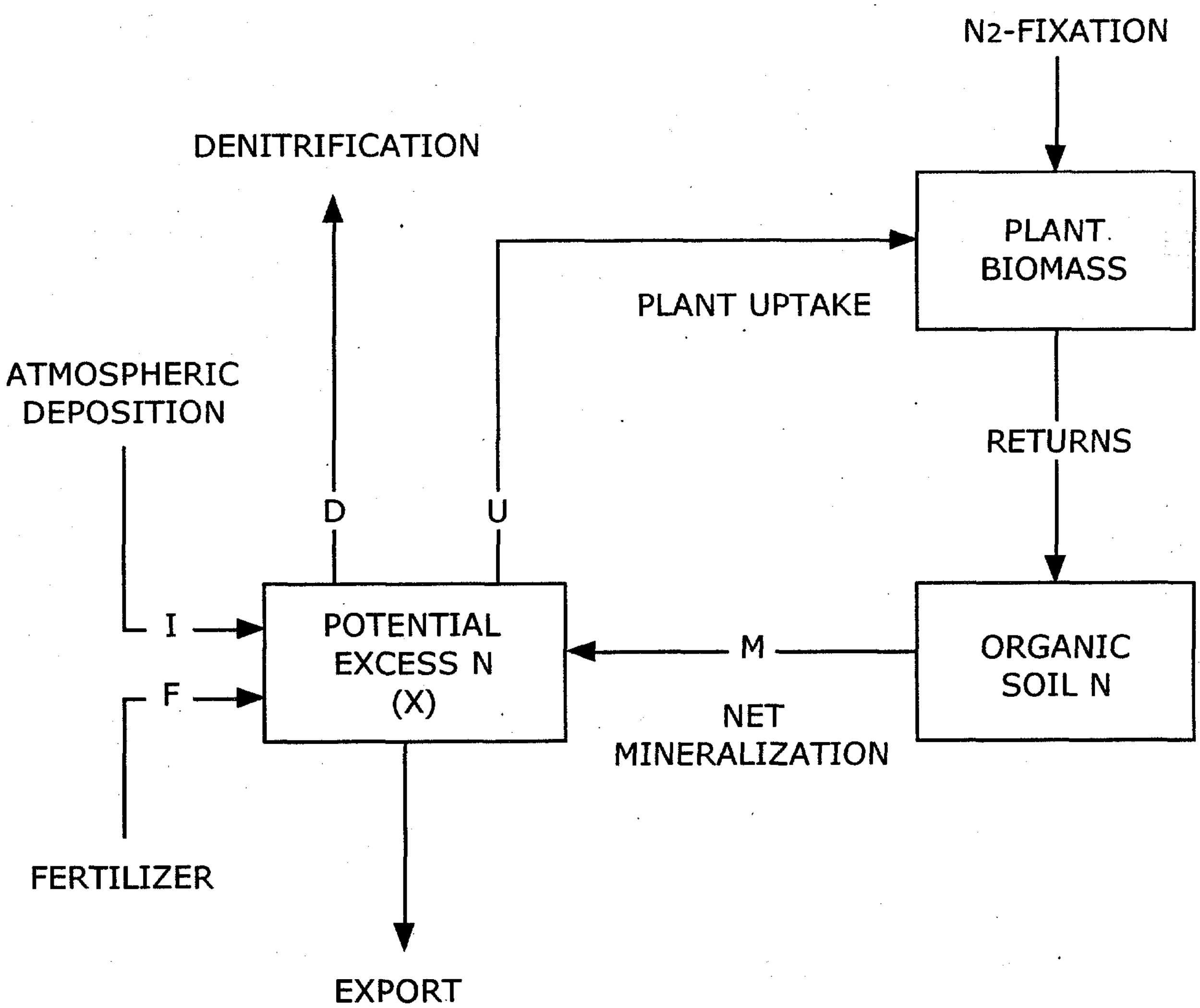
Fluxes in the model are illustrated in Figure 1. Equation 1 was solved on a seasonal basis. Seasonal N fluxes were estimated by multiplying each annual N flux by an associated seasonal factor representing the fraction of the annual flux that occurred during spring, summer, autumn, and winter. Seasonal factors were derived on the basis of the literature review, expected intra-annual variations in climate, and best professional judgment.

Using equation 1, different LULC categories can be a potential N source or N sink depending upon the mass balance between N loading and N losses from inorganic N stocks (X). When inputs exceeded outputs, potential excess N assumed a positive value. In other words, potential excess inorganic N was indicated when the estimated assimilative capacity of plant biomass and denitrification was exceeded by N loading from atmospheric deposition, fertilizer applications, and net N mineralization.

Net primary production in terrestrial ecosystems in the southeastern United States is frequently limited by available inorganic soil N. Widespread N deficiencies create the potential for some LULC categories to act like potential N sinks. Forest ecosystems are generally N sinks and wetlands are generally strong N sinks. Negative values for potential excess N identify potential sinks for N on the landscape or areas were the potential assimilative capacity of vegetation and denitrification exceeds estimated N inputs. Beyond this theoretical significance, negative values for potential excess N have no true biological meaning.

Finally, we arbitrarily defined some LULC categories as borderline or "too close to call" with respect to whether the areas were N sources or N sinks. A final qualitative analysis of potential excess N in the Neuse River Basin divided the landscape into 3 broad categories: (1) potential N sources ($X \geq 1$ g N m^{-2}), (2) potential N sinks ($X \leq -1$ g N m^{-2}), and (3) potentially either a N source or N sink (-1 g N $m^{-2} \leq X \leq +1$ g N m^{-2}).

Figure 1. Conceptual model of processes contributing to potential excess N. Potential excess N (X) is at risk of export from the terrestrial system to surface receiving waters and groundwater.



5. LITERATURE REVIEW

Data on five primary processes that contribute to potential excess N under different LULC categories were obtained from a literature review. Inputs to inorganic N include atmospheric deposition (I), additions of fertilizer N (F), and inorganic N released through decomposition of organic matter or net N mineralization (M). Outputs from the inorganic N pool included N uptake by plants (U) and denitrification (D).

The purpose of the literature review was to derive best estimates of process flux rates under different LULC categories for use in the mass balance N model. Factors were also estimated to apportion annual N fluxes among different seasons (spring, summer, fall, and winter). The timing of inputs and outputs can be a critical determinant of potential excess N and the possible export of N from terrestrial to aquatic ecosystems.

In most cases, median values were chosen as the summary statistic best suited to estimate N fluxes. The median is a "robust", nonparametric measure of central tendency and is less sensitive to anomalous or extreme data than the arithmetic mean. Frequency distributions for many of the summarized ecosystem processes suggested that N fluxes are not normally distributed, but it was impossible to make unequivocal statements about the probability distributions that describe N flux data within a particular LULC category in North Carolina. The use of median values also allowed us to preserve the original units of measurement rather than working in abstract units derived through a data transformation (e.g., logarithms).

5.1 Atmospheric N Deposition (I)

Atmospheric N deposition is comprised of wet (precipitation, snowfall, and cloud or fog water) and dry deposition (gases, aerosols, and coarse particle deposition). Data on wet deposition were obtained for five monitoring stations that are part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN)[29] in North Carolina (Table 2). Data from Sampson, Lewiston, Rowan, Scotland, and Wake counties were used to estimate annual wet deposition in the Neuse River basin. Over a 5-year period, the median value for wet deposition was 0.5 g N m^{-2} yr^{-1} (similar to the mean value of 0.48 g N m^{-2} yr^{-1}).

Table 2. Average seasonal and annual wet deposition of inorganic N at five NADP/NTN monitoring stations in North Carolina (1993 to 1997).

NADP/NTN Station	NC County	Deposition ($g\ N\ m^{-2}$) Spring	Summer	Autumn	Winter	Annual
NC 35	Sampson	0.11	0.24	0.10	0.07	0.51
NC 03	Lewiston	0.12	0.16	0.08	0.07	0.41
NC 34	Rowan	0.13	0.18	0.08	0.10	0.54
NC 36	Scotland	0.10	0.16	0.09	0.08	0.42
NC 41	Wake	0.17	0.15	0.09	0.08	0.50
Mean		0.13 (27%)	0.18 (38%)	0.09 (19%)	0.08 (16%)	0.48

A scaling factor to convert wet deposition to total N deposition (wet + dry deposition) was derived from data collected during the Integrated Forest Study.[30,31] This scaling factor averaged 2.0 across four sites in the southeastern United States (Table 3). Thus, total atmospheric N deposition, not directly influenced by strong atmospheric sources (like livestock operations), was assigned a value of 1.0 $g\ N\ m^{-2}\ yr^{-1}$ in the Neuse River Basin.

Seasonal factors for atmospheric N deposition were derived from NADP/NTN data. The fraction of annual wet deposition that occurs in a given season was averaged over 5 NADP/NTN stations in eastern North Carolina to arrive at seasonal factors for N deposition (Table 2). The seasonal pattern in atmospheric N deposition indicated a summer maximum (0.38) and a winter minimum (0.16). These factors are approximate and we recognize that large inter-annual variability in precipitation may be an important control on N fluxes from the terrestrial landscape to surface receiving waters.[32]

Our model assumes that the NADP/NTN data represent a regional mean value for deposition that includes all sources. However, there are a number of localized sources that will affect N deposition at any given pixel on the map. In particular, the ventilation systems, waste lagoons, and manure spray fields at animal operations represent major local sources within the Neuse River basin. To the extent that these sources can be quantified on a spatial basis, they could be incorporated into later versions of the current model. Lacking such information, however, we have restricted the model to consider only non-point sources.

Table 3. Atmospheric N deposition over a three year period (1986-1989) at four locations in the southeastern United States.

	Deposition (kg N ha^{-1} yr^{-1})							
	Dry			Wet			Total Dry + Wet	Ratio Total: Wet
Location	NO_3-N	NH_4-N	Total	NO_3-N	NH_4-N	Total		
Coweeta, NC	2.5	0.63	3.1	2.1	1.9	4.1	7.2	1.76
Duke, NC	5.5	1.4	6.9	2.8	4.3	7.1	14	1.97
Eatonton, GA	4.4	0.9	5.3	2.1	1.6	3.7	9.1	2.46
Oak Ridge, TN	4.1	0.36	4.5	3.0	2.5	5.5	10.0	1.82
Mean								2.00
Coefficient of variation							0.16	

Source: Lovett, G. M., and S. E. Lindberg. 1993. Atmospheric deposition and canopy interactions of nitrogen in forests. Canadian Journal of Forest Research 23: 1603-1616.

5.2 Nitrogen Fertilization (F)

Data on major agricultural crops in the Neuse River basin were obtained from McMahon and Lloyd[33] (as summarized by Osmond et al.[34]) More than 95% of the agricultural land in the Neuse River Basin is planted in the following six major crop types: soybeans, cotton, corn, tobacco, wheat, and hay. Fertilizer N inputs were based on crop specific rates of fertilizer application.

Recommended rates of N fertilizer for row crops and forage pastures in North Carolina range from 0 to 25 g N m^{-2} yr^{-1}.[35] Annual rates of N fertilization for major crop types in the Neuse River basin were estimated from national, regional, and state data (Table 4).

Although soybeans fix atmospheric N_2, 1995 agricultural statistics indicated that 44% of the soybeans planted in North Carolina received fertilizer at a rate of 4.6 g N m^{-2} yr^{-1} (41 lbs $acre^{-1}$). Averaged over all soybeans planted, the annual rate of N fertilization was estimated at 2.1 g N m^{-2} yr^{-1}. Fertilizer usage statistics for 1995 also indicated that 98% of the corn planted in North Carolina received fertilizer at an annual rate of 24 g N m^{-2} (215 lbs $acre^{-1}$). For other crops, fertilizer rates vary from 8.6 to 21.8 g N m^{-2} yr^{-1}. Depending on crop type, current estimates of fertilizer N inputs were similar to or different from those recently published.

Table 4. Estimated rates of N fertilization for agricultural field crops in the Neuse River basin. Data are from the National Agricultural Statistics Service (http://www.usda.gov/nass/) and the North Carolina Agricultural Statistics Service (http://www.agr.state.nc.us/stats/).

	Crop Specific Fertilizer Rate (yr^{-1})			Estimated Fertilizer Rate (g N m^{-2} yr^{-1})	
Crop	lbs N $acre^{-1}$		g N m^{-2}	Current	Previous (a)
Soybeans	24	(b)	0.41		
Soybeans	39	(c)	4.6	2.1	0
Cotton	100	(b)	8.6		
Cotton	92	(d)	10.3	9.5	9.0
Corn	133	(b)	14.9		
Corn	114	(e)	12.8		
Corn	215	(f)	24.1	24.1	15.7
Winter wheat	61	(b)	6.8		
Spring wheat	67	(b)	7.5	7.2	12.3
Tobacco	88	(b)	9.8		
Tobacco	86	(e)	9.6	9.7	5.6
Hay/other crops	--		--	10.0	10.1 - 15.7

Notes:
(a) estimates from McMahon and Woodside (1997)[36]
(b) average over all US acreage planted
(c) 44% of the soybeans in NC received N fertilizer at a rate of 41 lb $acre^{-1}$ in 1995
(d) average for southeastern states
(e) data specific to North Carolina
(f) 98% of the corn in NC received N fertilizer at a rate of 215 lb $acre^{-1}$ in 1995

Although commercial fertilizers are used in urban areas, nonfarm uses of commercial fertilizers are only 15% of the U.S. fertilizer demand.[37] Maintained herbaceous vegetation (primarily lawns) and unspecified agricultural categories were assigned a default fertilizer value of 10 g N m^{-2} yr^{-1}. Negligible inputs of commercial N fertilizer (F = 0) were assigned to barren land, fallow agricultural land, natural herbaceous vegetation, forests, wetlands, and surface waters.

With the exception of row crops, seasonal factors for N fertilization were estimated from commercial fertilizer tonnage shipped to North Carolina from July 1998 through June 1999.[38] The fraction of annual N fertilization allocated to spring, summer, autumn, and winter was 0.58, 0.17, 0.10, and 0.16, respectively, for all LULC categories except corn, cotton, soybean, and tobacco. Annual N fertilization for the latter four row crops was evenly divided between spring (0.50) and summer (0.50).

5.3 Net Soil N Mineralization (M)

Net soil N mineralization is influenced by many factors, including vegetation type.[39,40,41,42,43,44,45] Although rates of net N mineralization can exhibit large variations across relatively short distances,[46,47,48] some data suggest that rates at a particular site exhibit small variations between years with similar climate conditions.[49] A review of the foregoing studies suggested that LULC category can be used to characterize spatial patterns in net N mineralization over a regional landscape such as the Neuse River basin.

Data on net soil N mineralization, from the literature review, were assigned to defined LULC categories (Appendix I). Estimates of annual net N mineralization based on lab studies were significantly greater than those based on field studies (Mann-Whitney U test, $\alpha = 0.001$). Lab studies may overestimate actual rates of net N mineralization in the field because lab studies are usually performed on sieved soil under constant temperature and moisture conditions. For this reason, laboratory studies were omitted and estimates of net soil N mineralization for the model were based solely on the remaining field studies.

Table 5 presents summary statistics for estimates of net N mineralization based on the literature review. Herbaceous and forest land covers were the only categories with a sufficient number of published field measurements. Measurements of net N mineralization in forests were normally distributed while those under herbaceous vegetation were positively skewed. Differences between rates of net N mineralization in forest and grassland soils were statistically significant (Mann-Whitney U test, $\alpha = 0.05$).

Table 5. Summary statistics for field studies of net soil N mineralization (see Appendix I).

Variable	LULC category	n	Percentile 10th	25th	50th	75th	90th
Net N mineralization (g N m^{-2} yr^{-1})							
	Forest	128	2.6	4.1	7.3	9.1	11.3
	Herbaceous	62	1.5	2.3	3.5	6.0	7.7
	All data	190	1.9	3.0	5.9	8.4	10.9
Net N mineralization rate (yr^{-1})							
	Forest	82	0.010	0.015	0.021	0.034	0.054
	Herbaceous	62	0.009	0.018	0.028	0.044	0.062
	All data	144	0.009	0.015	0.023	0.040	0.060

The following values for net N mineralization (g N m^{-2} yr^{-1}) were assigned to land cover categories with missing data: fallow agricultural land (3.5, same as herbaceous vegetation), row crops and general agricultural land (5.9, median value for all field data), barren and urban land (0), water (0), and wetlands (10.9, the 90th percentile for all field data).

In addition, a close inspection of the data (Appendix I) indicated that most studies of net soil N mineralization were from locations outside the southeastern United States. Twelve studies of net soil N mineralization from southeastern states indicated a median value of 5.1 g N m^{-2} yr^{-1} with 10th and 90th percentiles of 0.2 and 10.8 g N m^{-2} yr^{-1}, respectively. A regional value of 5.1 g N m^{-2} yr^{-1} was assigned to M in the final model for forest land. Overall, the literature review indicated that annual rates of net N mineralization range from 1 to 6% of the surface soil N inventory.

The fraction of annual net N mineralization occurring in spring, summer, fall, and winter was 0.4, 0.3, 0.2, and 0.1, respectively. The assumed seasonal pattern was consistent with prior studies of seasonal variation in net soil N mineralization that indicate a spring maximum and a winter minimum for this process.[50,51,52,53,54,55,56] Elevated levels of N mineralization are expected during the spring when warming temperatures stimulate soil microbial activity and decomposition of soil organic matter.

Estimates of annual fluxes (g N m^{-2} yr^{-1}) and rates (yr^{-1}) of net soil N mineralization presented the opportunity to compare predictions of potential excess N in the Neuse River Basin from two different landscape based models. The first approach, referred to as "Model 1", was based solely on LULC categories derived from remote sensing data. The second approach, referred to as "Model 2", was partially based on an estimate of soil N inventories.

In Model 1, annual fluxes of net soil N mineralization (M) from Table 5 were simply assigned to each LULC category. In Model 2, the soil N inventory (g N m^{-2} to a 30 cm soil depth) was multiplied by an annual net N mineralization rate (yr^{-1}), based on the literature review, to arrive at the annual flux of N entering the available soil N pool (X) for each 15-m pixel in the LULC map. Thus, the flux of net soil N mineralization was a function of both the LULC (Table 5) and the soil N inventory underlying each 15-m pixel in the LULC map. Predictions from Model 2 accounted for regional differences in soil N stocks within the Neuse River Basin while predictions from Model 1 could not account for such differences.

A national map[57] was used to derive a map layer of soil N inventories in the Neuse River Basin. The map had a 1 km^2 resolution and was based on total soil N measurements from the National Soil Characterization Database (NSCD) and information on soil taxonomy in the State Soil Geographic (STATSGO) database.[58]

5.4 N Uptake By Plants (U)

Numerous factors affect soil N uptake by plants, including land cover and land use. Data on annual N uptake by plants were assigned to previously defined LULC categories based on published descriptions of vegetation in each study that was reviewed (Appendix II). Only N uptake by aboveground biomass was considered because N storage in roots was assumed to be returned annually to soil organic N through root mortality and decomposition. There are very few reliable data on which to build estimates of root N dynamics.

Summary statistics for annual N uptake by plants are presented in Table 6. The median values for N uptake by crops, herbaceous vegetation, and herbaceous wetlands were similar (≈12 to 14 g N m^{-2} yr^{-1}) and greater than the median value of N uptake by forests. Estimates of N uptake by soybeans were almost twice those of other row crops due, in part, to N_2 fixation. Nitrogen fixation by soybeans tends to decline with additions of N fertilizer, but as a general value for plant uptake we assumed that 25% of the N uptake by soybeans was derived from soil.[59]

Table 6. Summary statistics for N uptake (g N m^{-2} yr^{-1}) by land cover category ("n" denotes the number of measurements from literature sources in Appendix II).

		Percentile				
LULC category	n	10th	25th	50th	75th	90th
Agriculture (general)	439	6.4	9.1	13.5	18.9	22.6
Row crops						
Corn	261	5.8	7.9	12.2	16.3	20.1
Cotton	27	7.2	8.3	9.2	10.4	12.3
Tobacco	6	7.1	10.6	14.0	16.0	19.2
Soybeans	9	13.6	19.6	21.6	22.8	27.4
Herbaceous	130	3.7	6.9	12.2	21.6	42.0
Forest	58	2.5	4.5	6.2	8.8	11.6
Emergent Wetlands	13	5.0	7.1	12.5	18.1	34.0

Frequency distributions for measurements of N uptake by agricultural crops, herbaceous vegetation, and forests were positively skewed. The median estimate of soil N uptake by forests (6.2 g N m^{-2} yr^{-1}) compared well with previously published mean (±SD) estimates of N uptake by temperate coniferous forests (4.7 ± 1.7 g N m^{-2} yr^{-1}) and temperate deciduous forests (7.5 ± 1.8 g N m^{-2} yr^{-1}).[60] Plant N uptake by wooded wetlands was assigned the same value used for forests, and plant N uptake by herbaceous wetlands was assigned a median value of 12.5 g N m^{-2} yr^{-1}. Negligible plant uptake of soil N (U = 0) was assumed for urban land, barren land, and surface water.

Seasonal variation in N uptake by plants was assumed to track expected seasonal differences in plant tissue production. Generally, N uptake under all LULC categories is lowest during autumn and winter when biomass production and plant demands for soil N decline. The fraction of annual N uptake occurring in spring, summer, fall, and winter was 0.4, 0.3, 0.2, and 0.1 for all LULC categories except corn, cotton, soybeans, and tobacco. For the latter four row crops, plant N uptake was evenly divided between spring and summer.

5.5 Denitrification (D)

There are numerous environmental factors that interact to cause both temporal and spatial variation in denitrification, including: plant community type,[61,62,63] soil moisture,[64,65,66,67] and season of the year.[68,69,70] Denitrification data, from the literature review, were assigned to one of the previously defined LULC categories based on published site descriptions (Appendix III).

Denitrification rates are frequently reported in daily or weekly time units because extreme temporal variation can result from precipitation or irrigation events that stimulate episodes of denitrification in soil.[71,72] In order to integrate over short-term fluctuations in soil nitrate availability, temperature, and soil moisture, the present analysis included only reported annual denitrification rates.

Measurements of denitrification in soils under agriculture, herbaceous vegetation, and forests were positively skewed. Table 7 presents the median values for annual denitrification rates by land cover type. Considering four LULC categories, higher denitrification rates were reported under agricultural land and herbaceous vegetation than under forest cover, but the chief difference between LULC categories was greatly elevated denitrification rates in wetland soils versus non-wetland soils. Negligible denitrification (D = 0) was assigned to urban land, barren land, and surface water.

Our estimates of denitrification under forest and agricultural land also compare favorably with those reported in a recent review[73] where the median annual rates of denitrification in forest and agricultural soils were 0.22 and 1.3 g N m^{-2}, respectively. The highest rates of denitrification reported here included agricultural soils characterized by high water and soil N content. The median annual rate of denitrification under agricultural land, from the literature review, was similar to an estimated maximum annual denitrification rate for disturbed forest soils in North Carolina.[74]

It is well established that flooding leads to anaerobic conditions in soil that can facilitate N losses through denitrification.[75] Despite an expectation of elevated denitrification rates, the data from Appendix III indicated denitrification rates ranging between 0 to 5 kg N m^{-2} yr^{-1} for non-wetland hydric soils. Soil drainage undoubtedly affects denitrification within the non-wetland land cover categories, however the estimates of annual denitrification from non-wetland hydric soils did not approach the reported high rates of annual denitrification from wetlands. Land cover and soil moisture status are confounded in wetlands which, by definition, occupy hydric soils. Wetlands are a reliable indicator of hydric soils and, therefore, elevated annual rates of denitrification.

Table 7. Summary statistics for estimated annual rates of soil N loss through denitrification (g N m^{-2} yr^{-1}) by land cover category (see Appendix III).

		Percentile				
LULC category	n	10th	25th	50th	75th	90th
Forest	67	0.09	0.24	0.44	1.15	3.09
Agriculture	20	0.60	0.92	1.55	13.7	17.8
Herbaceous	40	0.22	0.55	2.38	5.34	17.0
Wetlands	7	19.6	22.0	43.0	45.3	46.0

The largest part of the annual denitrification flux was allocated to winter (0.35) and spring (0.35) seasons. Reduced evapotranspiration, increased soil moisture, and higher levels of inorganic N (in the absence of plant uptake) are expected to occur during those times. Less denitrification was expected during summer (0.15) and fall (0.15) when soils tend to be drier and inorganic soil N has been reduced by the seasonal demands of plant uptake.

6. GIS DATA PROCESSING

The model was implemented in a geographic information system database consisting of two input layers. The first layer was a high-resolution LULC grid provided by the U.S. Environmental Protection Agency's Landscape Characterization Branch. This layer consisted of 35 possible LULC categories applied to 15-m pixels across the entire Neuse

River watershed. The second layer was a soil N map for North Carolina generated from the Natural Resource Conservation Service's STATSGO database.[76] The values in this latter grid are total Kjeldahl N for the top 30 cm of soil. Resolution of this layer was coarse, with 1-km pixels.

The model was implemented in two versions. In the first version (Model 1), the seasonal excess N values for each LULC category from the literature search were applied to each pixel of the LULC grid, by using an Arc Macro Language (AML) script (Appendix IV). This approach yields a mass-balance model of potential excess N based simply on land cover for each season. In the second version (Model 2), we accounted for the effect that total soil N has on mineralization by utilizing a first-order model for mineralization and incorporating that value into the mass-balance calculations. Model 2 required creation of an individual grid for each N flux (I, F, M, U, and D) for each season. The grids were generated by applying literature-derived values for each parameter multiplied by seasonal factors to each pixel based on LULC category. The mineralization grid (M) was derived by multiplying the total soil N inventory from the STATSGO-based soil N grid by an annual N mineralization rate and a seasonal factor. Once the individual grids were created, an AML script (Appendix V) was run to combine the grids into a single grid of potential excess N. All GIS processing was accomplished using Arc/Info[77] Version 7.2.1 on a Sun Ultra 5 running SunOS 5.6.

7. RESULTS

7.1 LULC Model Matrix

Parameter values for the model, seasonal factors, calculated N fluxes and potential excess N (on a seasonal and an annual basis) are summarized in 3 tables. Table 8 presents estimated annual N fluxes (g N m^{-2} yr^{-1}) for atmospheric N deposition (I), fertilization (F), net soil N mineralization (M), plant uptake (U), and denitrification (D) in different LULC categories (based on the literature review). Table 9 presents the seasonal factors that were used to apportion the annual N fluxes between spring (spr), summer (sum), fall (fll), and winter (win) based on the literature review and best professional judgment. Table 10 presents calculated N fluxes and potential excess N (g N m^{-2}) in (1) spring, (2) summer, (3) fall, and (4) winter and an annual estimate (X_a) based on calculations using information in the previous tables.

7.2 Model 1 Predictions

Several patterns emerged from a visual analysis of the seasonal N maps used in Model 1. Fertilizer inputs to potential excess N were highest in the spring and summer and were primarily concentrated in the middle portion of the Neuse River Basin (Figure 2). The highest rates of soil N mineralization occurred during spring and summer and were primarily concentrated in pixels bordering streams and tributaries (Figure 3). The highest rates of plant N uptake from soil also occurred during spring and summer and were primarily concentrated in the middle portion of the Neuse River Basin (Figure 4). Finally, the highest rates of denitrification occurred during spring and winter and were primarily concentrated in pixels bordering streams and tributaries (Figure 5). Predicted potential excess N was highest during the spring and summer and was primarily concentrated in the middle portion of the Neuse River Basin (Figure 6). Large land areas surrounding the lower reach of the Neuse River were identified as potential "N sinks" in Model 1.

7.3 Model 2 Predictions

Seasonal maps for atmospheric deposition (I), fertilization (F), plant uptake (U), and denitrification (D) were the same in Models 1 and 2. Model 2, unlike Model 1, accounted for spatial patterns in surface soil N inventories. The highest soil N inventories were located in the middle and lower portions of the Neuse River Basin (Figure 7). Patches of elevated net soil N mineralization during spring and summer, in Model 2, were associated with areas characterized by high soil N stocks (Figure 8). Predicted potential excess N was highest during the summer and was primarily concentrated in the middle portion of the Neuse River Basin (Figure 9).

7.4 Model Comparisons

Model 1 and 2 were different with respect to predicted potential excess N in the Neuse River Basin. Much of the spatial heterogeneity in predictions of potential excess N using Model 1, which accounted only for LULC category, was eliminated in predictions of potential excess N using Model 2, which accounted for both LULC category and soil N inventories.

Table 8. Estimated annual N fluxes (g N m^{-2} yr^{-1}).

LULC VALUE	LULC CATEGORY	I	F	M	U	D
230	Agriculture - Fallow	1.0	0.0	3.5	0.0	1.55
220	Agriculture - Pasture/Hay	1.0	10.0	3.5	12.2	1.55
212	Agriculture - Row - Corn	1.0	24.1	5.9	12.2	1.55
211	Agriculture - Row - Cotton	1.0	9.5	5.9	9.2	1.55
213	Agriculture - Row - Soybean	1.0	2.1	5.9	5.4	1.55
214	Agriculture - Row - Tobacco	1.0	9.7	5.9	14.0	1.55
710	Barren - Non-vegetated	1.0	0.0	0.0	0.0	0.00
720	Barren - Transitional	1.0	0.0	0.0	0.0	0.00
420	Herbaceous - Maintained	1.0	10.0	3.5	12.2	2.38
410	Herbaceous - Natural	1.0	0.0	3.5	3.7	2.38
110	Urban - High Density	1.0	0.0	0.0	0.0	0.00
132	Urban - Low - Agriculture	1.0	10.0	5.9	13.5	0.00
137	Urban - Low - Barren	1.0	0.0	0.0	0.0	0.00
134	Urban - Low - Herbaceous	1.0	10.0	3.5	12.2	2.38
135	Urban - Low - Water	1.0	0.0	0.0	0.0	0.00
136	Urban - Low - Wetland	1.0	0.0	10.9	12.5	43.00
133	Urban - Low - Woody	1.0	0.0	5.1	6.2	0.44
130	Urban - Low Density	1.0	0.0	0.0	0.0	0.00
122	Urban - Medium - Agriculture	1.0	10.0	5.9	13.5	0.00
127	Urban - Medium - Barren	1.0	0.0	0.0	0.0	0.00
124	Urban - Medium - Herbaceous	1.0	10.0	3.5	12.2	2.38
125	Urban - Medium - Water	1.0	0.0	0.0	0.0	0.00
126	Urban - Medium - Wetland	1.0	0.0	10.9	12.5	43.00
123	Urban - Medium - Woody	1.0	0.0	5.1	6.2	0.44
120	Urban - Medium Density	1.0	0.0	0.0	0.0	0.00
500	Water	1.0	0.0	0.0	0.0	0.00
540	Water - Estuaries	1.0	0.0	0.0	0.0	0.00
550	Water - Ponds	1.0	0.0	0.0	0.0	0.00
530	Water - Reservoirs	1.0	0.0	0.0	0.0	0.00
510	Water - Streams/Rivers	1.0	0.0	0.0	0.0	0.00
610	Wetlands - Herbaceous	1.0	0.0	10.9	12.5	43.00
620	Wetlands - Woody	1.0	0.0	10.9	6.2	43.00
310	Woody - Deciduous	1.0	0.0	5.1	6.2	0.44
320	Woody - Evergreen	1.0	0.0	5.1	6.2	0.44
330	Woody - Mixed	1.0	0.0	5.1	6.2	0.44

Table 9. Seasonal factors for N fluxes in different LULC categories.

LULC	I spr	I sum	I fll	I win	F spr	F sum	F fll	F win	M spr	M sum	M fll	M win	U spr	U sum	U fll	U win	D spr	D sum	D fll	D win
230	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
220	0.27	0.38	0.19	0.16	0.50	0.50	0.00	0.00	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
212	0.27	0.38	0.19	0.16	0.50	0.50	0.00	0.00	0.40	0.30	0.20	0.10	0.50	0.50	0.00	0.00	0.35	0.15	0.15	0.35
211	0.27	0.38	0.19	0.16	0.50	0.50	0.00	0.00	0.40	0.30	0.20	0.10	0.50	0.50	0.00	0.00	0.35	0.15	0.15	0.35
213	0.27	0.38	0.19	0.16	0.50	0.50	0.00	0.00	0.40	0.30	0.20	0.10	0.50	0.50	0.00	0.00	0.35	0.15	0.15	0.35
214	0.27	0.38	0.19	0.16	0.50	0.50	0.00	0.00	0.40	0.30	0.20	0.10	0.50	0.50	0.00	0.00	0.35	0.15	0.15	0.35
710	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
720	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
420	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
410	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
110	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
132	0.27	0.38	0.19	0.16	0.50	0.50	0.00	0.00	0.40	0.30	0.20	0.10	0.50	0.50	0.00	0.00	0.35	0.15	0.15	0.35
137	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.00	0.00	0.00	0.00	0.35	0.15	0.15	0.35
134	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
135	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.00	0.00	0.00	0.00	0.35	0.15	0.15	0.35
136	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
133	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
130	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.00	0.00	0.00	0.00	0.35	0.15	0.15	0.35
122	0.27	0.38	0.19	0.16	0.50	0.50	0.00	0.00	0.40	0.30	0.20	0.10	0.50	0.50	0.00	0.00	0.35	0.15	0.15	0.35
127	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.00	0.00	0.00	0.00	0.35	0.15	0.15	0.35
124	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
125	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.00	0.00	0.00	0.00	0.35	0.15	0.15	0.35
126	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
123	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
120	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.00	0.00	0.00	0.00	0.35	0.15	0.15	0.35
500	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.00	0.00	0.00	0.00	0.35	0.15	0.15	0.35
540	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.00	0.00	0.00	0.00	0.35	0.15	0.15	0.35
550	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.00	0.00	0.00	0.00	0.35	0.15	0.15	0.35
530	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.00	0.00	0.00	0.00	0.35	0.15	0.15	0.35
510	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.00	0.00	0.00	0.00	0.35	0.15	0.15	0.35
610	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
620	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
310	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
320	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35
330	0.27	0.38	0.19	0.16	0.58	0.16	0.10	0.16	0.40	0.30	0.20	0.10	0.40	0.30	0.20	0.10	0.35	0.15	0.15	0.35

Table 10. Calculated seasonal fluxes and potential excess N (X).

LULC	I1	I2	I3	I4	F1	F2	F3	F4	M1	M2	M3	M4	U1	U2	U3	U4	D1	D2	D3	D4	X1	X2	X3	X4	Xa
230	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	1.4	1.1	0.7	0.3	0.0	0.0	0.0	0.0	0.5	0.2	0.2	0.5	1.13	1.20	0.66	-0.03	2.95
220	0.27	0.38	0.19	0.16	5.0	5.0	0.0	0.0	1.4	1.1	0.7	0.3	4.9	3.7	2.4	1.2	0.5	0.2	0.2	0.5	1.25	2.54	-1.78	-1.25	0.75
212	0.27	0.38	0.19	0.16	12.1	12.1	0.0	0.0	2.4	1.8	1.2	0.6	6.1	6.1	0.0	0.0	0.5	0.2	0.2	0.5	8.04	7.87	1.14	0.21	17.25
211	0.27	0.38	0.19	0.16	4.8	4.8	0.0	0.0	2.4	1.8	1.2	0.6	4.6	4.6	0.0	0.0	0.5	0.2	0.2	0.5	2.24	2.07	1.14	0.21	5.65
213	0.27	0.38	0.19	0.16	1.1	1.1	0.0	0.0	2.4	1.8	1.2	0.6	2.7	2.7	0.0	0.0	0.5	0.2	0.2	0.5	0.44	0.27	1.14	0.21	2.05
214	0.27	0.38	0.19	0.16	4.8	4.8	0.0	0.0	2.4	1.8	1.2	0.6	7.0	7.0	0.0	0.0	0.5	0.2	0.2	0.5	-0.06	-0.23	1.14	0.21	1.05
710	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.38	0.19	0.16	1.00
720	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.38	0.19	0.16	1.00
420	0.27	0.38	0.19	0.16	5.8	1.6	1.0	1.6	1.4	1.1	0.7	0.3	4.9	3.7	2.4	1.2	0.8	0.4	0.4	0.8	1.76	-0.99	-0.91	0.06	-0.08
410	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	1.4	1.1	0.7	0.3	1.5	1.1	0.7	0.4	0.8	0.4	0.4	0.8	-0.64	-0.04	-0.21	-0.69	-1.58
110	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.38	0.19	0.16	1.00
132	0.27	0.38	0.19	0.16	5.0	5.0	0.0	0.0	2.4	1.8	1.2	0.6	6.8	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.88	0.40	1.37	0.75	3.40
137	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.38	0.19	0.16	1.00
134	0.27	0.38	0.19	0.16	5.8	1.6	1.0	1.6	1.4	1.1	0.7	0.3	4.9	3.7	2.4	1.2	0.8	0.4	0.4	0.8	1.76	-0.99	-0.91	0.06	-0.08
135	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.38	0.19	0.16	1.00
136	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	4.4	3.3	2.2	1.1	5.0	3.8	2.5	1.2	15.1	6.5	6.5	15.1	-15.42	-6.55	-6.58	-15.05	-43.60
133	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	2.0	1.5	1.0	0.5	2.5	1.9	1.2	0.6	0.2	0.1	0.1	0.2	-0.32	-0.02	-0.10	-0.10	-0.54
130	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.38	0.19	0.16	1.00
122	0.27	0.38	0.19	0.16	5.0	5.0	0.0	0.0	2.4	1.8	1.2	0.6	6.8	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.88	0.40	1.37	0.75	3.40
127	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.38	0.19	0.16	1.00
124	0.27	0.38	0.19	0.16	5.8	1.6	1.0	1.6	1.4	1.1	0.7	0.3	4.9	3.7	2.4	1.2	0.8	0.4	0.4	0.8	1.76	-0.99	-0.91	0.06	-0.08
125	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.38	0.19	0.16	1.00
126	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	4.4	3.3	2.2	1.1	5.0	3.8	2.5	1.2	15.1	6.5	6.5	15.1	-15.42	-6.55	-6.58	-15.05	-43.60
123	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	2.0	1.5	1.0	0.5	2.5	1.9	1.2	0.6	0.2	0.1	0.1	0.2	-0.32	-0.02	-0.10	-0.10	-0.54
120	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.38	0.19	0.16	1.00
500	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.38	0.19	0.16	1.00
540	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.38	0.19	0.16	1.00
550	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.38	0.19	0.16	1.00
530	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.38	0.19	0.16	1.00
510	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.27	0.38	0.19	0.16	1.00
610	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	4.4	3.3	2.2	1.1	5.0	3.8	2.5	1.2	15.1	6.5	6.5	15.1	-15.42	-6.55	-6.58	-15.05	-43.60
620	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	4.4	3.3	2.2	1.1	2.5	1.9	1.2	0.6	15.1	6.5	6.5	15.1	-12.90	-4.66	-5.32	-14.42	-37.30
310	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	2.0	1.5	1.0	0.5	2.5	1.9	1.2	0.6	0.2	0.1	0.1	0.2	-0.32	-0.02	-0.10	-0.10	-0.54
320	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	2.0	1.5	1.0	0.5	2.5	1.9	1.2	0.6	0.2	0.1	0.1	0.2	-0.32	-0.02	-0.10	-0.10	-0.54
330	0.27	0.38	0.19	0.16	0.0	0.0	0.0	0.0	2.0	1.5	1.0	0.5	2.5	1.9	1.2	0.6	0.2	0.1	0.1	0.2	-0.32	-0.02	-0.10	-0.10	-0.54

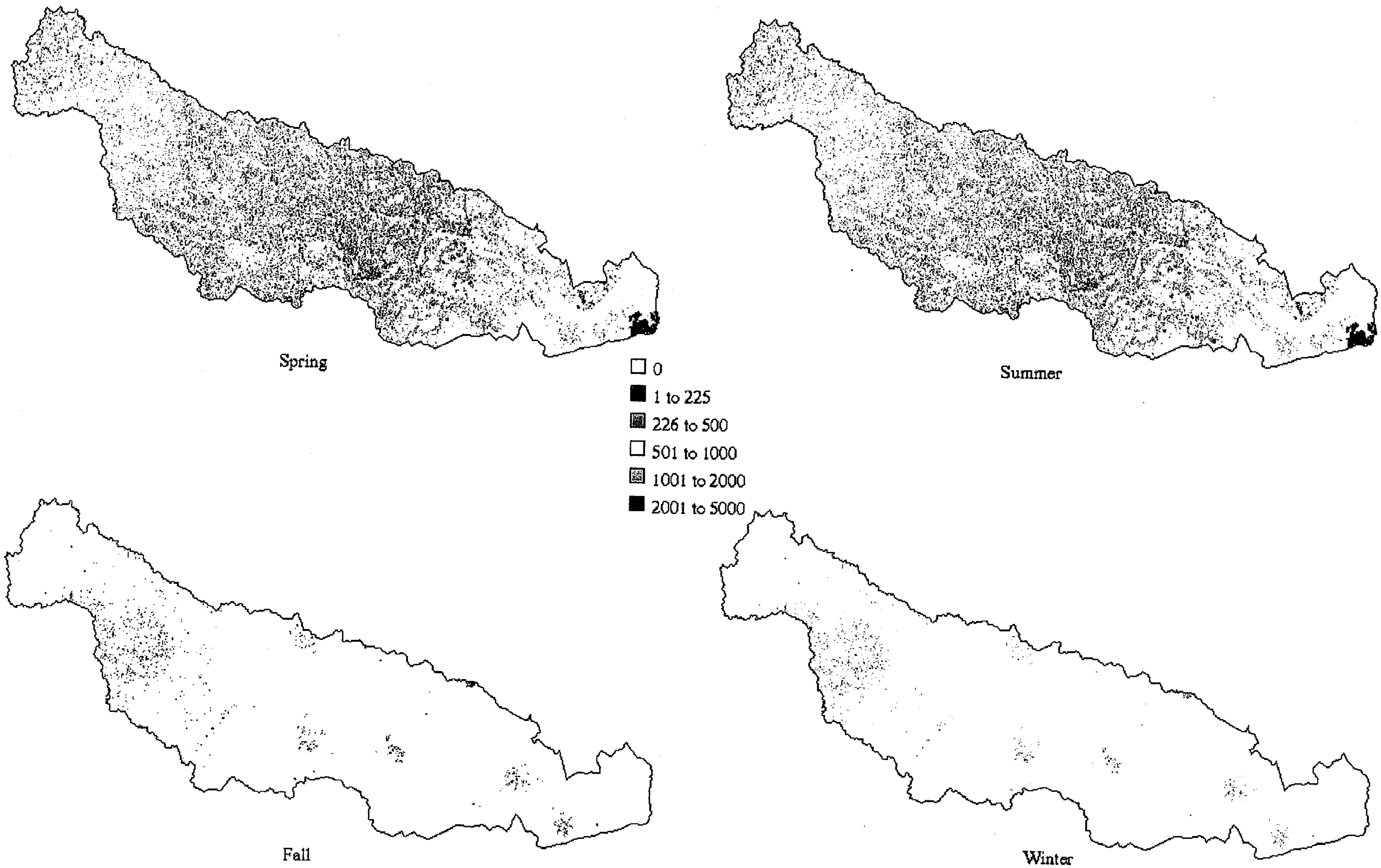


Figure 2. Estimated N fertilizer (F, g N pixel^{-1}) in the Neuse River Basin.

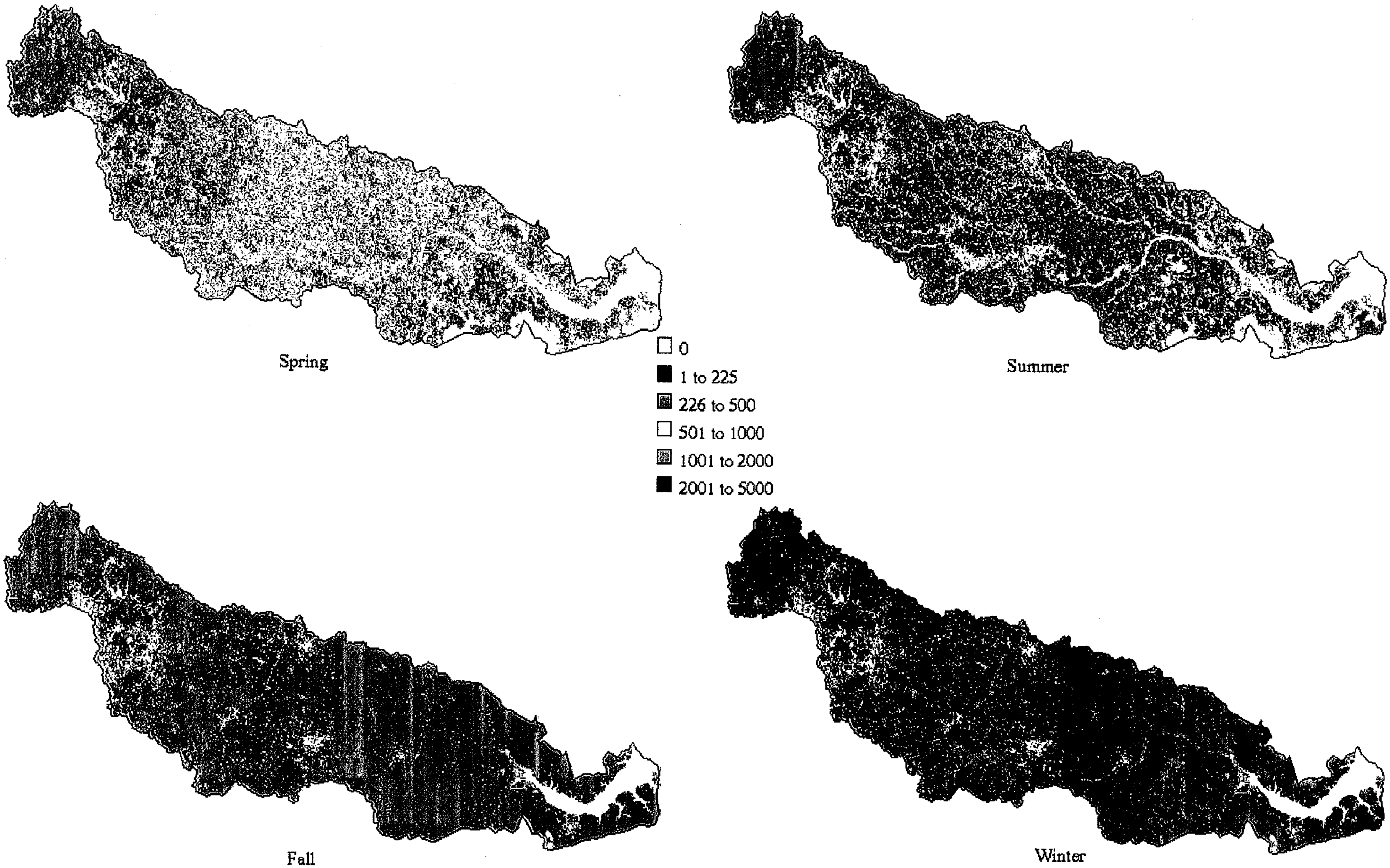


Figure 3. Estimated net soil mineralization (M, g N $pixel^{-1}$) in the Neuse River Basin (Model 1).

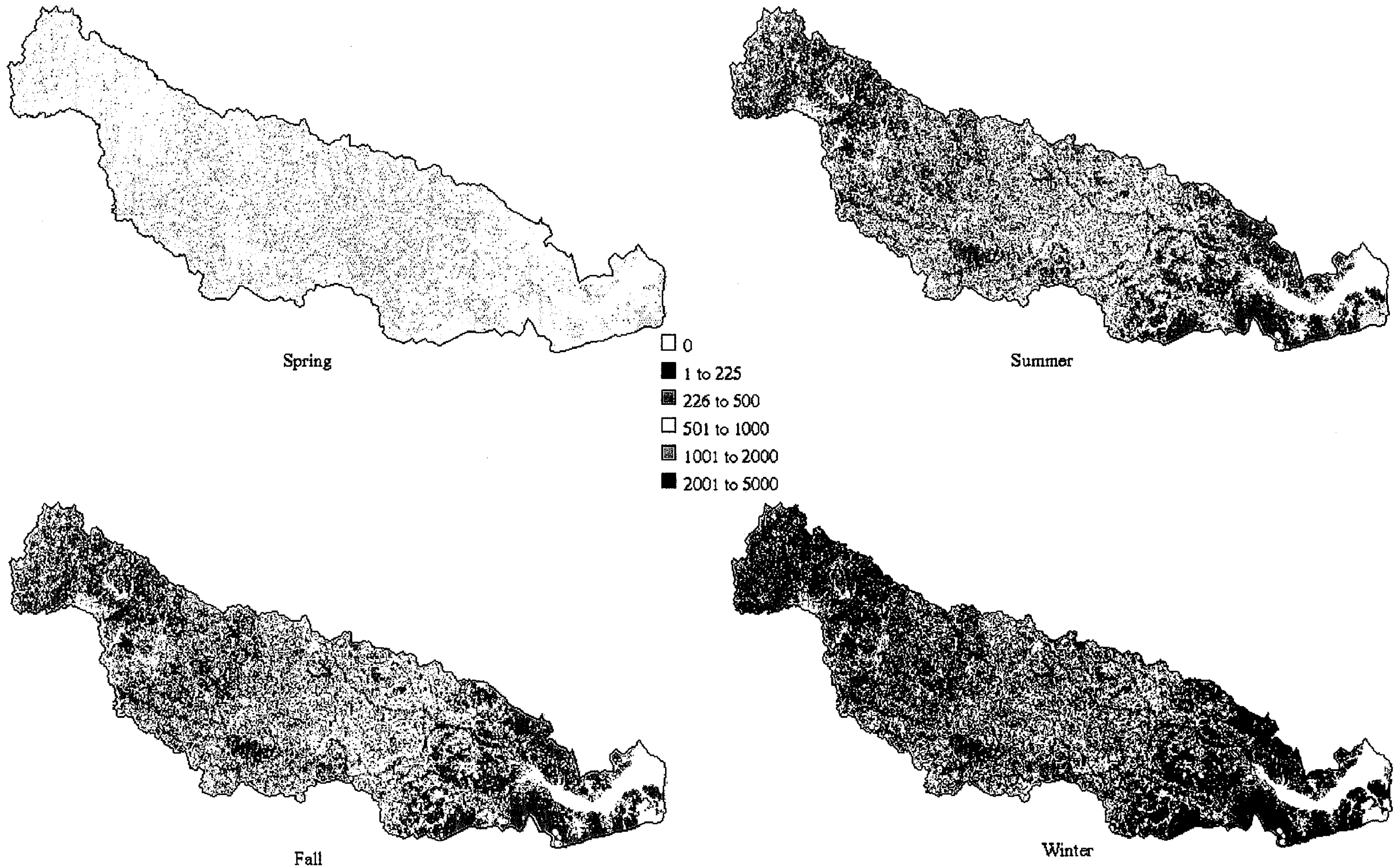


Figure 4. Estimated plant uptake (U, g N pixel^{-1}) in the Neuse River Basin.

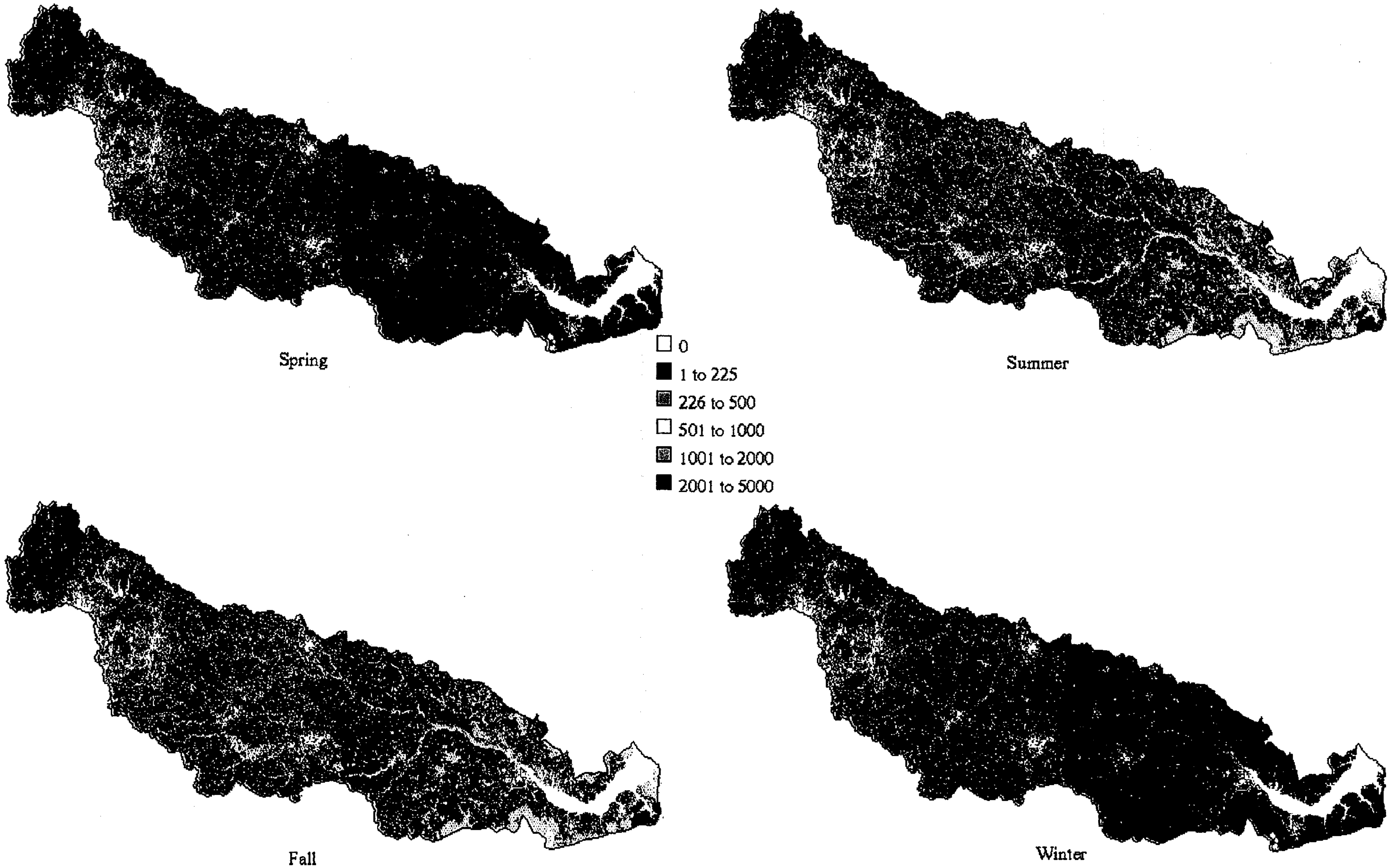


Figure 5. Estimated denitrification (D, g N $pixel^{-1}$) in the Neuse River Basin.

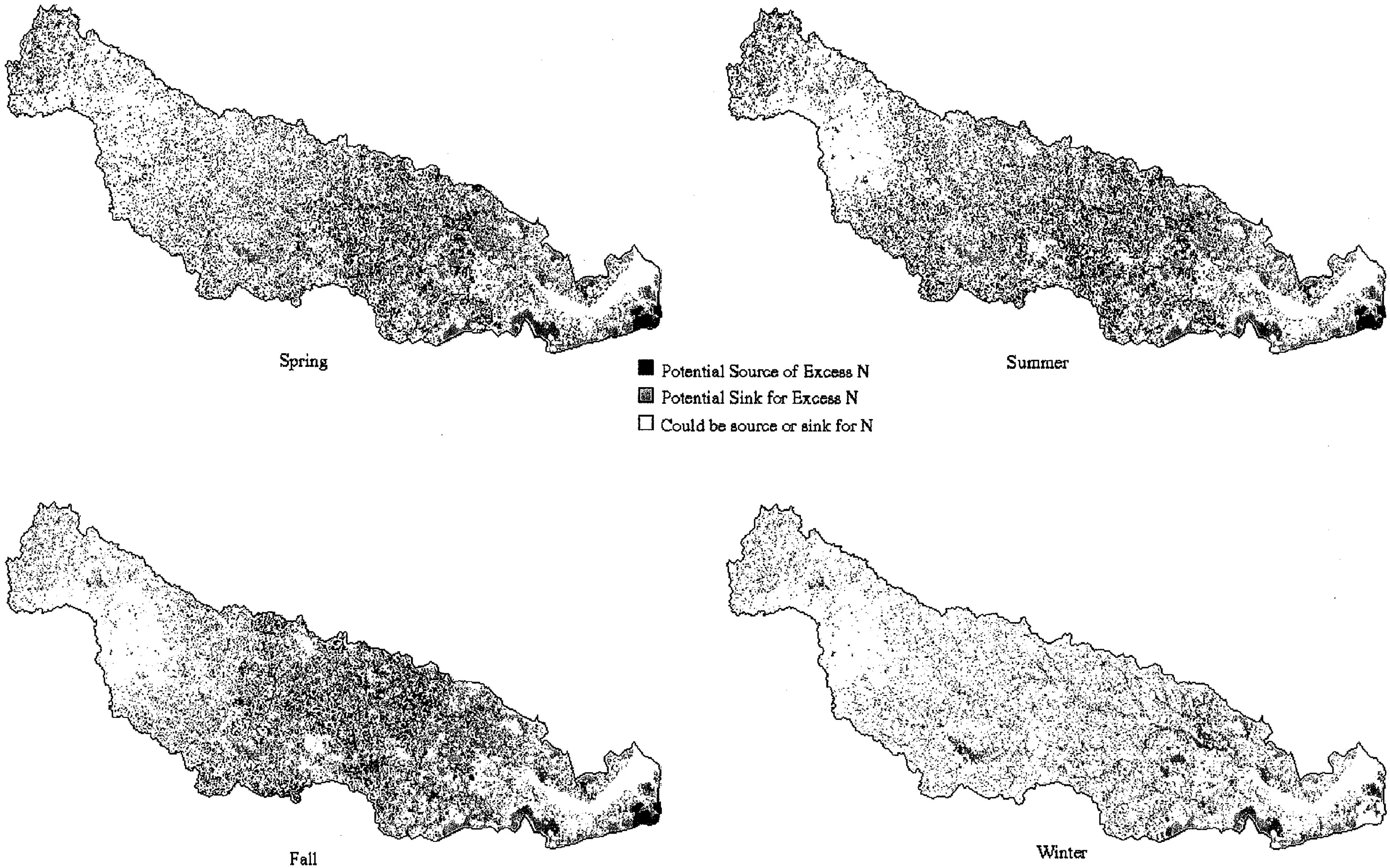


Figure 6. Qualitative assessment of potential excess N (X) in the Neuse River Basin (Model 1).

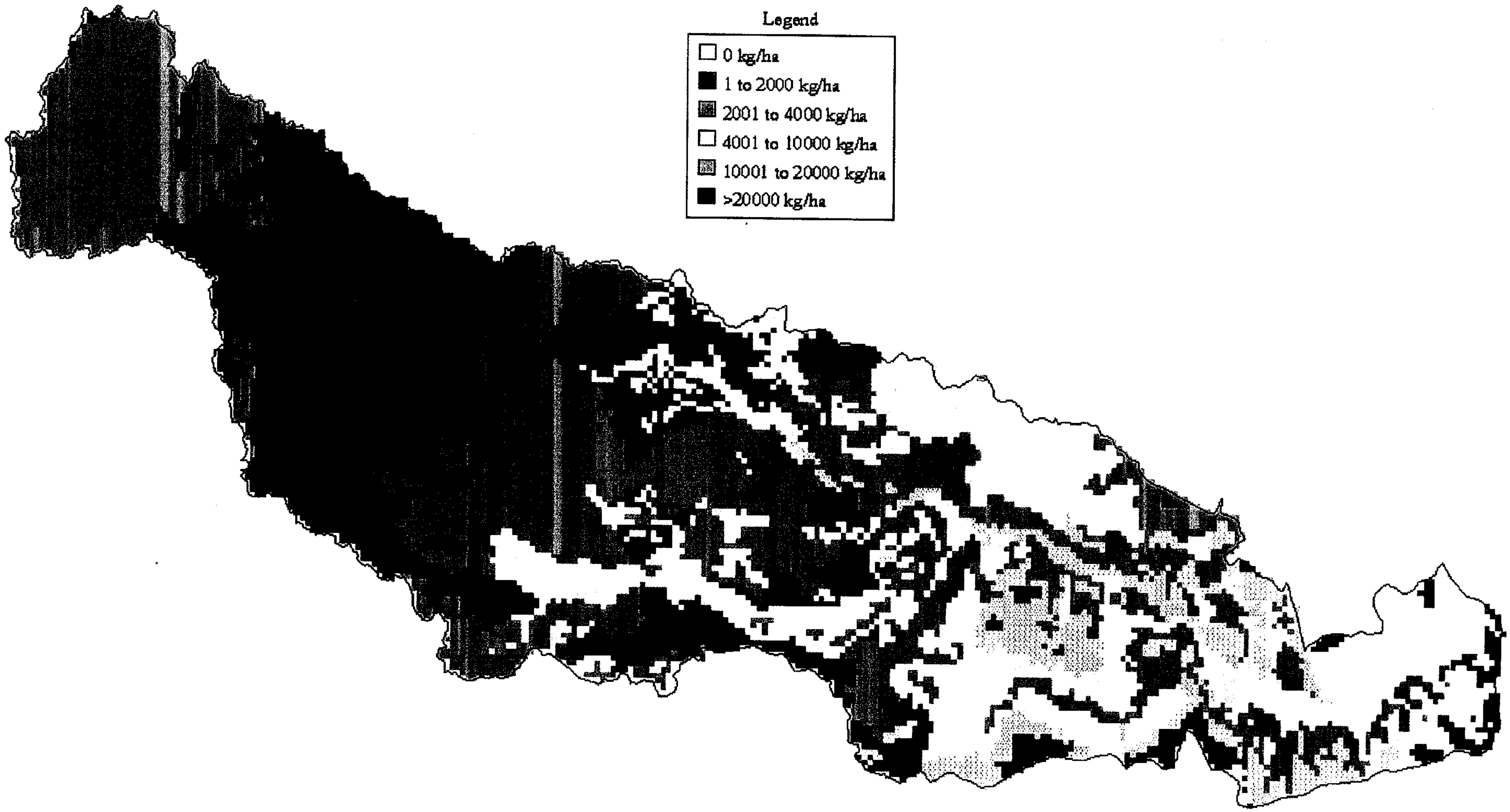


Figure 7. Estimated soil N inventories (30 cm soil depth) in the Neuse River Basin (Model 2).

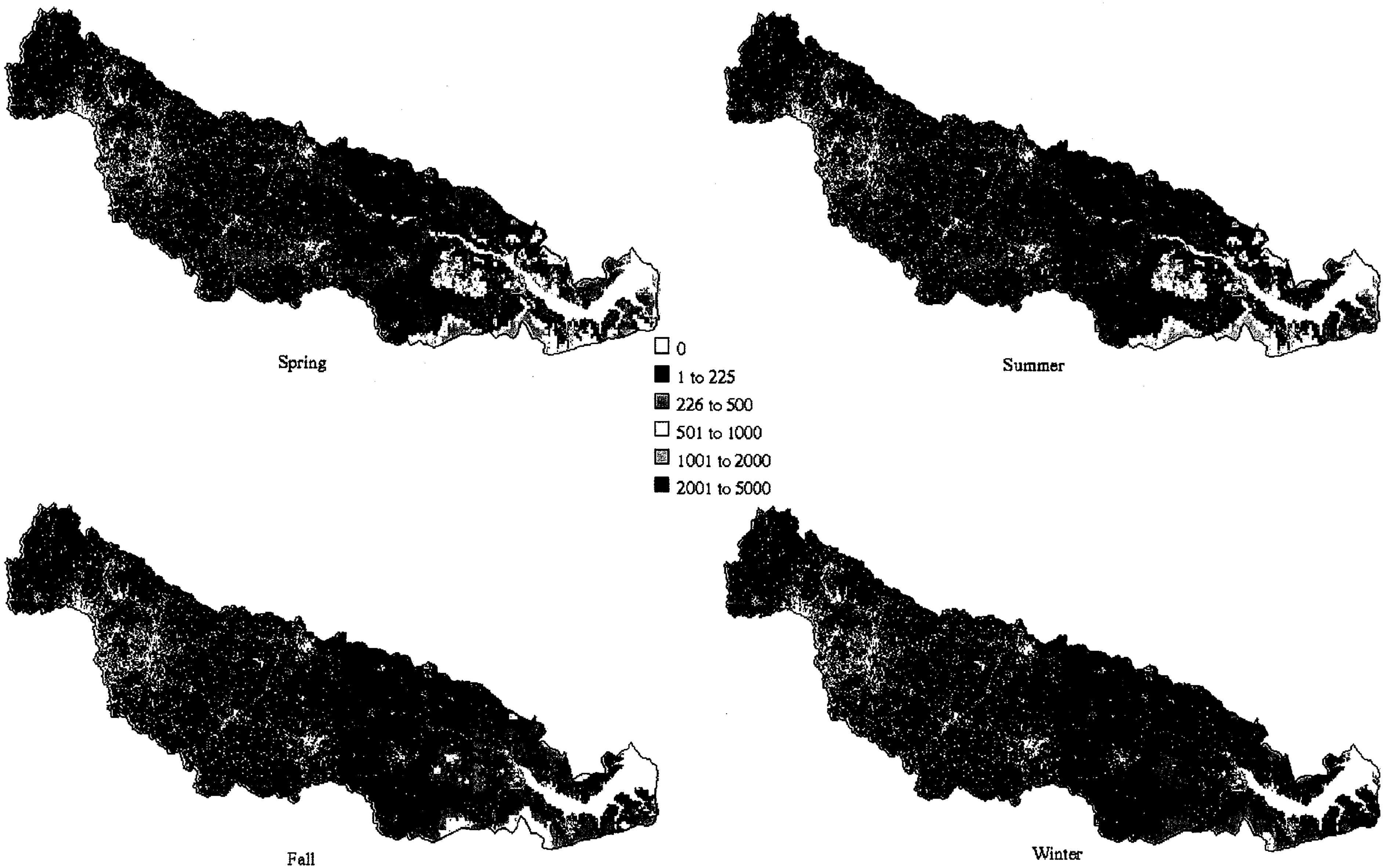


Figure 8. Soil-based rates of net N mineralization (M, g N $pixel^{-1}$) in the Neuse River Basin (Model 2).

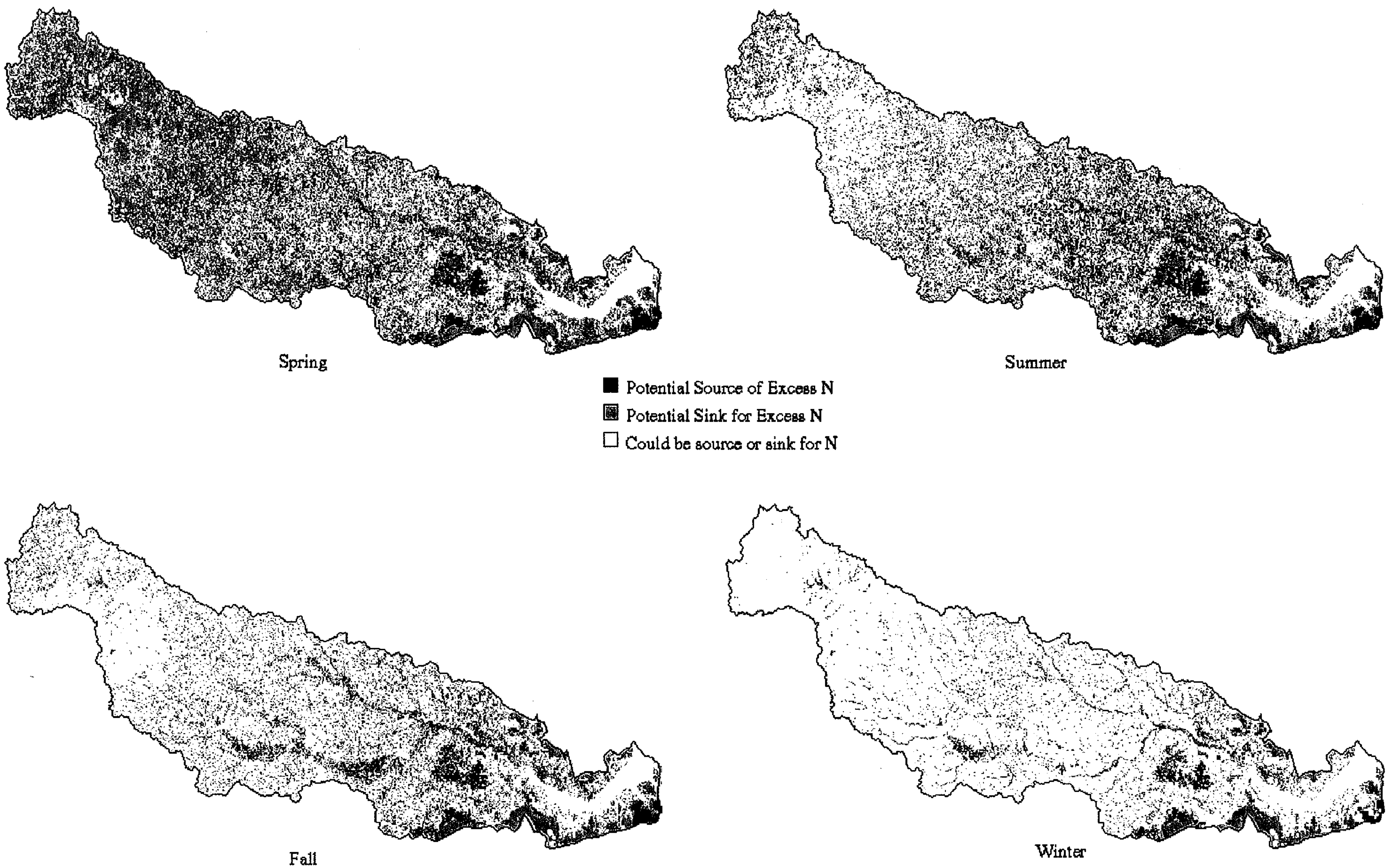


Figure 9. Qualitative assessment of potential excess N (X) in the Neuse River Basin (Model 2).

Results from both models indicate large areas of land surrounding the lower reach of the Neuse River as well as pixels bordering streams and tributaries may act as potential "N sinks". Landscape patches that corresponded to potential "N sources" appeared to be influenced by soil N inventories and rates of net soil N mineralization (which is a natural process). The overall flux of N in net soil N mineralization was generally lower in Model 2 than in Model 1.

Both models indicated large areas of the landscape were approximately in balance (-1 g N $m^{-2} \leq X \leq 1$ g N m^{-2}) with respect to excess N. In these areas, future changes in land use could be a critical determinant of N retention or N export. Finally, there are no field data to validate predictions of potential excess N from Model 1 or 2, but we believe predictions from Model 2 provide additional information supplied by estimated stocks of surface soil N across the Neuse River Basin.

8. DISCUSSION

Outbreaks of *Pfiesteria* and other harmful algal blooms in coastal waters of the United States, including the Neuse River estuary, may be indicative of a national problem of too much N (and P) in runoff from terrestrial ecosystems.[78] Large scale animal operations have definitely resulted in the import of significant amounts of N into the Neuse River Basin, as well as other parts of east-central North Carolina, in the form of animal feeds, but only a small fraction of these nutrient imports have apparently entered the Neuse River.[79] This indicates the overall importance of a more complete assessment of nonpoint sources of N loading to the Neuse River and its tributaries.

Mass balance methods for estimating N runoff from terrestrial to aquatic ecosystems are more comprehensive than empirically derived export coefficients because mass balance methods include process level information that can be used to identify possible controls on N exports. Despite this additional information, there are numerous shortcomings to the current analysis which must be recognized and appreciated from the standpoint of how they limit application of the results and how they present opportunities for future improvements in landscape based models of excess nutrients.

One of the primary limiting assumptions to the mass balance approach is that terrestrial ecosystems are in steady state. This means that the stocks of plant N and organic soil N are not changing with respect to time.

Other assessments have included processes like N_2-fixation as a means of increasing soil N stocks.[80] The current model treats N_2-fixation as an input to organic soil N which must be mineralized in order to contribute to potential excess N. It was assumed in the current assessment that amounts of organic soil N do not change because N inputs to organic soil N (through plant mortality) balance the decomposition process which drives net soil N mineralization.

In reality, there can be significant inter-annual variations in N inputs to soil, soil N transformation rates, and plant uptake, thus a true steady state does not exist in terrestrial ecosystems. Steady state in the context of this model means that although there may be significant year to year fluctuations in N fluxes for a particular LULC category, there is no systematic long-term trend. We do not know to what extent this assumption is valid because there are no long-term studies of changing soil N stocks within the Neuse River Basin.

Two other major limitations of mass balance models for estimating critical N loads to forest ecosystems[81] also apply to the current landscape-based model of potential excess N. The first is failure to consider episodic events which can be extremely important in controlling the flux of N from the landscape.[82] The current model operates on a seasonal time-step because there are simply not enough studies of at a fine enough temporal resolution to elucidate the detailed time dependent behavior of N biogeochemistry in terrestrial ecosystems. The second limitation is a scarcity of information on N transfers in different terrestrial ecosystems in the southeastern United States. This latter limitation made it impossible for us to parametrize the mass balance model at the same level of detail as was represented in the final LULC map. Nitrogen fluxes were estimated for many LULC categories because of missing critical data for different types of terrestrial ecosystems. The inability of the model to deal with episodic events (e.g., precipitation events) and the lack of field measurements for N fluxes in different ecosystems representative of those in the Neuse River Basin makes the current model unsuitable for predictions of total maximum daily loads.

More than a decade ago, Kesner and Meentemeyer published a landscape based approach to the regional analysis of potential N sources and sinks in an agricultural watershed in southern Georgia.[83] In many respects, their GIS approach to the problem of predicting spatial patterns in excess N is similar to the one used here for the Neuse River Basin. However, there are important differences in the conceptual mass balance models that are the foundation of these separate analyses. The main difference is that Kesner and Meentemeyer used mass balance to calculate N sinks and sources on the basis of total soil N. Most of total soil N is organically bound and is available for uptake by plant roots or denitrification by soil microorganisms only as a result of N mineralization. The models used in this report on the Neuse River Basin treat potential excess N as an inorganic N pool rather than a total soil N pool. This difference may lead to substantially different estimates of potential excess N, than those based on total soil N, because net N mineralization is such an important process for producing potential excess N.

Poiani et al. also previously used a landscape based model of N leaching to evaluate non-point source N loading in nine watersheds in central New York state.[84] They calculated potential excess N (i.e., "N available for leaching") by considering a balance between N inputs (atmospheric deposition and fertilization) and outputs (plant uptake and denitrification). Several important sources of uncertainty in their analysis also apply to the current model: (1) the approximate nature of estimates for N inputs, (2) uncertainties in GIS data (i.e., accuracy of LULC maps), and (3) high spatial and temporal variation in N fluxes (like soil N mineralization and denitrification). These limitations indicate the need for site specific studies of N cycling in the Neuse River Basin under different LULC categories to improve assessments of potential excess N on a regional scale. Nitrogen inputs, in particular, could be refined through monitoring atmospheric N deposition at a finer spatial scale than the NADP/NTN monitoring network and obtaining data on actual crop fertilization rates through the use of farm surveys.

Burkart and James also recently published an assessment of N loading to the Gulf of Mexico from agricultural nonpoint sources in the Mississippi River Basin and concluded that the largest potential excess N (i.e., "residual N") was located in the Upper Mississippi River and Ohio River Basins.[85] Their assessment treated some processes, in particular volatilization and redeposition of ammonia, differently than the manner in which they are treated in the current model.

Ammonia (NH_3) volatilization is a widely reported occurrence following the surface application of manure and N fertilizers.[86] A weighted average emission factor, derived from data on fertilizer shipments to North Carolina in 1997, indicated that only about 4% of fertilizer N is lost through volatilization.[87] Although considerable research is being done on the transport and fate of NH_3 from agricultural operations,[88] there is still a lack of consensus on the range over which redeposition occurs. The present model incorporates the following two assumptions: (1) most of the NH_3 is redeposited on the same pixel (so no volatilization parameter is included), and (2) the regionally dispersed fraction of volatilized NH_3 is captured as part of the NADP/NTN data used to estimate atmospheric N deposition. Clearly, both of these assumptions are suspect, but they are logically consistent from a mass-balance standpoint.

Manure application is, perhaps, more like a point source than a nonpoint source of N loading on the landscape because it is most commonly associated with large scale animal operations. Based on estimates from Burkart and James, applications of N in manure can approximately balance manure N losses through volatilization. Because animal operations represent point sources, they are not included in this version of the model. Future versions of the model may address the location of large scale animal operations and the N loading associated with land disposal of animal wastes but more data will be required on the frequency and amount of spray field operations in the Neuse River Basin.

Like the current model, other mass balance models for N frequently make no distinction between soil NH_4-N and NO_3-N and they generally assume that all excess N is at risk of export from the landscape. This is a fairly conservative assumption that many tend to overestimate potential excess N on the landscape. Nitrate, and not NH_4-N, is the chemical form that is more readily leached from soil. Future versions of the model could be improved by additional data on the contribution of ammonification and nitrification to the process of net soil N mineralization under different LULC categories in the Neuse River Basin. This is especially important given the fact that net N mineralization is the process that apparently contributes most to potential excess N on nonagricultural lands.

Few of the terms in the current mass balance model for potential excess N in the Neuse River Basin were actually derived from studies in North Carolina. We consider the highest uncertainties in the model to be associated with estimates of N inputs through fertilization and net soil N mineralization (two large N fluxes). The uncertainty associated with atmospheric N deposition is somewhat less simply because the size of the flux is small relative to the two former inputs. Uncertainties associated with plant uptake of soil N and denitrification are also high due to a wide range of possible values depending upon the nutrient demands of the vegetation, land management practice, and soil properties. Although median values were used in the current model to approximate the inputs to and outputs from a pool of potential excess N, there is the opportunity and the need to reduce uncertainties in landscape based models through site specific studies under different LULC categories.

A final important limitation associated with the current model is lack of validation. We view the "validation" process as an integral and important step in model development, but one that is beyond the scope of the current research. It has been suggested that the model could be tested against measurements of stream N. There are basically three problems associated with "validation" of the landscape model using stream data: (1) potential excess N exists only as a theoretical concept and not as a truly measurable entity, (2) the uncertainty bands are so wide that testing for a specific predicted value becomes trivial, and (3) attempts to validate the terrestrial model by looking at N values in the stream are confounded because they also require validating the model used to transport N to the stream and they require some understanding of in-stream N processing. What is ultimately important from the perspective of best management practices is whether the pixel in the LULC map is a N source or a N sink. Qualitative assessments of potential excess N may be sufficient to accomplish the original stated goal of best management practices, but are not sufficient for the purpose of establishing total maximum daily loads to surface receiving waters.

Despite many shortcomings, predictions from the model are useful for the original objective of this research: helping to develop a landscape based tool for implementing best management practices to abate N loading to surface receiving waters in the Neuse River Basin through the identification of potential N sources and sinks by LULC category. With this model landscape patterns of potential excess N in the Neuse River Basin can be evaluated in the context of the nutrient storage capabilities of different terrestrial ecosystems, the proximity of terrestrial N sources to streams and rivers, and the likelihood of intercepting N runoff from the landscape as it moves through vegetated riparian buffer zones, wetlands, or soils, where removal processes (like denitrification) might help to reduce N loading to aquatic systems. Both Model 1 and Model 2 predicted that there are large land areas in the Neuse River Basin that cannot be classified as either a N source or a N sink. Such areas are potentially sensitive because future changes in land use, or small alterations in N fluxes, could convert areas that are essentially in balance with respect to N biogeochemistry into the N source or N sink category. In this respect, model predictions indicate that the timing of N inputs and outputs on the landscape can be a critical determinant of potential excess N and the possible export of N from terrestrial to aquatic ecosystems.

9. ACKNOWLEDGMENTS

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[1] Carpenter, S. R., N. F. Caraco, D. L. Correll, R. W. Howarth, A. N. Sharpley, and V. H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8: 559-568.

[2] Burkart, M. R., and D. E. James. 1999. Agricultural-nitrogen contributions to hypoxia in the Gulf of Mexico. Journal of Environmental Quality 28: 850-859.

[3] Nolan, B. T., B. C. Ruddy, K. J. Hitt, and D. R. Helsel. 1997. Risk of nitrate in groundwaters of the United States -- a national perspective. Environmental Science and Technology 31: 2229-2236.

[4] Nolan, B. T. 1999. Nitrate behavior in ground waters of the southeastern USA. Journal of Environmental Quality 28: 1518-1527.

[5] Ward, M. H., S. D. Mark, K. P. Cantor, D. D. Weisenburger, A. Correa Villasenor, and S. H. Zahm. 1996. Drinking-water nitrate and the risk of non-hodgkins-lymphoma. Epidemiology 7: 465-471.

[6] Burkholder, J. M. 1998. Implications of harmful microalgae and heterotrophic dinoflagellates in management of sustainable marine fisheries. Ecological Applications 8: 537-562.

[7] Burkart, M. R., and D. E. James. 1999. Agricultural-nitrogen contributions to hypoxia in the Gulf of Mexico. Journal of Environmental Quality 28: 850-859.

[8] Beaulac, M. N., and K. H. Reckhow. 1982. An examination of land use-nutrient export relationships. Water Resources Bulletin 18: 1013-1024.

[9] Frink, C. R. 1991. Estimating nutrient exports to estuaries. Journal of Environmental Quality 20: 717-724.

[10] Schreiber, J. D., P. D. Duffy, and D. C. McClurkin. 1976. Dissolved nutrient losses in storm runoff from five southern pine watersheds. Journal of Environmental Quality 5: 201-205.

[11] Jacobs, T. C., and J. W. Gilliam. 1985. Riparian losses of nitrate from agricultural drainage waters. Journal of Environmental Quality 14: 472-478.

[12] Hill, A. R. 1978. Factors affecting the export of nitrate-nitrogen from drainage basins in southern Ontario. Water Research 12: 1045-1057.

[13] Neill, M. 1989. Nitrate concentrations in river waters in the south-east of Ireland and their relationship with agricultural practice. Water Research 23: 1339-1355.

[14] Nearing, M. A., R. M. Risse, and L. F. Rogers. 1993. Estimating daily nutrient fluxes to a large Piedmont reservoir from limited tributary data. Journal of Environmental Quality 22: 666-671.

[15] Lunetta, R. S., C. T. Garten, Jr., J. J. Heisler, E. Decker, and R. Olivieria. 1998. Landscape Based Nutrient Modeling of *Pfiesteria piscicida* Control Mechanisms in the Neuse River Basin of North Carolina. Proposal Submitted in response to the Environmental Protection Agency (EPA) Intra-Agency Advanced Measurement Initiative Program, July 1998.

[16] Pearl, H. W. 1997. Coastal eutrophication and harmful algal blooms: importance of atmospheric deposition and groundwater as "new" nitrogen and other nutrient sources. Limnology and Oceanography 45: 1154-1165.

[17] Glasgow, H. B., and J. M. Burkholder. 2000. Water quality trends and management implications from a five-year study of a eutrophic estuary. Ecological Applications 10: 1024-1046.

[18] Fried, M., K. K. Tanji, and R. M. Van de Pol. 1976. Simplified long term concept for evaluating leaching of nitrogen from agricultural land. Journal of Environmental Quality 5: 197-200.

[19] Tanji, K. K., M. Fried, and R. M. Van de Pol. 1977. A steady-state conceptual nitrogen model for estimating nitrogen emissions from cropped lands. Journal of Environmental Quality 6: 155-159.

[20] MacDuff, J. H., and R. E. White. 1984. Components of the nitrogen cycle measured for cropped and grassland soil-plant systems. Plant and Soil 76: 35-47.

[21] Fisher, D. C., and M. Oppenheimer. 1991. Atmospheric nitrogen deposition and the Chesapeake Bay estuary. Ambio 20: 102-108.

[22] Kesner, B. T., and V. Meentenmeyer. 1989. A regional analysis of total nitrogen in an agricultural landscape. Landscape Ecology 2: 151-163.

[23] Jaworski, N. A., P. M. Groffman, A. A. Keller, and J. C. Prager. 1992. A watershed nitrogen and phosphorus balance: the upper Potomac River basin. Estuaries 15: 83-95.

[24] Correll, D. L., T. E. Jordan, and D. E. Weller. 1992. Nutrient flux in a landscape: effects of coastal land use and terrestrial community mosaic on nutrient transport to coastal waters. Estuaries 15: 431-442.

[25] David, M. B., L. E. Gentry, D. A. Kovacic, and K. M. Smith. 1997. Nitrogen balance in and export from an agricultural watershed. Journal of Environmental Quality 26: 1038-1048.

[26] Jordan, T. E., D. L. Correll, and D. E. Weller. 1997. Effects of agriculture on discharges of nutrients from coastal plain watersheds of Chesapeake Bay. Journal of Environmental Quality 26: 836-848.

[27] Puckett, L. J., T. K. Cowdery, D. L. Lorenz, and J. D. Stoner. 1999. Estimation of nitrate contamination of an agro-ecosystem outwash aquifer using a nitrogen mass-balance budget. Journal of Environmental Quality 28: 2015-2025.

[28] Burkart, M. R., and D. E. James. 1999. Agricultural-nitrogen contributions to hypoxia in the Gulf of Mexico. Journal of Environmental Quality 28: 850-859.

[29] National Atmospheric Deposition Program (http://nadp.sws.uiuc.edu/)

[30] Johnson, D. W., and S. E. Lindberg (eds.) 1992. Atmospheric Deposition and Forest Nutrient Cycling: A Synthesis of the Integrated Forest Study. Springer-Verlag, New York.

[31] Lovett, G. M., and S. E. Lindberg. 1993. Atmospheric deposition and canopy interactions of nitrogen in forests. Canadian Journal of Forest Research 23: 1603-1616.

[32] Glasgow, H. G., and J. M. Burkholder. 2000. Water quality trends and management implications from a five-year study of a eutrophic estuary. Ecological Applications 10: 1024-1046.

[33] McMahon, G., and O. Lloyd. 1995. Water-quality assessment of the Albemarle-Pamlico drainage basin, North Carolina and Virginia -- Environmental setting and water-quality issues. Open File Report 95-136, U. S. Geological Survey, Raleigh, NC.

[34] Osmond, D. L., D. Hardy, L. H. Johnson, W. G. Lord, R. H. Pleasants, M. E. Regans and J. A. Gale. Agriculture and the Neuse River Basin (http://ces.soil.ncsu.edu/net/agriculture.html)

[35] Tucker, M. R., J. K. Messiek, and C. C. Carter. 1997. Crop fertilization based on North Carolina soil tests. North Carolina Department of Agriculture and Consumer Services Agronomic Division. Raleigh, North Carolina.

[36] McMahon, G., and M. D. Woodside. 1997. Nutrient mass balance for the Albemarle-Pamlico drainage basin, North Carolina and Virginia. Journal of the American Water Resources Association 33: 573-589.

[37] Reisch, M. S. 2000. Seeing green: producers of lawn and garden chemicals hit pay dirt as market grows. Chemical and Engineering News 78: 23-27.

[38] North Carolina Department of Agriculture and Consumer Services (http://www.agr.state.nc.us/stats/fert_use/Fertrpt.htm)

[39] Robertson, G. P., and P. M. Vitousek. 1981. Nitrification potentials in primary and secondary succession. Ecology 62: 376-386.

[40] Zak, D. R., K. S. Pregitzer, and G. E. Host. 1986. Landscape variation in nitrogen mineralization and nitrification. Canadian Journal of Forest Research 16: 1258-1263.

[41] Zak, D. R., G. E. Host, and K. S. Pregitzer. 1989. Regional variability in nitrogen mineralization, nitrification, and overstory biomass in northern lower Michigan. Canadian Journal of Forest Research 19: 1521-1526.

[42] Zak, D. R., and K. S. Pregitzer. 1990. Spatial and temporal variability of nitrogen cycling in northern lower Michigan. Forest Science 36: 367-380.

[43] Zak, D. R., and D. F. Grigal. 1991. Nitrogen mineralization, nitrification and denitrification in upland and wetland ecosystems. Oecologia 88: 189-196.

[44] Compton, J. E., R. D. Boone, G. Motzkin, and D. R. Foster. 1998. Soil carbon and nitrogen in a pine-oak sand plain in central Massachusetts: role of vegetation and land-use history. Oecologia 116: 536-542.

[45] Knoepp, J. D., and W. T. Swank. 1998. Rates of nitrogen mineralization across an elevation and vegetation gradient in the southern Appalachians. Plant and Soil 204: 235-241.

[46] Hill, A. R., and M. Shackleton. 1989. Soil N mineralization and nitrification in relation to nitrogen solution chemistry in a small forested watershed. Biogeochemistry 8: 167-184.

[47] Zak, D. R., and D. F. Grigal. 1991. Nitrogen mineralization, nitrification and denitrification in upland and wetland ecosystems. Oecologia 88: 189-196.

[48] Garten, C. T., Jr., M. A. Huston, and C. A. Thoms. 1994. Topographic variation of soil nitrogen dynamics at Walker Branch Watershed, Tennessee. Forest Science 40: 497-512.

[49] Goovaerts, P., and C. N. Chiang. 1993. Temporal persistence of spatial patterns for mineralizable nitrogen and selected soil properties. Soil Science Society America Journal 57: 372-381.

[50] Nadelhoffer, K. J., J. D. Aber, and J. M. Melillo. 1983. Leaf-litter production and soil organic matter dynamics along a nitrogen-availability gradient in southern Wisconsin (USA). Canadian Journal of Forest Research 13: 12-21.

[51] Nadelhoffer, K. J., J. D. Aber, and J. M. Melillo. 1984. Seasonal patterns of ammonium and nitrate uptake in nine temperate forest ecosystems. Plant and Soil 80: 321-335.

[52] Pastor, J., J. D. Aber, C. A. McClaugherty, and J. M. Melillo. 1984. Aboveground production and N and P cycling along a nitrogen mineralization gradient on Blackhawk Island, Wisconsin. Ecology 65: 256-268.

[53] Gosz, J. R., and C. S. White. 1986. Seasonal and annual variation in nitrogen mineralization and nitrification along an elevational gradient in New Mexico. Biogeochemistry 2: 281-297.

[54] Garten, C. T., Jr., M. A. Huston, and C. A. Thoms. 1994. Topographic variation of soil nitrogen dynamics at Walker Branch Watershed, Tennessee. Forest Science 40: 497-512.

[55] Knoepp, J. D., and W. T. Swank. 1998. Rates of nitrogen mineralization across an elevation and vegetation gradient in the southern Appalachians. Plant and Soil 204: 235-241.

[56] Zak, D. R., and K. S. Pregitzer. 1990. Spatial and temporal variability of nitrogen cycling in northern lower Michigan. Forest Science 36: 367-380.

[57] Hargrove, W. W., and W. M. Post. 1998. A high-resolution nitrogen map produced by linking NCSD with STATSGO. 1998 Annual Meeting Abstracts American Society of Agronomy (90th Annual Meeting), p. 253.

[58] U. S. Department of Agriculture. 1994. State Soil Geographic (STATGO) data base: data use information. National Cartography and GIS Center, U. S. Department of Agriculture, Natural Resource Conservation Service, Fort Worth, TX.

[59] Johnson, J. W., L. F. Welch, and L. T. Kurtz. 1975. Environmental implications of N fixation by soybeans. Journal of Environmental Quality 4: 303-306.

[60] Cole, D. W., and M. Rapp. 1981. Elemental cycling in forest ecosystem, pp. 341-409. IN (D. E. Reichle, ed.) Dynamic Properties of Forest Ecosystems. Cambridge University Press, Cambridge.

[61] Robertson, G. P., and J. M. Tiedje. 1984. Denitrification and nitrous oxide production in successional and old-growth Michigan forests. Soil Science Society America Journal 48: 383-389.

[62] Zak, D. R., and D. F. Grigal. 1991. Nitrogen mineralization, nitrification and denitrification in upland and wetland ecosystems. Oecologia 88: 189-196.

[63] Groffman, P. M., E. A. Axelrod, J. L. Lemunyon, and W. M. Sullivan. 1991. Denitrification in grass and forest vegetated filter strips. Journal of Environmental Quality 20: 671-674.

[64] Ryden, J. C. 1983. Denitrification loss from a grassland soil in the field receiving different rates of nitrogen as ammonium nitrate. Journal of Soil Science 34: 355-365.

[65] Colbourn, P., and R. J. Dowdell. 1984. Denitrification in field soils. Plant and Soil 76: 213-226.

[66] Sexstone, A. J., T. B. Parkin, and J. M. Tiedje. 1985. Temporal response of soil denitrification rates to rainfall and irrigation. Soil Science Society America Journal 49: 99-103.

[67] Groffman, P. M., and J. M. Tiedje. 1988. Denitrification hysteresis during wetting and drying cycles in soil. Soil Science Society America Journal 52: 1626-1629.

[68] Groffman, P. M., and J. M. Tiedje. 1988. Denitrification hysteresis during wetting and drying cycles in soil. Soil Science Society America Journal 52: 1626-1629.

[69] Struwe, S., and A. Kjoller. 1990. Seasonality of denitrification in water-logged alder stands. Plant and Soil 128: 109-113.

[70] Pinay, G., L. Roques, and A. Fabre. 1993. Spatial and temporal patterns of denitrification in a riparian forest. Journal of Applied Ecology 30: 581-591.

[71] Sexstone, A. J., T. B. Parkin, and J. M. Tiedje. 1985. Temporal response of soil denitrification rates to rainfall and irrigation. Soil Science Society America Journal 49: 99-103.

[72] Groffman, P. M., and J. M. Tiedje. 1988. Denitrification hysteresis during wetting and drying cycles in soil. Soil Science Society America Journal 52: 1626-1629.

[73] Barton, L., C. D. A. McLay, L. A. Schipper, and C. T. Smith. 1999. Annual denitrification rates in agricultural and forest soils: a review. Australian Journal of Soil Research 37: 1073-1093.

[74] Robertson, G. P., and J. M. Tiedje. 1984. Denitrification and nitrous oxide production in successional and old-growth Michigan forests. Soil Science Society America Journal 48: 383-389.

[75] Reddy, K. R., and W. H. Patrick, Jr. 1984. Nitrogen transformations and loss in flooded soils and sediments. CRC Critical Reviews in Environmental Control 13: 273-309.

[76] Hargrove, W. W., and W. M. Post. 1998. A high-resolution nitrogen map produced by linking NCSD with STATSGO. 1998 Annual Meeting Abstracts American Society of Agronomy (90th annual Meeting), p. 253.

[77] ESRI. 1998. ARC Version 7.2.1. Environmental Systems Research Institute, Inc., Redlands, CA.

[78] Bueschen, E. 1998. *Pfiesteria piscicida*: a regional symptom of a national problem. The Environmental Law Reporter 28: 10317-10330.

[79] Cahoon, L. B., J. A. Mikucki, and M. A. Mallin. 1999. Nitrogen and phosphorus imports to the Cape Fear and Neuse River Basins to support intensive livestock production. Environmental Science and Technology 33: 410-415.

[80] McMahon, G., and M. D. Woodside. 1997. Nutrient mass balance for the Albemarle-Pamlico drainage basin, North Carolina and Virginia, 1990. Journal of the American Water Resources Association 33: 573-589.

[81] Pardo, L. H., and C. T. Driscoll. 1993. A critical review of mass balance methods for calculating critical loads of nitrogen for forested ecosystems. Environmental Reviews 1: 145-156.

[82] Jaworski, N. A., P. M. Groffman, A. A. Keller, and J. C. Prager. 1992. A watershed nitrogen and phosphorus balance: the Upper Potomac River Basin. Estuaries 15: 83-95.

[83] Kesner, B. T., and V. Meentemeyer. 1989. A regional analysis of total nitrogen in an agricultural landscape. Landscape Ecology 2: 151-163.

[84] Poiani, K. A., B. L. Bedford, and M. D. Merrill. 1996. A GIS-based index for relating landscape characteristics to potential nitrogen leaching to wetlands. Landscape Ecology 11: 237-255.

[85] Burkart, M. R., and D. E. James. 1999. Agricultural-nitrogen contributions to hypoxia in the Gulf of Mexico. Journal of Environmental Quality 28: 850-859.

[86] Moal, J.-F., J. Martinez, F. Guiziou, and C.-M. Coste. 1995. Ammonia volatilization following surface-applied pig and cattle slurry in France. Journal of Agricultural Science, Cambridge 125: 245-252.

[87] DEHNR (Division of Air Quality, North Carolina Department of Environment, Health, and Natural Resources). 1997. Assessment Plan for Atmospheric Nitrogen Compounds: Emissions, Transport, Transformation, and Fate. IN (V. P. Aneja, G. Murray, and J. Southerland, eds.) Proceedings of the Workshop on Atmospheric Nitrogen Compound, March 1997, North Carolina State University.

[88] Aneja, V. P., C. Murray, and J. Southerland. 1999. Proceedings of Workshop on Atmospheric Nitrogen Compounds II: Emissions, Transport, Deposition, and Assessment. June 7-9, 1999, Chapel Hill, North Carolina.

APPENDIX I. Literature review of annual net soil N mineralization. RN = record number; SITE = state abbreviation or other geographic location; BRIEF DESCRIPTION = vegetation cover; LULC = forest (F), agriculture (A), herbaceous (G), emergent wetland (EW), woody wetland (WW); L/F = laboratory (L) or field (F) study; M = potential net soil N mineralization; Mr = annual rate of net soil N mineralization; SOIL = soil depth (cm); SOIL N = soil N inventory; REF = reference source.

RN	SITE	BRIEF DESCRIPTION	LULC	L/F	M	UNITS	Mr yr-1	SOIL (cm)	SOIL N g N m-2	REF
1	WI	Red Pine	F	F	2.80	g N m-2	.	15	.	AB85
2	WI	White Pine	F	F	5.20	g N m-2	.	15	.	AB85
3	WI	Red Oak	F	F	7.80	g N m-2	.	15	.	AB85
4	WI	White Oak	F	F	8.40	g N m-2	.	15	.	AB85
5	WI	Sugar Maple	F	F	12.50	g N m-2	.	15	.	AB85
6	MA	Red Pine	F	F	8.10	g N m-2	.	.	.	AB85
7	MA	Oak-Maple	F	F	9.30	g N m-2	.	.	.	AB85
8	WI	Red Pine	F	F	3.90	g N m-2	.	20	.	AB85
9	WI	White Pine	F	F	8.60	g N m-2	.	20	.	AB85
10	WI	Sugar Maple	F	F	9.40	g N m-2	.	20	.	AB85
11	WI	White Oak	F	F	9.90	g N m-2	.	20		AB85
12	WI	Red Oak	F	F	12.50	g N m-2	.	20		AB85
13	WI	Black Oak	F	F	13.50	g N m-2	.	20		AB85
23	IL	Soybean	A	.	3.61	g N m-2	.	.	.	DA97
24	IL	Soybean	A	.	3.61	g N m-2	.	.	.	DA97
25	IL	Soybean	A	.	3.62	g N m-2	.	.	.	DA97
26	IL	Soybean	A	.	3.68	g N m-2	.	.	.	DA97
27	IL	Soybean	A	.	3.68	g N m-2	.	.	.	DA97
28	IL	Soybean	A	.	3.87	g N m-2	.	.	.	DA97
29	IL	Corn	A	.	5.72	g N m-2	.	.	.	DA97
30	IL	Corn	A	.	5.97	g N m-2	.	.	.	DA97
31	IL	Corn	A	.	6.06	g N m-2	.	.	.	DA97
32	IL	Corn	A	.	6.16	g N m-2	.	.	.	DA97
33	IL	Corn	A	.	6.19	g N m-2	.	.	.	DA97
34	IL	Corn	A	.	6.31	g N m-2	.	.	.	DA97
35	CA	Conifer	F	F	1.20	g N m-2	0.007	18	172	FR90
36	CA	Conifer	F	F	3.10	g N m-2	0.018	18	171	FR90

37	CA	Conifer	F	F	4.90	g	N	m-2	0.024	18	203	FR90
38	TN	Forest (Decid)	F	L	7.64	g	N	m-2	0.076	7	100	GA94
39	TN	Forest (Decid)	F	L	7.64	g	N	m-2	0.070	7	109	GA94
40	TN	Forest (Decid)	F	L	7.64	g	N	m-2	0.070	7	109	GA94
41	TN	Forest (Decid)	F	L	7.64	g	N	m-2	0.056	7	137	GA94
42	TN	Forest (Decid)	F	L	9.30	g	N	m-2	0.102	7	91	GA94
43	TN	Forest (Decid)	F	L	9.30	g	N	m-2	0.102	7	91	GA94
44	TN	Forest (Decid)	F	L	9.30	g	N	m-2	0.093	7	100	GA94
45	TN	Forest (Decid)	F	L	9.30	g	N	m-2	0.093	7	100	GA94
46	TN	Forest (Decid)	F	L	9.30	g	N	m-2	0.068	7	137	GA94
47	TN	Forest (Decid)	F	L	9.30	g	N	m-2	0.068	7	137	GA94
48	TN	Forest (Decid)	F	L	10.96	g	N	m-2	0.075	7	146	GA94
49	TN	Forest (Decid)	F	L	10.96	g	N	m-2	0.075	7	146	GA94
50	TN	Forest (Decid)	F	L	10.96	g	N	m-2	0.075	7	146	GA94
51	TN	Forest (Decid)	F	L	10.96	g	N	m-2	0.071	7	155	GA94
52	TN	Forest (Decid)	F	L	10.96	g	N	m-2	0.071	7	155	GA94
53	TN	Forest (Decid)	F	L	10.96	g	N	m-2	0.063	7	173	GA94
54	TN	Forest (Decid)	F	L	17.27	g	N	m-2	0.079	7	218	GA94
55	TN	Forest (Decid)	F	L	17.27	g	N	m-2	0.076	7	228	GA94
64	MI	Maple-Red Oak	F	F	13.00	g	N	m-2	.	15	.	HO94
65	MI	Maple-Basswood	F	F	14.30	g	N	m-2	.	15	.	HO94
76	WI	Sugar Maple	F	F	2.60	g	N	m-2	0.006	19	428	LE85
77	WI	Sugar Maple	F	F	3.40	g	N	m-2	0.011	26	316	LE85
78	WI	Sugar Maple	F	F	4.10	g	N	m-2	0.012	21	353	LE85
79	WI	Sugar Maple	F	F	4.10	g	N	m-2	0.011	23	372	LE85
80	WI	Sugar Maple	F	F	6.40	g	N	m-2	0.012	28	521	LE85
81	WI	Sugar Maple	F	F	8.40	g	N	m-2	0.023	23	372	LE85
82	WI	Sugar Maple	F	F	9.40	g	N	m-2	0.027	30	353	LE85
89	WI	Red Pine	F	F	3.24	g	N	m-2	0.018	10	177	NA83
90	WI	Spruce	F	F	4.73	g	N	m-2	0.027	10	175	NA83
91	WI	Mixed Pine	F	F	5.01	g	N	m-2	0.034	10	147	NA83
92	WI	Birch	F	F	5.14	g	N	m-2	0.025	10	206	NA83
93	WI	Maple	F	F	6.21	g	N	m-2	0.035	10	175	NA83
94	WI	White Pine	F	F	8.97	g	N	m-2	0.055	10	162	NA83
95	WI	White Oak	F	F	9.10	g	N	m-2	0.048	10	189	NA83
96	WI	Red Oak	F	F	10.00	g	N	m-2	0.039	10	259	NA83

97	WI	Black Oak	F	F	11.13	g N m-2	0.079	10	141	NA83
98	WI	Red Pine	F	F	3.90	g N m-2	0.010	20	378	NA85
99	WI	Spruce	F	F	5.80	g N m-2	0.015	20	400	NA85
100	WI	Mixed Pine	F	F	6.10	g N m-2	0.021	20	297	NA85
101	WI	White Pine	F	F	8.10	g N m-2	0.021	20	395	NA85
102	WI	Birch	F	F	8.40	g N m-2	0.020	20	428	NA85
103	WI	Maple	F	F	9.40	g N m-2	0.025	20	371	NA85
104	WI	White Oak	F	F	9.90	g N m-2	0.020	20	490	NA85
105	WI	Red Oak	F	F	12.50	g N m-2	0.034	20	371	NA85
106	WI	Black Oak	F	F	13.50	g N m-2	0.043	20	315	NA85
107	WI	Red Pine	F	F	2.60	g N m-2	.	4	.	PA84
108	WI	White Pine	F	F	2.60	g N m-2	.	4	.	PA84
109	WI	Hemlock	F	F	2.90	g N m-2	.	4	.	PA84
110	WI	Red Oak	F	F	3.90	g N m-2	.	4	.	PA84
111	WI	White Pine	F	F	3.90	g N m-2	.	4	.	PA84
112	WI	Red Oak	F	F	5.30	g N m-2	.	4	.	PA84
113	WI	White Oak	F	F	5.30	g N m-2	.	4	.	PA84
114	WI	Red Oak	F	F	6.00	g N m-2	.	4	.	PA84
115	WI	Sugar Maple	F	F	6.00	g N m-2	.	4	.	PA84
116	WI	White Oak	F	F	6.00	g N m-2	.	4	.	PA84
117	WI	Red Oak	F	F	6.70	g N m-2	.	4	.	PA84
118	WI	White Oak	F	F	6.70	g N m-2	.	4	.	PA84
119	WI	White Pine	F	F	6.70	g N m-2	.	4	.	PA84
120	WI	Basswood	F	F	7.80	g N m-2	.	4	.	PA84
121	WI	Red Oak	F	F	7.80	g N m-2	.	4	.	PA84
122	WI	Sugar Maple	F	F	7.80	g N m-2	.	4	.	PA84
123	WI	White Oak	F	F	7.80	g N m-2	.	4	.	PA84
124	WI	Basswood	F	F	8.40	g N m-2	.	4	.	PA84
125	WI	Red Oak	F	F	8.40	g N m-2	.	4	.	PA84
126	WI	Sugar Maple	F	F	8.40	g N m-2	.	4	.	PA84
127	WI	White Ash	F	F	8.40	g N m-2	.	4	.	PA84
128	MN	Oldfield (fert.)	G	F	7.50	g N m-2	0.100	10	70	PA87
129	MN	Oldfield (fert.)	G	F	3.00	g N m-2	0.050	10	77	PA87
130	MN	Oldfield (fert.)	G	F	3.00	g N m-2	0.050	10	77	PA87
131	MN	Oldfield (control)	G	F	4.00	g N m-2	0.060	10	77	PA87
132	MN	Oldfield (control)	G	F	4.50	g N m-2	0.065	10	70	PA87

133	MN	Oldfield (control)	G	F	5.00	g N m-2	0.045	10	104	PA87
134	MN	Oldfield (fert.)	G	F	6.00	g N m-2	0.060	10	104	PA87
135	MN	Oldfield (fert.)	G	F	6.00	g N m-2	0.060	10	104	PA87
136	MN	Oldfield (control)	G	F	6.50	g N m-2	0.045	10	137	PA87
137	MN	Oldfield (fert.)	G	F	12.00	g N m-2	0.090	10	137	PA87
138	MN	Oldfield (fert.)	G	F	7.50	g N m-2	0.100	10	70	PA87
139	MN	Oldfield (fert.)	G	F	12.00	g N m-2	0.090	10	137	PA87
140	FL	Loblolly Pine (R)	F	F	0.01	g N m-2	.	5	.	PO92
141	FL	Loblolly Pine (W)	F	F	0.28	g N m-2	.	5	.	PO92
142	FL	Slash Pine (W)	F	F	0.28	g N m-2	.	5	.	PO92
143	FL	Loblolly Pine (F)	F	F	0.42	g N m-2	.	5	.	PO92
144	FL	Loblolly Pine (WF)	F	F	0.45	g N m-2	.	5	.	PO92
145	FL	Cultivated Soil	A	L	82.80	g N m-2	0.027	30	3119	RE82
146	FL	Cultivated Soil	A	L	74.00	g N m-2	0.021	30	3533	RE82
147	FL	Cultivated Soil	A	L	72.80	g N m-2	0.029	30	2495	RE82
148	FL	Virgin Soil	EW	L	87.40	g N m-2	0.087	30	1008	RE82
149	FL	Cultivated Soil	A	L	41.00	.	0.021	30	1962	RE82
150	FL	Cultivated Soil	A	L	93.80	.	0.023	30	4115	RE82
151	FL	Virgin Soil	EW	L	125.00	.	0.034	30	3662	RE82
214	NC	Hardwoods	F	.	.	.	0.015	10	.	VA92
215	NC	White Pine	F	.	.	.	0.070	10	.	VA92
216	NC	Loblolly Pine	F	.	.	.	0.045	10	.	VA92
217	WA	Hemlock	F	.	.	.	0.005	10	.	VA92
218	NY	Hardwoods	F	.	.	.	0.040	10	.	VA92
219	TN	Loblolly Pine	F	.	.	.	0.025	10	.	VA92
220	WA	Douglas Fir	F	.	.	.	0.015	10	.	VA92
221	Ont.	Hardwoods	F	.	.	.	0.045	10	.	VA92
239	NC	Loblolly Pine	F	F	2.60	g N m-2	0.015	15	170	VI85
240	NC	Loblolly Pine	F	L	5.60	g N m-2	0.033	15	170	VI85
241	NC	Clear-Cut Pine	F	F	7.65	g N m-2	0.039	15	195	VI85
242	NC	Clear-Cut Pine	F	F	8.10	g N m-2	0.045	15	180	VI85
243	NC	Clear-Cut Pine	F	F	8.55	g N m-2	0.052	15	165	VI85
244	NC	Clear-Cut Pine	F	F	8.95	g N m-2	0.054	15	165	VI85
245	NC	Clear-Cut Pine	F	F	10.50	g N m-2	0.057	15	183	VI85
246	NC	Clear-Cut Pine	F	L	10.75	g N m-2	0.065	15	165	VI85
247	NC	Clear-Cut Pine	F	L	10.95	g N m-2	0.056	15	195	VI85

248	NC	Clear-Cut Pine	F	L	11.10	g N m-2	0.062	15	180 VI85
249	NC	Clear-Cut Pine	F	L	11.20	g N m-2	0.068	15	165 VI85
250	NC	Clear-Cut Pine	F	F	11.50	g N m-2	0.080	15	144 VI85
251	NC	Clear-Cut Pine	F	L	12.35	g N m-2	0.086	15	144 VI85
252	NC	Clear-Cut Pine	F	L	14.80	g N m-2	0.081	15	183 VI85
301	MI	Oak	F	L	12.27	g N m-2	0.039	2.5	319 ZA86
302	MI	Maple-Oak	F	L	22.64	g N m-2	0.071	2.5	320 ZA86
303	MI	Maple-Basswood	F	L	30.00	g N m-2	0.056	2.5	531 ZA86
313	MI	Maple-Basswood	F	F	8.09	g N m-2	0.013	3.8	635 ZA90
314	MI	Oak	F	F	8.35	g N m-2	0.017	3.8	497 ZA90
315	MI	Oak	F	F	7.01	g N m-2	0.017	3.8	403 ZA90
316	MI	Oak	F	F	9.18	g N m-2	0.016	3.8	557 ZA90
317	MI	Maple-Oak	F	F	8.62	g N m-2	0.020	3.8	435 ZA90
318	MI	Maple-Oak	F	F	11.11	g N m-2	0.024	3.8	455 ZA90
319	MI	Maple-Oak	F	F	10.52	g N m-2	0.019	3.8	556 ZA90
320	MI	Maple-Basswood	F	F	12.74	g N m-2	0.014	3.8	930 ZA90
321	MI	Maple-Basswood	F	F	11.78	g N m-2	0.016	3.8	755 ZA90
322	MN	Swamp Forest	WW	F	1.20	g N m-2	0.003	10	344 ZA91
323	MN	Swamp Forest	WW	F	1.80	g N m-2	0.005	10	344 ZA91
324	MN	Old Field	G	F	2.30	g N m-2	0.022	10	106 ZA91
325	MN	Savanna	G	F	3.40	g N m-2	0.027	10	125 ZA91
326	MN	Old Field	G	F	4.80	g N m-2	0.045	10	106 ZA91
327	MN	Savanna	G	F	5.00	g N m-2	0.040	10	125 ZA91
328	MN	Upland Oak	F	F	7.20	g N m-2	0.049	10	146 ZA91
329	MN	Upland Oak	F	F	10.00	g N m-2	0.068	10	146 ZA91
340	.	Norway spruce	F	F	9.70	g N m-2	0.023	.	430 GU91
341	.	Norway spruce	F	F	2.60	g N m-2	0.008	.	330 GU91
342	Can.	Maple	F	F	7.42	g N m-2	0.040	8	186 HI89
343	Can.	Maple	F	F	11.35	g N m-2	0.061	8	186 HI89
344	Can.	Pine	F	F	1.79	g N m-2	0.018	8	98 HI89
345	Can.	Pine	F	F	2.88	g N m-2	0.029	8	98 HI89
346	Can.	Hemlock	F	F	0.12	g N m-2	0.001	8	237 HI89
347	Can.	Hemlock	F	F	0.55	g N m-2	0.002	8	237 HI89
354	Aust.	Pinus radiata	F	F	2.60	g N m-2	0.011	20	231 CA98
355	Aust.	Pinus radiata	F	F	4.70	g N m-2	0.019	20	242 CA98
356	Aust.	Pinus radiata	F	F	4.00	g N m-2	0.068	20	58 CA98

357	Aust.	Pinus radiata	F	F	3.10	g N m-2	0.018	20	173	CA98
358	Aust.	Pinus radiata	F	F	2.70	g N m-2	0.013	20	206	CA98
359	Aust.	Pinus radiata	F	F	2.70	g N m-2	0.049	20	56	CA98
360	Aust.	Pinus radiata	F	F	4.30	g N m-2	0.023	20	189	CA98
361	Aust.	Pinus radiata	F	F	9.40	g N m-2	0.036	20	265	CA98
362	Aust.	Pinus radiata	F	F	8.50	g N m-2	0.015	20	552	CA98
363	Aust.	Pinus radiata	F	F	7.50	g N m-2	0.072	20	104	CA98
364	Aust.	Pinus radiata	F	F	2.30	g N m-2	0.010	20	232	CA98
365	WI	Spruce	F	F	4.60	g N m-2	.	20	.	GO92
367	WI	Red pine	F	F	5.10	g N m-2	.	20	.	GO92
368	WI	Red oak	F	F	5.50	g N m-2	.	20	.	GO92
369	WI	White pine	F	F	8.70	g N m-2	.	20	.	GO92
370	WI	Larch	F	F	11.70	g N m-2	.	20	.	GO92
371	MN	Agrostis scabra	G	F	2.50	g N m-2	0.037	23	69	WE90
372	MN	Agrostis scabra	G	F	2.50	g N m-2	0.037	23	69	WE90
373	MN	Agrostis scabra	G	F	4.50	g N m-2	0.066	23	69	WE90
374	MN	Agrostis scabra	G	F	4.00	g N m-2	0.024	23	168	WE90
375	MN	Agrostis scabra	G	F	6.00	g N m-2	0.036	23	168	WE90
376	MN	Agrostis scabra	G	F	7.00	g N m-2	0.042	23	168	WE90
377	MN	Agrostis scabra	G	F	6.50	g N m-2	0.020	23	323	WE90
378	MN	Agrostis scabra	G	F	11.00	g N m-2	0.034	23	323	WE90
379	MN	Agrostis scabra	G	F	12.00	g N m-2	0.037	23	323	WE90
380	MN	Agropyron repens	G	F	2.50	g N m-2	0.037	23	69	WE90
381	MN	Agropyron repens	G	F	3.00	g N m-2	0.044	23	69	WE90
382	MN	Agropyron repens	G	F	3.00	g N m-2	0.044	23	69	WE90
383	MN	Agropyron repens	G	F	4.50	g N m-2	0.027	23	168	WE90
384	MN	Agropyron repens	G	F	3.50	g N m-2	0.021	23	168	WE90
385	MN	Agropyron repens	G	F	3.00	g N m-2	0.018	23	168	WE90
386	MN	Agropyron repens	G	F	8.00	g N m-2	0.025	23	323	WE90
387	MN	Agropyron repens	G	F	5.50	g N m-2	0.017	23	323	WE90
388	MN	Agropyron repens	G	F	4.00	g N m-2	0.012	23	323	WE90
389	MN	Poa pratensis	G	F	3.50	g N m-2	0.051	23	69	WE90
390	MN	Poa pratensis	G	F	3.00	g N m-2	0.044	23	69	WE90
391	MN	Poa pratensis	G	F	3.00	g N m-2	0.044	23	69	WE90
392	MN	Poa pratensis	G	F	6.00	g N m-2	0.036	23	168	WE90
393	MN	Poa pratensis	G	F	4.00	g N m-2	0.024	23	168	WE90

394	MN	Poa pratensis	G	F	3.00	g N m-2	0.018	23	168	WE90
395	MN	Poa pratensis	G	F	10.00	g N m-2	0.031	23	323	WE90
396	MN	Poa pratensis	G	F	7.00	g N m-2	0.022	23	323	WE90
397	MN	Poa pratensis	G	F	3.00	g N m-2	0.009	23	323	WE90
398	MN	Schizachyrium	G	F	2.00	g N m-2	0.029	23	69	WE90
399	MN	Schizachyrium	G	F	1.50	g N m-2	0.022	23	69	WE90
400	MN	Schizachyrium	G	F	1.50	g N m-2	0.022	23	69	WE90
401	MN	Schizachyrium	G	F	3.50	g N m-2	0.021	23	168	WE90
402	MN	Schizachyrium	G	F	2.00	g N m-2	0.012	23	168	WE90
403	MN	Schizachyrium	G	F	1.50	g N m-2	0.009	23	168	WE90
404	MN	Schizachyrium	G	F	5.50	g N m-2	0.017	23	323	WE90
405	MN	Schizachyrium	G	F	2.50	g N m-2	0.008	23	323	WE90
406	MN	Schizachyrium	G	F	1.00	g N m-2	0.003	23	323	WE90
407	MN	Andropogon	G	F	2.00	g N m-2	0.029	23	69	WE90
408	MN	Andropogon	G	F	1.50	g N m-2	0.022	23	69	WE90
409	MN	Andropogon	G	F	1.50	g N m-2	0.022	23	69	WE90
410	MN	Andropogon	G	F	2.00	g N m-2	0.012	23	168	WE90
411	MN	Andropogon	G	F	2.00	g N m-2	0.012	23	168	WE90
412	MN	Andropogon	G	F	1.50	g N m-2	0.009	23	168	WE90
413	MN	Andropogon	G	F	3.00	g N m-2	0.009	23	323	WE90
414	MN	Andropogon	G	F	2.00	g N m-2	0.006	23	323	WE90
415	MN	Andropogon	G	F	2.00	g N m-2	0.006	23	323	WE90
416	MN	Oak	F	F	5.66	g N m-2	0.026	15	218	GR94
417	MN	Pine oak	F	F	6.62	g N m-2	0.032	15	208	GR94
418	MN	Mesic hardwoods	F	F	5.01	g N m-2	0.023	15	216	GR94
419	MN	White cedar	F	F	0.10	g N m-2	0.000	15	318	GR94
420	MN	Hardwoods	F	F	1.62	g N m-2	0.003	15	467	GR94
421	MN	Savanna	G	F	1.87	g N m-2	0.012	15	162	GR94
422	MA	Red pine	F	F	8.55	g N m-2	0.021	10	406	AB93
423	MA	Red pine	F	F	7.51	g N m-2	0.019	10	406	AB93
424	MA	Red pine	F	F	10.76	g N m-2	0.027	10	406	AB93
425	MA	Red pine	F	F	8.37	g N m-2	0.021	10	406	AB93
426	MA	Red pine	F	F	13.51	g N m-2	0.033	10	406	AB93
427	MA	Red pine	F	F	10.78	g N m-2	0.027	10	406	AB93
428	MA	Hardwood	F	F	7.09	g N m-2	0.014	10	508	AB93
429	MA	Hardwood	F	F	7.00	g N m-2	0.014	10	508	AB93

430	MA	Hardwood	F	F	8.34	g N m-2	0.016	10	508	AB93
431	MA	Hardwood	F	F	6.56	g N m-2	0.013	10	508	AB93
432	MA	Hardwood	F	F	9.99	g N m-2	0.020	10	508	AB93
433	MA	Hardwood	F	F	9.22	g N m-2	0.018	10	508	AB93
434	MN	Bog	EW	L	.	.	0.110	.	.	BR98
435	MN	Acidic fen	EW	L	.	.	0.101	.	.	BR98
436	MN	Intermed. fen	EW	L	.	.	0.031	.	.	BR98
437	MN	Cedar swamp	WW	L	.	.	0.044	.	.	BR98
438	MN	Tamar. swamp	WW	L	.	.	0.062	.	.	BR98
439	MN	Meadow	EW	L	.	.	0.070	.	.	BR98
440	MI	Agriculture	A	L	.	g N m-2	0.098	.	.	CH98
441	MI	Agriculture	A	L	.	g N m-2	0.092	.	.	CH98
442	MI	Agriculture	A	L	.	g N m-2	0.074	.	.	CH98
443	MI	Agriculture	A	L	.	g N m-2	0.088	.	.	CH98
444	MI	Agriculture	A	L	.	g N m-2	0.085	.	.	CH98
445	MI	Agriculture	A	L	.	g N m-2	0.080	.	.	CH98
446	MI	Agricultural soil	A	L	.	.	0.123	.	.	CH98
447	MI	Agricultural soil	A	L	.	.	0.105	.	.	CH98
448	MI	Agricultural soil	A	L	.	.	0.081	.	.	CH98
449	MI	Agricultural soil	A	L	.	.	0.102	.	.	CH98
450	MI	Agricultural soil	A	L	.	.	0.112	.	.	CH98
451	MI	Agricultural soil	A	L	.	.	0.090	.	.	CH98
452	MI	Agricultural soil	A	L	.	.	0.059	.	.	CH98
453	MI	Agricultural soil	A	L	.	.	0.117	.	.	CH98
454	MI	Agricultural soil	A	L	.	.	0.095	.	.	CH98
455	MI	Agricultural soil	A	L	.	.	0.098	.	.	CH98
456	MI	Agricultural soil	A	L	.	.	0.040	.	.	CH98
		End of File								

APPENDIX I REFERENCES

AB85 Aber, J. D., J. M. Melillo, K. J. Nadelhoffer, C. A. McClaugherty, and J. Pastor. 1985. Fine root turnover in forest ecosystems in relation to quantity and form of nitrogen availability: a comparison of two methods. Oecologia (Berlin) 66: 317-321.

AB93 Aber, J. D., A. Magill, R. Boone, J. M. Melillo, P. Steudler, and R. Bowden. 1993. Plant and soil responses to chronic nitrogen additions at the Harvard Forest, Massachusetts. Ecological Applications 3: 156-166.

BR98 Bridgham, S. D., K. Updegraff, and J. Pastor. 1998. Carbon, nitrogen, and phosphorus mineralization in northern wetlands. Ecology 79: 1545-1561.

CA98 Carlyle, J. C., E. K. S. Nambiar, and M. W. Bligh. 1998. The use of laboratory measurements to predict nitrogen mineralization and nitrification in Pinus radiata plantations after harvesting. Canadian Journal of Forest Research 28: 1213-1221.

CH98 Christenson, D. R., and M. B. Butt. 1998. Nitrogen mineralization in soils from Michigan's Saginaw Valley and Thumb Region. Communications in Soil Science and Plant Analysis 29: 2355-2363.

DA97 David, M. B., L. E. Gentry, D. A. Kovacic, and K. M. Smith. 1997. Nitrogen balance in and export from an agricultural watershed. Journal of Environmental Quality 26: 1038-1048.

FR90 Frazer, D. W., J. G. McColl, and R. F. Powers. 1990. Soil nitrogen mineralization in a clearcutting chronosequence in a northern California conifer forest. Soil Science Society America Journal 54: 1145-1152.

GA94 Garten, C. T., Jr., M. A. Huston, and C. A. Thoms. 1994. Topographic variation of soil nitrogen dynamics at Walker Branch Watershed, Tennessee. Forest Science 40: 497-512.

GO92 Gower, S. T., and Y. Son. 1992. Differences in soil and leaf litterfall nitrogen dynamics for five forest plantations. Soil Science Society America Journal 56: 1959-1966.

GR94 Grigal, D. F., and P. S. Homann. 1994. Nitrogen mineralization, groundwater dynamics, and forest growth on a Minnesota outwash landscape. Biogeochemistry 27: 171-185.

GU91 Gundersen, P. 1991. Nitrogen deposition and the forest nitrogen cycle: role of denitrification. Forest Ecology and Management 44: 15-28.

HI89 Hill, A. R., and M. Shackleton. 1989. Soil N mineralization and nitrification in relation to nitrogen solution chemistry in a small forested watershed. Biogeochemistry 8: 167-184.

HO94 Holmes, W. E., and D. R. Zak. 1994. Soil microbial biomass dynamics and net nitrogen mineralization in northern hardwood ecosystems. Soil Science Society America Journal 58: 238-243.

LE85 Lennon, J. M., J. D. Aber, and J. M. Melillo. 1985. Primary production and nitrogen allocation of field grown sugar maple in relation to nitrogen availability. Biogeochemistry 1: 135-154.

NA83 Nadelhoffer, K. J., J. D. Aber, and J. M. Melillo. 1983. Leaf-litter production and soil organic matter dynamics along a nitrogen-availability gradient in Southern Wisconsin (U.S.A.). Canadian Journal of Forest Research 13: 12-21.

NA85 Nadelhoffer, K. J., J. D. Aber, and J. M. Melillo. 1985. Fine roots, net primary production, and nitrogen availability: a new hypothesis. Ecology 66: 1377-1390.

PA84 Pastor, J., J. D. Aber, C. A. McClaugherty, and J. M. Melillo. 1984. Above-ground production and N and P cycling along a nitrogen mineralization gradient on Blackhawk Island, Wisconsin. Ecology 65: 256-268.

PA87 Pastor, J., M. A. Stillwell, and D. Tilman. 1987. Nitrogen mineralization and nitrification in four Minnesota old fields. Oecologia 71: 481-485.

PO92 Polglase, P. J., N. B. Comerford, and E. J. Jokela. 1992. Mineralization of nitrogen and phosphorus from soil organic matter in southern pine plantations. Soil Science Society America Journal 56: 921-927.

RE82 Reddy, K. R. 1982. Mineralization of nitrogen in organic soils. Soil Science Society America Journal 46: 561-566.

VA92 Van Miegroet, H., D. W. Cole, and N. W. Foster. 1992. Nitrogen distribution and cycling, pp. 178-196. IN (Johnson, D. W., and S. E. Lindberg,eds.) Atmospheric Deposition and Forest Nutrient Cycling: A Synthesis of the Integrated Forest Study. Springer-Verlag, New York.

VI85 Vitousek, P. M., and P. A. Matson. 1985. Disturbance, nitrogen availability, and nitrogen losses in an intensively managed loblolly pine plantation. Ecology 66: 1360-1376.

WE90 Wedin, D. A., and D. Tilman. 1990. Species effects on nitrogen cycling: a test with perennial grasses. Oecologia 84: 433-441.

ZA86 Zak, D. R., K. S. Pregitzer, and G. E. Host. 1986. Landscape variation in nitrogen mineralization and nitrification. Canadian Journal of Forest Research 16: 1258-1263.

ZA90 Zak, D. R., and K. S. Pregitzer. 1990. Spatial and temporal variability of nitrogen cycling in northern lower Michigan. Forest Science 36: 367-380.

ZA91 Zak, D. R., and D. F. Grigal. 1991. Nitrogen mineralization, nitrification and denitrification in upland and wetland ecosystems. Oecologia 88: 189-196.

APPENDIX II. Literature review of annual N uptake by plants. RN = record number; SITE = state abbreviation or other geographic location; BRIEF DESCRIPTION = vegetation cover; LULC = forest (F), agriculture (A), herbaceous (G), emergent wetland (EW), woody wetland (WW); SOIL TYPE = sand (S), loam (L), loamy sand (LS), silt loam (SIL), loam (L), sandy loam (SL), sandy clay loam (SCL), clay loam (CL); F = reported N fertilization (g N m^{-2}); U = annual N uptake by aboveground plant biomass; REF = reference source.

RN	SITE	BRIEF DESCRIPTION	LULC	SOIL TYPE	F	U	UNITS	REF
1	GA	Snap Bean	A	S	11.2	8.8	g N m-2	LO88
2	GA	Snap Bean	A	S	11.2	10.2	g N m-2	LO88
3	GA	Squash	A	S	10.3	7.1	g N m-2	LO88
4	GA	Squash	A	S	10.3	8.9	g N m-2	LO88
5	GA	Squash	A	S	10.3	10.4	g N m-2	LO88
6	GA	Squash	A	S	10.3	10.6	g N m-2	LO88
7	MA	Hardwood	F	.	0.0	10.3	g N m-2	AB83
8	MA	Pine	F	.	0.0	8.9	g N m-2	AB83
9	CA	Sugarbeets (ANP)	A	L	0.0	22.5	g N m-2	AB84
10	CA	Sugarbeets (ANP)	A	L	15.7	30.5	g N m-2	AB84
11	CA	Wheat	G	L	0.0	9.0	g N m-2	AB84
12	CA	Wheat	G	L	0.0	9.5	g N m-2	AB84
13	CA	Wheat	G	L	0.0	13.8	g N m-2	AB84
14	CA	Wheat	G	L	0.0	14.3	g N m-2	AB84
15	CA	Wheat	G	L	6.2	12.3	g N m-2	AB84
16	CA	Wheat	G	L	6.2	14.7	g N m-2	AB84
17	CA	Wheat	G	L	6.2	18.8	g N m-2	AB84
18	CA	Wheat	G	L	6.2	20.2	g N m-2	AB84
19	CA	Wheat	G	L	12.4	17.8	g N m-2	AB84
20	CA	Wheat	G	L	12.4	18.1	g N m-2	AB84
21	CA	Wheat	G	L	12.4	21.0	g N m-2	AB84
22	CA	Wheat	G	L	12.4	24.0	g N m-2	AB84
23	CA	Wheat	G	L	18.6	21.0	g N m-2	AB84
24	CA	Wheat	G	L	18.6	21.6	g N m-2	AB84
25	CA	Wheat	G	L	18.6	24.3	g N m-2	AB84
26	CA	Wheat	G	L	18.6	24.9	g N m-2	AB84
27	NC	Bermudagrass	G	LS	34.0	19.8	g N m-2	BU85

28	NC	Bermudagrass	G	LS	34.0	20.4	g N m-2	BU85
29	NC	Bermudagrass	G	LS	34.0	22.5	g N m-2	BU85
30	NC	Bermudagrass	G	LS	34.0	25.6	g N m-2	BU85
31	NC	Bermudagrass	G	LS	34.0	27.1	g N m-2	BU85
32	NC	Bermudagrass	G	LS	34.0	27.6	g N m-2	BU85
34	NC	Bermudagrass	G	LS	67.0	30.5	g N m-2	BU85
35	NC	Bermudagrass	G	LS	67.0	33.1	g N m-2	BU85
36	NC	Bermudagrass	G	LS	67.0	34.6	g N m-2	BU85
37	NC	Bermudagrass	G	LS	67.0	40.1	g N m-2	BU85
38	NC	Bermudagrass	G	LS	67.0	44.7	g N m-2	BU85
39	NC	Bermudagrass	G	LS	67.0	45.4	g N m-2	BU85
40	NC	Bermudagrass	G	LS	67.0	45.6	g N m-2	BU85
41	NC	Bermudagrass	G	LS	133.0	28.7	g N m-2	BU85
42	NC	Bermudagrass	G	LS	133.0	41.2	g N m-2	BU85
43	NC	Bermudagrass	G	LS	133.0	42.8	g N m-2	BU85
44	NC	Bermudagrass	G	LS	133.0	46.3	g N m-2	BU85
45	NC	Bermudagrass	G	LS	133.0	52.1	g N m-2	BU85
46	NC	Bermudagrass	G	LS	133.0	56.0	g N m-2	BU85
47	NC	Bermudagrass	G	LS	133.0	58.9	g N m-2	BU85
48	WI	Corn-Corn	A	LS	0.0	4.3	g N m-2	BU93
49	WI	Corn-Corn	A	LS	0.0	5.0	g N m-2	BU93
50	WI	Corn-Corn	A	LS	0.0	6.3	g N m-2	BU93
51	WI	Corn-Corn	A	LS	0.0	7.3	g N m-2	BU93
52	WI	Corn-Corn	A	SIL	0.0	9.9	g N m-2	BU93
53	WI	Corn-Corn	A	SIL	0.0	11.1	g N m-2	BU93
54	WI	Corn-Corn	A	SIL	0.0	14.6	g N m-2	BU93
55	WI	Corn-Corn	A	SIL	0.0	15.1	g N m-2	BU93
56	WI	Corn-Corn	A	SIL	0.0	6.4	g N m-2	BU93
57	WI	Corn-Corn	A	SIL	0.0	7.4	g N m-2	BU93
58	WI	Corn-Corn	A	SIL	0.0	11.9	g N m-2	BU93
59	WI	Corn-Corn	A	SIL	0.0	11.9	g N m-2	BU93
60	WI	Soybean-Corn	A	LS	0.0	5.4	g N m-2	BU93
61	WI	Soybean-Corn	A	LS	0.0	6.7	g N m-2	BU93
62	WI	Soybean-Corn	A	LS	0.0	7.4	g N m-2	BU93
63	WI	Soybean-Corn	A	LS	0.0	7.7	g N m-2	BU93
64	WI	Soybean-Corn	A	SIL	0.0	13.8	g N m-2	BU93

65	WI	Soybean-Corn	A	SIL	0.0	17.2	g N m-2	BU93
66	WI	Soybean-Corn	A	SIL	0.0	18.7	g N m-2	BU93
67	WI	Soybean-Corn	A	SIL	0.0	23.9	g N m-2	BU93
68	WI	Soybean-Corn	A	SIL	0.0	13.5	g N m-2	BU93
69	WI	Soybean-Corn	A	SIL	0.0	16.3	g N m-2	BU93
70	WI	Soybean-Corn	A	SIL	0.0	21.7	g N m-2	BU93
71	WI	Soybean-Corn	A	SIL	0.0	22.2	g N m-2	BU93
72	WI	Soybean-Corn-Corn	A	LS	0.0	3.0	g N m-2	BU93
73	WI	Soybean-Corn-Corn	A	LS	0.0	4.3	g N m-2	BU93
74	WI	Soybean-Corn-Corn	A	LS	0.0	8.2	g N m-2	BU93
75	WI	Soybean-Corn-Corn	A	SIL	0.0	8.4	g N m-2	BU93
76	WI	Soybean-Corn-Corn	A	SIL	0.0	10.7	g N m-2	BU93
77	WI	Soybean-Corn-Corn	A	SIL	0.0	12.2	g N m-2	BU93
78	WI	Soybean-Corn-Corn	A	SIL	0.0	8.4	g N m-2	BU93
79	WI	Soybean-Corn-Corn	A	SIL	0.0	10.3	g N m-2	BU93
80	WI	Soybean-Corn-Corn	A	SIL	0.0	12.6	g N m-2	BU93
81	WI	Corn-Corn	A	LS	4.5	6.2	g N m-2	BU93
82	WI	Corn-Corn	A	LS	4.5	8.0	g N m-2	BU93
83	WI	Corn-Corn	A	LS	4.5	9.5	g N m-2	BU93
84	WI	Corn-Corn	A	LS	4.5	9.7	g N m-2	BU93
85	WI	Corn-Corn	A	SIL	4.5	11.3	g N m-2	BU93
86	WI	Corn-Corn	A	SIL	4.5	12.5	g N m-2	BU93
87	WI	Corn-Corn	A	SIL	4.5	16.3	g N m-2	BU93
88	WI	Corn-Corn	A	SIL	4.5	16.5	g N m-2	BU93
89	WI	Corn-Corn	A	SIL	4.5	7.2	g N m-2	BU93
90	WI	Corn-Corn	A	SIL	4.5	12.9	g N m-2	BU93
91	WI	Corn-Corn	A	SIL	4.5	16.5	g N m-2	BU93
92	WI	Corn-Corn	A	SIL	4.5	18.4	g N m-2	BU93
93	WI	Soybean-Corn	A	LS	4.5	8.3	g N m-2	BU93
94	WI	Soybean-Corn	A	LS	4.5	8.4	g N m-2	BU93
95	WI	Soybean-Corn	A	LS	4.5	10.8	g N m-2	BU93
96	WI	Soybean-Corn	A	LS	4.5	11.4	g N m-2	BU93
97	WI	Soybean-Corn	A	SIL	4.5	16.6	g N m-2	BU93
98	WI	Soybean-Corn	A	SIL	4.5	19.9	g N m-2	BU93
99	WI	Soybean-Corn	A	SIL	4.5	25.0	g N m-2	BU93
100	WI	Soybean-Corn	A	SIL	4.5	25.1	g N m-2	BU93

101	WI	Soybean-Corn	A	SIL	4.5	13.0 g N m-2	BU93
102	WI	Soybean-Corn	A	SIL	4.5	22.4 g N m-2	BU93
103	WI	Soybean-Corn	A	SIL	4.5	23.9 g N m-2	BU93
104	WI	Soybean-Corn	A	SIL	4.5	26.5 g N m-2	BU93
105	WI	Soybean-Corn-Corn	A	LS	4.5	5.0 g N m-2	BU93
106	WI	Soybean-Corn-Corn	A	LS	4.5	6.3 g N m-2	BU93
107	WI	Soybean-Corn-Corn	A	LS	4.5	9.9 g N m-2	BU93
108	WI	Soybean-Corn-Corn	A	SIL	4.5	12.6 g N m-2	BU93
109	WI	Soybean-Corn-Corn	A	SIL	4.5	13.3 g N m-2	BU93
110	WI	Soybean-Corn-Corn	A	SIL	4.5	18.3 g N m-2	BU93
111	WI	Soybean-Corn-Corn	A	SIL	4.5	12.1 g N m-2	BU93
112	WI	Soybean-Corn-Corn	A	SIL	4.5	12.6 g N m-2	BU93
113	WI	Soybean-Corn-Corn	A	SIL	4.5	14.2 g N m-2	BU93
114	WI	Corn-Corn	A	LS	9.0	9.4 g N m-2	BU93
115	WI	Corn-Corn	A	LS	9.0	12.7 g N m-2	BU93
116	WI	Corn-Corn	A	LS	9.0	13.5 g N m-2	BU93
117	WI	Corn-Corn	A	LS	9.0	14.0 g N m-2	BU93
118	WI	Corn-Corn	A	SIL	9.0	13.7 g N m-2	BU93
119	WI	Corn-Corn	A	SIL	9.0	14.2 g N m-2	BU93
120	WI	Corn-Corn	A	SIL	9.0	19.6 g N m-2	BU93
121	WI	Corn-Corn	A	SIL	9.0	19.6 g N m-2	BU93
122	WI	Corn-Corn	A	SIL	9.0	12.2 g N m-2	BU93
123	WI	Corn-Corn	A	SIL	9.0	17.2 g N m-2	BU93
124	WI	Corn-Corn	A	SIL	9.0	20.4 g N m-2	BU93
125	WI	Corn-Corn	A	SIL	9.0	23.5 g N m-2	BU93
126	WI	Soybean-Corn	A	LS	9.0	11.4 g N m-2	BU93
127	WI	Soybean-Corn	A	LS	9.0	12.5 g N m-2	BU93
128	WI	Soybean-Corn	A	LS	9.0	12.8 g N m-2	BU93
129	WI	Soybean-Corn	A	LS	9.0	14.7 g N m-2	BU93
130	WI	Soybean-Corn	A	SIL	9.0	17.7 g N m-2	BU93
131	WI	Soybean-Corn	A	SIL	9.0	21.5 g N m-2	BU93
132	WI	Soybean-Corn	A	SIL	9.0	22.6 g N m-2	BU93
133	WI	Soybean-Corn	A	SIL	9.0	26.2 g N m-2	BU93
134	WI	Soybean-Corn	A	SIL	9.0	19.9 g N m-2	BU93
135	WI	Soybean-Corn	A	SIL	9.0	23.3 g N m-2	BU93
136	WI	Soybean-Corn	A	SIL	9.0	23.5 g N m-2	BU93

137	WI	Soybean-Corn	A	SIL	9.0	24.3 g N m-2	BU93
138	WI	Soybean-Corn-Corn	A	LS	9.0	6.4 g N m-2	BU93
139	WI	Soybean-Corn-Corn	A	LS	9.0	9.3 g N m-2	BU93
140	WI	Soybean-Corn-Corn	A	LS	9.0	13.3 g N m-2	BU93
141	WI	Soybean-Corn-Corn	A	SIL	9.0	16.6 g N m-2	BU93
142	WI	Soybean-Corn-Corn	A	SIL	9.0	17.6 g N m-2	BU93
143	WI	Soybean-Corn-Corn	A	SIL	9.0	18.4 g N m-2	BU93
144	WI	Soybean-Corn-Corn	A	SIL	9.0	14.4 g N m-2	BU93
145	WI	Soybean-Corn-Corn	A	SIL	9.0	18.0 g N m-2	BU93
146	WI	Soybean-Corn-Corn	A	SIL	9.0	22.0 g N m-2	BU93
147	WI	Corn-Corn	A	LS	13.5	12.9 g N m-2	BU93
148	WI	Corn-Corn	A	LS	13.5	13.2 g N m-2	BU93
149	WI	Corn-Corn	A	LS	13.5	13.4 g N m-2	BU93
150	WI	Corn-Corn	A	LS	13.5	16.2 g N m-2	BU93
151	WI	Corn-Corn	A	SIL	13.5	17.2 g N m-2	BU93
152	WI	Corn-Corn	A	SIL	13.5	18.3 g N m-2	BU93
153	WI	Corn-Corn	A	SIL	13.5	21.5 g N m-2	BU93
154	WI	Corn-Corn	A	SIL	13.5	21.8 g N m-2	BU93
155	WI	Corn-Corn	A	SIL	13.5	16.3 g N m-2	BU93
156	WI	Corn-Corn	A	SIL	13.5	19.6 g N m-2	BU93
157	WI	Corn-Corn	A	SIL	13.5	21.7 g N m-2	BU93
158	WI	Corn-Corn	A	SIL	13.5	22.9 g N m-2	BU93
159	WI	Soybean-Corn	A	LS	13.5	12.6 g N m-2	BU93
160	WI	Soybean-Corn	A	LS	13.5	13.9 g N m-2	BU93
161	WI	Soybean-Corn	A	LS	13.5	14.5 g N m-2	BU93
162	WI	Soybean-Corn	A	LS	13.5	14.6 g N m-2	BU93
163	WI	Soybean-Corn	A	SIL	13.5	19.1 g N m-2	BU93
164	WI	Soybean-Corn	A	SIL	13.5	20.6 g N m-2	BU93
165	WI	Soybean-Corn	A	SIL	13.5	25.0 g N m-2	BU93
166	WI	Soybean-Corn	A	SIL	13.5	26.5 g N m-2	BU93
167	WI	Soybean-Corn	A	SIL	13.5	17.6 g N m-2	BU93
168	WI	Soybean-Corn	A	SIL	13.5	23.7 g N m-2	BU93
169	WI	Soybean-Corn	A	SIL	13.5	25.9 g N m-2	BU93
170	WI	Soybean-Corn	A	SIL	13.5	26.7 g N m-2	BU93
171	WI	Soybean-Corn-Corn	A	LS	13.5	13.2 g N m-2	BU93
172	WI	Soybean-Corn-Corn	A	LS	13.5	13.9 g N m-2	BU93

173	WI	Soybean-Corn-Corn	A	LS	13.5	14.2 g N m-2	BU93
174	WI	Soybean-Corn-Corn	A	SIL	13.5	18.5 g N m-2	BU93
175	WI	Soybean-Corn-Corn	A	SIL	13.5	19.8 g N m-2	BU93
176	WI	Soybean-Corn-Corn	A	SIL	13.5	20.7 g N m-2	BU93
177	WI	Soybean-Corn-Corn	A	SIL	13.5	17.5 g N m-2	BU93
178	WI	Soybean-Corn-Corn	A	SIL	13.5	18.8 g N m-2	BU93
179	WI	Soybean-Corn-Corn	A	SIL	13.5	25.7 g N m-2	BU93
180	WI	Corn-Corn	A	LS	18.0	14.1 g N m-2	BU93
181	WI	Corn-Corn	A	LS	18.0	15.8 g N m-2	BU93
182	WI	Corn-Corn	A	LS	18.0	17.2 g N m-2	BU93
183	WI	Corn-Corn	A	LS	18.0	19.8 g N m-2	BU93
184	WI	Corn-Corn	A	SIL	18.0	20.1 g N m-2	BU93
185	WI	Corn-Corn	A	SIL	18.0	20.2 g N m-2	BU93
186	WI	Corn-Corn	A	SIL	18.0	20.6 g N m-2	BU93
187	WI	Corn-Corn	A	SIL	18.0	22.8 g N m-2	BU93
188	WI	Corn-Corn	A	SIL	18.0	17.2 g N m-2	BU93
189	WI	Corn-Corn	A	SIL	18.0	19.4 g N m-2	BU93
190	WI	Corn-Corn	A	SIL	18.0	20.1 g N m-2	BU93
191	WI	Corn-Corn	A	SIL	18.0	25.6 g N m-2	BU93
192	WI	Soybean-Corn	A	LS	18.0	16.3 g N m-2	BU93
193	WI	Soybean-Corn	A	LS	18.0	16.5 g N m-2	BU93
194	WI	Soybean-Corn	A	LS	18.0	16.7 g N m-2	BU93
195	WI	Soybean-Corn	A	LS	18.0	20.8 g N m-2	BU93
196	WI	Soybean-Corn	A	SIL	18.0	21.7 g N m-2	BU93
197	WI	Soybean-Corn	A	SIL	18.0	22.0 g N m-2	BU93
198	WI	Soybean-Corn	A	SIL	18.0	24.8 g N m-2	BU93
199	WI	Soybean-Corn	A	SIL	18.0	28.2 g N m-2	BU93
200	WI	Soybean-Corn	A	SIL	18.0	21.2 g N m-2	BU93
201	WI	Soybean-Corn	A	SIL	18.0	24.0 g N m-2	BU93
202	WI	Soybean-Corn	A	SIL	18.0	27.5 g N m-2	BU93
203	WI	Soybean-Corn	A	SIL	18.0	28.4 g N m-2	BU93
204	WI	Soybean-Corn-Corn	A	LS	18.0	17.2 g N m-2	BU93
205	WI	Soybean-Corn-Corn	A	LS	18.0	17.6 g N m-2	BU93
206	WI	Soybean-Corn-Corn	A	LS	18.0	21.5 g N m-2	BU93
207	WI	Soybean-Corn-Corn	A	SIL	18.0	17.2 g N m-2	BU93
208	WI	Soybean-Corn-Corn	A	SIL	18.0	20.3 g N m-2	BU93

209	WI	Soybean-Corn-Corn	A	SIL	18.0	24.1 g N m-2	BU93
210	WI	Soybean-Corn-Corn	A	SIL	18.0	18.4 g N m-2	BU93
211	WI	Soybean-Corn-Corn	A	SIL	18.0	20.1 g N m-2	BU93
212	WI	Soybean-Corn-Corn	A	SIL	18.0	28.8 g N m-2	BU93
213	WI	Corn-Corn	A	LS	22.5	15.0 g N m-2	BU93
214	WI	Corn-Corn	A	LS	22.5	19.2 g N m-2	BU93
215	WI	Corn-Corn	A	LS	22.5	20.9 g N m-2	BU93
216	WI	Corn-Corn	A	LS	22.5	22.4 g N m-2	BU93
217	WI	Corn-Corn	A	SIL	22.5	18.4 g N m-2	BU93
218	WI	Corn-Corn	A	SIL	22.5	21.0 g N m-2	BU93
219	WI	Corn-Corn	A	SIL	22.5	21.4 g N m-2	BU93
220	WI	Corn-Corn	A	SIL	22.5	26.6 g N m-2	BU93
221	WI	Corn-Corn	A	SIL	22.5	17.8 g N m-2	BU93
222	WI	Corn-Corn	A	SIL	22.5	19.1 g N m-2	BU93
223	WI	Corn-Corn	A	SIL	22.5	22.4 g N m-2	BU93
224	WI	Corn-Corn	A	SIL	22.5	25.2 g N m-2	BU93
225	WI	Soybean-Corn	A	LS	22.5	15.3 g N m-2	BU93
226	WI	Soybean-Corn	A	LS	22.5	18.2 g N m-2	BU93
227	WI	Soybean-Corn	A	LS	22.5	18.2 g N m-2	BU93
228	WI	Soybean-Corn	A	LS	22.5	19.0 g N m-2	BU93
229	WI	Soybean-Corn	A	SIL	22.5	21.5 g N m-2	BU93
230	WI	Soybean-Corn	A	SIL	22.5	21.7 g N m-2	BU93
231	WI	Soybean-Corn	A	SIL	22.5	28.3 g N m-2	BU93
232	WI	Soybean-Corn	A	SIL	22.5	31.1 g N m-2	BU93
233	WI	Soybean-Corn	A	SIL	22.5	22.7 g N m-2	BU93
234	WI	Soybean-Corn	A	SIL	22.5	23.3 g N m-2	BU93
235	WI	Soybean-Corn	A	SIL	22.5	24.3 g N m-2	BU93
236	WI	Soybean-Corn	A	SIL	22.5	25.0 g N m-2	BU93
237	WI	Soybean-Corn-Corn	A	LS	22.5	15.0 g N m-2	BU93
238	WI	Soybean-Corn-Corn	A	LS	22.5	17.3 g N m-2	BU93
239	WI	Soybean-Corn-Corn	A	LS	22.5	19.7 g N m-2	BU93
240	WI	Soybean-Corn-Corn	A	SIL	22.5	19.5 g N m-2	BU93
241	WI	Soybean-Corn-Corn	A	SIL	22.5	21.1 g N m-2	BU93
242	WI	Soybean-Corn-Corn	A	SIL	22.5	22.0 g N m-2	BU93
243	WI	Soybean-Corn-Corn	A	SIL	22.5	21.3 g N m-2	BU93
244	WI	Soybean-Corn-Corn	A	SIL	22.5	24.5 g N m-2	BU93

245	WI	Soybean-Corn-Corn	A	SIL	22.5	25.2 g N m-2	BU93
246	TN	Chestnut Oak	F	.	0.0	6.9 g N m-2	CO81
247	NC	Oak Hickory	F	L	0.0	4.3 g N m-2	CO81
248	TN	Oak Hickory	F	.	0.0	6.9 g N m-2	CO81
249	TN	Pine	F	.	0.0	4.9 g N m-2	CO81
250	NC	White Pine	F	L	0.0	5.0 g N m-2	CO81
251	TN	Yellow Poplar	F	SIL	0.0	4.8 g N m-2	CO81
252	TN	Yellow Poplar	F	.	0.0	5.8 g N m-2	CO81
253	NC	Corn	A	SL	7.0	4.3 g N m-2	CR98
254	NC	Corn	A	SL	7.0	7.0 g N m-2	CR98
255	NC	Corn	A	SL	9.8	7.6 g N m-2	CR98
256	NC	Corn	A	SL	13.5	6.4 g N m-2	CR98
257	.	Corn	A	SCL	22.4	12.8 g N m-2	CU81
258	.	Corn	A	SCL	56.0	14.2 g N m-2	CU81
259	.	Corn	A	SCL	89.7	14.9 g N m-2	CU81
268	.	Cotton	A	L	10.0	22.4 g N m-2	HA76
269	.	Cotton	A	L	10.0	23.5 g N m-2	HA76
270	GA	Corn	A	SL	12.6	19.0 g N m-2	HA85
271	GA	Corn	A	SL	12.6	21.2 g N m-2	HA85
272	GA	Corn	A	SL	12.6	22.7 g N m-2	HA85
273	MN	Corn	A	CL	0.0	2.6 g N m-2	IR97
274	MN	Corn	A	CL	0.0	3.7 g N m-2	IR97
275	MN	Corn	A	CL	0.0	4.0 g N m-2	IR97
276	MN	Corn	A	CL	0.0	4.6 g N m-2	IR97
277	MN	Corn	A	CL	0.0	5.2 g N m-2	IR97
278	MN	Corn	A	CL	0.0	5.3 g N m-2	IR97
279	MN	Corn	A	CL	0.0	5.4 g N m-2	IR97
280	MN	Corn	A	CL	0.0	5.5 g N m-2	IR97
281	MN	Corn	A	CL	0.0	5.7 g N m-2	IR97
282	MN	Corn	A	CL	0.0	5.8 g N m-2	IR97
283	MN	Corn	A	CL	0.0	6.3 g N m-2	IR97
284	MN	Corn	A	CL	0.0	6.4 g N m-2	IR97
285	MN	Corn	A	CL	0.0	6.6 g N m-2	IR97
286	MN	Corn	A	CL	0.0	7.1 g N m-2	IR97
287	MN	Corn	A	CL	0.0	7.4 g N m-2	IR97
288	MN	Corn	A	CL	0.0	5.4 g N m-2	IR97

289	MN	Corn	A	CL	0.0	5.9	g N m-2	IR97
290	MN	Corn	A	CL	0.0	6.4	g N m-2	IR97
291	MN	Corn	A	CL	0.0	6.8	g N m-2	IR97
292	MN	Corn	A	CL	0.0	6.9	g N m-2	IR97
293	MN	Corn	A	CL	0.0	7.5	g N m-2	IR97
294	MN	Corn	A	CL	0.0	7.6	g N m-2	IR97
295	MN	Corn	A	CL	0.0	7.7	g N m-2	IR97
296	MN	Corn	A	CL	0.0	7.7	g N m-2	IR97
297	MN	Corn	A	CL	0.0	8.1	g N m-2	IR97
298	MN	Corn	A	CL	0.0	8.5	g N m-2	IR97
299	MN	Corn	A	CL	0.0	8.6	g N m-2	IR97
300	MN	Corn	A	CL	0.0	9.0	g N m-2	IR97
301	MN	Corn	A	CL	0.0	9.1	g N m-2	IR97
302	MN	Corn	A	CL	0.0	9.2	g N m-2	IR97
303	MN	Corn	A	CL	13.5	5.4	g N m-2	IR97
304	MN	Corn	A	CL	13.5	7.4	g N m-2	IR97
305	MN	Corn	A	CL	13.5	7.8	g N m-2	IR97
306	MN	Corn	A	CL	13.5	8.7	g N m-2	IR97
307	MN	Corn	A	CL	13.5	8.9	g N m-2	IR97
308	MN	Corn	A	CL	13.5	9.0	g N m-2	IR97
309	MN	Corn	A	CL	13.5	9.2	g N m-2	IR97
310	MN	Corn	A	CL	13.5	9.7	g N m-2	IR97
311	MN	Corn	A	CL	13.5	10.1	g N m-2	IR97
312	MN	Corn	A	CL	13.5	10.1	g N m-2	IR97
313	MN	Corn	A	CL	13.5	10.5	g N m-2	IR97
314	MN	Corn	A	CL	13.5	11.0	g N m-2	IR97
315	MN	Corn	A	CL	13.5	11.3	g N m-2	IR97
316	MN	Corn	A	CL	13.5	11.7	g N m-2	IR97
317	MN	Corn	A	CL	13.5	12.0	g N m-2	IR97
318	MN	Corn	A	CL	13.5	9.5	g N m-2	IR97
319	MN	Corn	A	CL	13.5	10.1	g N m-2	IR97
320	MN	Corn	A	CL	13.5	10.1	g N m-2	IR97
321	MN	Corn	A	CL	13.5	10.9	g N m-2	IR97
322	MN	Corn	A	CL	13.5	11.1	g N m-2	IR97
323	MN	Corn	A	CL	13.5	11.4	g N m-2	IR97
324	MN	Corn	A	CL	13.5	11.8	g N m-2	IR97

325	MN	Corn	A	CL	13.5	11.8	g N m-2	IR97
326	MN	Corn	A	CL	13.5	12.1	g N m-2	IR97
327	MN	Corn	A	CL	13.5	12.9	g N m-2	IR97
328	MN	Corn	A	CL	13.5	13.2	g N m-2	IR97
329	MN	Corn	A	CL	13.5	13.5	g N m-2	IR97
330	MN	Corn	A	CL	13.5	13.8	g N m-2	IR97
331	MN	Corn	A	CL	13.5	14.0	g N m-2	IR97
332	MN	Corn	A	CL	13.5	14.3	g N m-2	IR97
333	MN	Alfalfa	G	CL	.	0.8	g N m-2	IR97
334	MN	Alfalfa	G	CL	.	2.2	g N m-2	IR97
335	MN	Alfalfa	G	CL	.	3.9	g N m-2	IR97
336	MN	Alfalfa	G	CL	.	2.0	g N m-2	IR97
337	MN	Alfalfa	G	CL	.	2.6	g N m-2	IR97
338	MN	Alfalfa	G	CL	.	3.7	g N m-2	IR97
339	MN	Hairy Vetch	G	CL	.	1.9	g N m-2	IR97
340	MN	Hairy Vetch	G	CL	.	2.2	g N m-2	IR97
341	MN	Hairy Vetch	G	CL	.	3.6	g N m-2	IR97
342	MN	Hairy Vetch	G	CL	.	4.2	g N m-2	IR97
343	MN	Hairy Vetch	G	CL	.	5.4	g N m-2	IR97
344	MN	Hairy Vetch	G	CL	.	5.7	g N m-2	IR97
345	IL	Soybeans (nodulating)	A	SIL	0.0	21.6	g N m-2	JO75
346	IL	Soybeans (non-nod)	A	SIL	0.0	11.3	g N m-2	JO75
347	IL	Soybeans (nodulating)	A	SIL	11.2	22.8	g N m-2	JO75
348	IL	Soybeans (non-nod)	A	SIL	11.2	17.0	g N m-2	JO75
349	IL	Soybeans (nodulating)	A	SIL	22.4	21.1	g N m-2	JO75
350	IL	Soybeans (non-nod)	A	SIL	22.4	20.5	g N m-2	JO75
353	IL	Soybeans (nodulating)	A	SIL	44.8	22.8	g N m-2	JO75
354	IL	Soybeans (non-nod)	A	SIL	44.8	22.3	g N m-2	JO75
355	TN	Chestnut Oak	F	.	0.0	6.2	g N m-2	JO89
356	TN	Oak Hickory	F	.	0.0	6.7	g N m-2	JO89
357	TN	Pine Hardwood	F	.	0.0	5.2	g N m-2	JO89
358	TN	Yellow Poplar	F	.	0.0	6.4	g N m-2	JO89
359	NC	Hardwood	F	.	0.0	3.4	g N m-2	JO92
360	NC	Pine	F	.	0.0	3.7	g N m-2	JO92
361	NC	Pine	F	.	0.0	2.5	g N m-2	JO92
362	FL	Pine	F	.	0.0	2.4	g N m-2	JO92

363	TN	Pine	F	.	0.0	1.7	g N m-2	JO92
364	TN	Pine	F	.	0.0	2.5	g N m-2	JO92
374	NC	Bermudagrass	G	LS	33.5	24.7	g N m-2	KI85
375	NC	Bermudagrass	G	LS	67.0	38.2	g N m-2	KI85
376	NC	Bermudagrass	G	LS	134.0	45.0	g N m-2	KI85
377	WI	Marsh	EW	.	.	17.5	g N m-2	KL75
378	WV	Corn	A	SIL	8.5	8.9	g N m-2	LE79
379	WV	Corn	A	SIL	8.5	9.8	g N m-2	LE79
380	WV	Corn	A	SIL	8.5	10.0	g N m-2	LE79
381	WV	Corn	A	SIL	8.5	11.5	g N m-2	LE79
382	WV	Corn	A	SIL	8.5	11.7	g N m-2	LE79
383	WV	Corn	A	SIL	8.5	11.8	g N m-2	LE79
384	WV	Corn	A	SIL	8.5	12.3	g N m-2	LE79
385	WV	Corn	A	SIL	8.5	14.1	g N m-2	LE79
386	WV	Corn	A	SIL	17.0	13.5	g N m-2	LE79
387	WV	Corn	A	SIL	17.0	15.5	g N m-2	LE79
388	WV	Corn	A	SIL	17.0	15.6	g N m-2	LE79
389	WV	Corn	A	SIL	17.0	16.1	g N m-2	LE79
390	WV	Corn	A	SIL	17.0	16.1	g N m-2	LE79
391	WV	Corn	A	SIL	17.0	18.0	g N m-2	LE79
392	WV	Corn	A	SIL	17.0	18.6	g N m-2	LE79
393	WV	Corn	A	SIL	17.0	18.9	g N m-2	LE79
394	WV	Corn	A	SIL	34.0	15.2	g N m-2	LE79
395	WV	Corn	A	SIL	34.0	16.1	g N m-2	LE79
396	WV	Corn	A	SIL	34.0	18.6	g N m-2	LE79
397	WV	Corn	A	SIL	34.0	19.9	g N m-2	LE79
398	WV	Corn	A	SIL	34.0	20.6	g N m-2	LE79
399	WV	Corn	A	SIL	34.0	20.7	g N m-2	LE79
400	WV	Corn	A	SIL	34.0	21.8	g N m-2	LE79
401	WV	Corn	A	SIL	34.0	22.6	g N m-2	LE79
402	.	Flooded Meadow	EW	.	.	11.0	g N m-2	LE94
403	AL	Bermudagrass-ryegrass	G	LS	0.0	23.1	g N m-2	LI97
404	AL	Bermudagrass-ryegrass	G	LS	56.0	40.4	g N m-2	LI97
405	AL	Bermudagrass-ryegrass	G	LS	56.0	41.0	g N m-2	LI97
406	AL	Bermudagrass-ryegrass	G	LS	112.0	48.2	g N m-2	LI97
407	AL	Bermudagrass-ryegrass	G	LS	224.0	51.2	g N m-2	LI97

408	CA	Wheat	G	.	0.0	11.0	g N m-2	MC98
409	CA	Wheat	G	.	2.8	14.1	g N m-2	MC98
410	CA	Wheat	G	.	11.2	16.2	g N m-2	MC98
411	MD	Corn	A	SIL	0.0	4.8	g N m-2	ME85
412	MD	Corn	A	SIL	0.0	7.1	g N m-2	ME85
413	MD	Corn	A	SIL	0.0	3.7	g N m-2	ME85
414	MD	Corn	A	SIL	0.0	4.1	g N m-2	ME85
415	MD	Corn	A	SIL	0.0	5.0	g N m-2	ME85
416	MD	Corn	A	SIL	0.0	6.0	g N m-2	ME85
417	MD	Corn	A	SIL	0.0	6.0	g N m-2	ME85
418	MD	Corn	A	SIL	0.0	6.5	g N m-2	ME85
419	MD	Corn	A	SIL	0.0	7.6	g N m-2	ME85
420	MD	Corn	A	SIL	0.0	8.1	g N m-2	ME85
421	MD	Corn	A	SIL	4.5	6.9	g N m-2	ME85
422	MD	Corn	A	SIL	4.5	10.6	g N m-2	ME85
423	MD	Corn	A	SIL	4.5	3.7	g N m-2	ME85
424	MD	Corn	A	SIL	4.5	5.3	g N m-2	ME85
425	MD	Corn	A	SIL	4.5	7.7	g N m-2	ME85
426	MD	Corn	A	SIL	4.5	8.4	g N m-2	ME85
427	MD	Corn	A	SIL	4.5	8.9	g N m-2	ME85
428	MD	Corn	A	SIL	4.5	12.1	g N m-2	ME85
429	MD	Corn	A	SIL	9.0	9.9	g N m-2	ME85
430	MD	Corn	A	SIL	9.0	13.5	g N m-2	ME85
431	MD	Corn	A	SIL	9.0	5.5	g N m-2	ME85
432	MD	Corn	A	SIL	9.0	8.2	g N m-2	ME85
433	MD	Corn	A	SIL	9.0	10.0	g N m-2	ME85
434	MD	Corn	A	SIL	9.0	11.6	g N m-2	ME85
435	MD	Corn	A	SIL	9.0	12.3	g N m-2	ME85
436	MD	Corn	A	SIL	9.0	12.8	g N m-2	ME85
437	MD	Corn	A	SIL	9.0	14.1	g N m-2	ME85
438	MD	Corn	A	SIL	9.0	14.4	g N m-2	ME85
439	MD	Corn	A	SIL	13.5	13.1	g N m-2	ME85
440	MD	Corn	A	SIL	13.5	16.8	g N m-2	ME85
441	MD	Corn	A	SIL	13.5	7.9	g N m-2	ME85
442	MD	Corn	A	SIL	13.5	11.9	g N m-2	ME85
443	MD	Corn	A	SIL	13.5	12.5	g N m-2	ME85

444	MD	Corn	A	SIL	13.5	14.1	g N m-2	ME85
445	MD	Corn	A	SIL	13.5	14.3	g N m-2	ME85
446	MD	Corn	A	SIL	13.5	15.0	g N m-2	ME85
447	MD	Corn	A	SIL	13.5	15.4	g N m-2	ME85
448	MD	Corn	A	SIL	13.5	18.0	g N m-2	ME85
449	MD	Corn	A	SIL	18.0	16.3	g N m-2	ME85
450	MD	Corn	A	SIL	18.0	17.3	g N m-2	ME85
451	MD	Corn	A	SIL	18.0	10.8	g N m-2	ME85
452	MD	Corn	A	SIL	18.0	14.0	g N m-2	ME85
453	MD	Corn	A	SIL	18.0	14.5	g N m-2	ME85
454	MD	Corn	A	SIL	18.0	14.9	g N m-2	ME85
455	MD	Corn	A	SIL	18.0	15.4	g N m-2	ME85
456	MD	Corn	A	SIL	18.0	15.7	g N m-2	ME85
457	MD	Corn	A	SIL	18.0	18.2	g N m-2	ME85
458	MD	Corn	A	SIL	18.0	19.3	g N m-2	ME85
459	MD	Corn	A	SIL	27.0	16.5	g N m-2	ME85
460	MD	Corn	A	SIL	27.0	17.0	g N m-2	ME85
461	Ont.	Deciduous Forest	F	.	.	3.2	g N m-2	MI92
462	NY	Deciduous Forest	F	.	.	4.5	g N m-2	MI92
463	MN	Wheat	G	L	0.0	4.5	g N m-2	MO96
464	MN	Wheat	G	L	0.0	5.0	g N m-2	MO96
465	MN	Wheat	G	L	4.1	5.8	g N m-2	MO96
466	MN	Wheat	G	L	4.5	6.7	g N m-2	MO96
467	MN	Wheat	G	L	4.5	7.3	g N m-2	MO96
468	MN	Wheat	G	L	6.4	5.4	g N m-2	MO96
469	MN	Wheat	G	L	8.5	6.3	g N m-2	MO96
470	MN	Wheat	G	L	9.0	8.7	g N m-2	MO96
471	MN	Wheat	G	L	9.0	10.0	g N m-2	MO96
472	MN	Wheat	G	L	13.5	10.7	g N m-2	MO96
473	MN	Wheat	G	L	13.5	12.9	g N m-2	MO96
474	MN	Wheat	G	L	18.0	11.9	g N m-2	MO96
475	MN	Wheat	G	L	18.0	13.8	g N m-2	MO96
476	MN	Wheat	G	L	20.8	12.3	g N m-2	MO96
477	MN	Wheat	G	L	27.1	12.1	g N m-2	MO96
478	MN	Wheat	G	L	34.7	15.2	g N m-2	MO96
479	WI	Birch	F	.	0.0	5.9	g N m-2	NA83

480	WI	Black Oak	F	.	0.0	11.9 g N m-2	NA83
481	WI	Maple	F	.	0.0	7.0 g N m-2	NA83
482	WI	Mixed Pine	F	.	0.0	5.8 g N m-2	NA83
483	WI	Red Oak	F	.	0.0	9.9 g N m-2	NA83
484	WI	Red Pine	F	.	0.0	4.0 g N m-2	NA83
485	WI	Spruce	F	.	0.0	5.5 g N m-2	NA83
486	WI	White Oak	F	.	0.0	10.8 g N m-2	NA83
487	WI	White Pine	F	.	0.0	7.8 g N m-2	NA83
488	WI	Mixed Pine	F	.	0.0	6.4 g N m-2	NA84
489	WI	Oak 1	F	.	0.0	11.4 g N m-2	NA84
490	WI	Oak 2	F	.	0.0	8.8 g N m-2	NA84
491	WI	Oak 3	F	.	0.0	7.4 g N m-2	NA84
492	WI	Paper Birch	F	.	0.0	5.1 g N m-2	NA84
493	WI	Red pine	F	.	0.0	3.2 g N m-2	NA84
494	WI	Spruce	F	.	0.0	4.7 g N m-2	NA84
495	WI	Sugar maple	F	.	0.0	6.0 g N m-2	NA84
496	WI	White Pine	F	.	0.0	8.6 g N m-2	NA84
497	WI	Birch	F	.	0.0	9.2 g N m-2	NA85
498	WI	Black Oak	F	.	0.0	14.3 g N m-2	NA85
499	WI	Maple	F	.	0.0	10.2 g N m-2	NA85
500	WI	Mixed Pine	F	.	0.0	6.9 g N m-2	NA85
501	WI	Red Oak	F	.	0.0	13.3 g N m-2	NA85
502	WI	Red Pine	F	.	0.0	4.7 g N m-2	NA85
503	WI	Spruce	F	.	0.0	6.6 g N m-2	NA85
504	WI	White Oak	F	.	0.0	10.7 g N m-2	NA85
505	WI	White Pine	F	.	0.0	7.9 g N m-2	NA85
506	KS	Corn	A	SIL	0.0	11.7 g N m-2	OL80
507	KS	Corn	A	SIL	0.0	19.6 g N m-2	OL80
508	KS	Corn	A	SIL	5.0	13.8 g N m-2	OL80
509	KS	Corn	A	SIL	5.0	21.6 g N m-2	OL80
510	KS	Corn	A	SIL	15.0	19.9 g N m-2	OL80
511	KS	Corn	A	SIL	15.0	24.6 g N m-2	OL80
529	NC	Corn	A	SL	.	13.6 g N m-2	OV94
530	NC	Corn	A	VFSL	.	15.0 g N m-2	OV94
531	NC	Corn	A	LS	.	20.9 g N m-2	OV94
532	SC	Typha stand	EW	.	.	3.2 g N m-2	PR84

533	MN	Typha stand	EW	.	.	15.8 g N m-2	PR84
534	MN	Typha stand	EW	.	.	7.4 g N m-2	PR84
535	MN	Typha stand	EW	.	.	14.1 g N m-2	PR84
536	MN	Typha stand	EW	.	.	6.0 g N m-2	PR84
537	MN	Typha stand	EW	.	.	5.4 g N m-2	PR84
538	MN	Typha stand	EW	.	.	10.8 g N m-2	PR84
539	SC	Pine	F	.	0.0	3.5 g N m-2	RI96
540	NC	Pine	F	.	0.0	2.5 g N m-2	RI96
541	FL	Pine	F	.	0.0	2.4 g N m-2	RI96
542	TN	Pine	F	.	0.0	2.1 g N m-2	RI96
543	GA	Wheat	G	SL	7.3	13.2 g N m-2	SH88
551	WV	Switchgrass	G	L	0.0	5.5 g N m-2	ST91
552	WV	Switchgrass	G	L	0.0	3.5 g N m-2	ST91
553	WV	Switchgrass	G	L	0.0	5.7 g N m-2	ST91
554	WV	Tall Fescue	G	L	0.0	3.2 g N m-2	ST91
555	WV	Tall Fescue	G	L	0.0	2.1 g N m-2	ST91
556	WV	Tall Fescue	G	L	0.0	4.0 g N m-2	ST91
557	WV	Switchgrass	G	L	9.0	10.7 g N m-2	ST91
558	WV	Switchgrass	G	L	9.0	7.8 g N m-2	ST91
559	WV	Switchgrass	G	L	9.0	11.5 g N m-2	ST91
560	WV	Tall Fescue	G	L	9.0	7.6 g N m-2	ST91
561	WV	Tall Fescue	G	L	9.0	5.6 g N m-2	ST91
562	WV	Tall Fescue	G	L	9.0	8.6 g N m-2	ST91
563	WV	Switchgrass	G	L	18.0	14.0 g N m-2	ST91
564	WV	Switchgrass	G	L	18.0	11.5 g N m-2	ST91
566	WV	Tall Fescue	G	L	18.0	11.5 g N m-2	ST91
567	WV	Tall Fescue	G	L	18.0	10.2 g N m-2	ST91
568	WV	Tall Fescue	G	L	18.0	15.6 g N m-2	ST91
569	WV	Corn	A	SIL	0.0	4.8 g N m-2	ST95
570	WV	Corn	A	SIL	0.0	5.7 g N m-2	ST95
571	WV	Corn	A	SIL	0.0	5.8 g N m-2	ST95
572	WV	Corn	A	SIL	0.0	6.9 g N m-2	ST95
573	WV	Corn	A	SIL	0.0	6.9 g N m-2	ST95
574	WV	Corn	A	SIL	0.0	7.0 g N m-2	ST95
575	WV	Corn	A	SIL	5.6	8.8 g N m-2	ST95
576	WV	Corn	A	SIL	5.6	10.0 g N m-2	ST95

577	WV	Corn	A	SIL	5.6	10.4	g N m-2	ST95
578	WV	Corn	A	SIL	5.6	10.6	g N m-2	ST95
579	WV	Corn	A	SIL	5.6	11.2	g N m-2	ST95
580	WV	Corn	A	SIL	5.6	11.8	g N m-2	ST95
581	WV	Corn	A	SIL	11.2	12.5	g N m-2	ST95
582	WV	Corn	A	SIL	11.2	13.1	g N m-2	ST95
583	WV	Corn	A	SIL	11.2	13.4	g N m-2	ST95
584	WV	Corn	A	SIL	11.2	13.5	g N m-2	ST95
585	WV	Corn	A	SIL	11.2	14.4	g N m-2	ST95
586	WV	Corn	A	SIL	11.2	14.9	g N m-2	ST95
587	WV	Corn	A	SIL	22.4	15.8	g N m-2	ST95
588	WV	Corn	A	SIL	22.4	16.1	g N m-2	ST95
589	WV	Corn	A	SIL	22.4	16.5	g N m-2	ST95
590	WV	Corn	A	SIL	22.4	17.6	g N m-2	ST95
591	WV	Corn	A	SIL	22.4	17.9	g N m-2	ST95
592	WV	Corn	A	SIL	22.4	18.1	g N m-2	ST95
593	MS	Cotton	A	SIL	0.0	6.8	g N m-2	ST96
594	MS	Cotton	A	SIL	0.0	7.0	g N m-2	ST96
595	MS	Cotton	A	SIL	0.0	7.1	g N m-2	ST96
596	MS	Cotton	A	SIL	0.0	7.5	g N m-2	ST96
597	MS	Cotton	A	SIL	0.0	7.7	g N m-2	ST96
598	MS	Cotton	A	SIL	4.5	7.9	g N m-2	ST96
599	MS	Cotton	A	SIL	4.5	8.2	g N m-2	ST96
600	MS	Cotton	A	SIL	4.5	8.5	g N m-2	ST96
601	MS	Cotton	A	SIL	4.5	9.2	g N m-2	ST96
602	MS	Cotton	A	SIL	4.5	9.2	g N m-2	ST96
603	MS	Cotton	A	SIL	9.0	8.9	g N m-2	ST96
604	MS	Cotton	A	SIL	9.0	9.9	g N m-2	ST96
605	MS	Cotton	A	SIL	9.0	10.0	g N m-2	ST96
606	MS	Cotton	A	SIL	9.0	10.3	g N m-2	ST96
607	MS	Cotton	A	SIL	9.0	10.7	g N m-2	ST96
608	MS	Cotton	A	SIL	13.5	8.7	g N m-2	ST96
609	MS	Cotton	A	SIL	13.5	9.2	g N m-2	ST96
610	MS	Cotton	A	SIL	13.5	9.5	g N m-2	ST96
611	MS	Cotton	A	SIL	13.5	9.7	g N m-2	ST96
612	MS	Cotton	A	SIL	13.5	9.9	g N m-2	ST96

613	MS	Cotton	A	SIL	18.0	9.2 g N m-2	ST96
614	MS	Cotton	A	SIL	18.0	10.4 g N m-2	ST96
615	MS	Cotton	A	SIL	18.0	11.1 g N m-2	ST96
616	MS	Cotton	A	SIL	18.0	11.8 g N m-2	ST96
617	MS	Cotton	A	SIL	18.0	12.4 g N m-2	ST96
618	USA	Loblolly Pine	F	.	.	6.9 g N m-2	SW72
619	USA	Loblolly Pine	F	.	.	11.7 g N m-2	WE75
620	KY	Sycamore (5-year old)	F	.	0.0	4.8 g N m-2	WI80
621	KY	Sycamore (5-year old)	F	.	0.0	6.1 g N m-2	WI80
622	KY	Sycamore (5-year old)	F	.	16.9	15.1 g N m-2	WI80
623	KY	Sycamore (5-year old)	F	.	16.9	16.5 g N m-2	WI80
624	KY	Tobacco	A	SIL	9.0	6.7 g N m-2	ZA76
625	KY	Tobacco	A	SIL	9.0	10.6 g N m-2	ZA76
626	KY	Tobacco	A	SIL	18.0	12.0 g N m-2	ZA76
627	KY	Tobacco	A	SIL	18.0	15.9 g N m-2	ZA76
629	.	Juncus	EW	.	.	80.0 g N m-2	KA96
630	.	Scirpus	EW	.	.	12.5 g N m-2	KA96
631	.	Phragmites	EW	.	.	22.5 g N m-2	KA96
632	GA	Forage production	G	LS	80.2	46.3 g N m-2	LO98
633	GA	Forage production	G	LS	64.3	43.4 g N m-2	LO98
634	GA	Forage production	G	LS	42.7	32.0 g N m-2	LO98
635	GA	Forage production	G	LS	24.6	16.1 g N m-2	LO98
636	.	Cypress swamp	WW	.	.	21.3 g N m-2	RE87
637	.	Cypress dome	WW	.	.	1.0 g N m-2	RE87
638	.	Cypress dome	WW	.	.	2.7 g N m-2	RE87
639	NJ	Tidal marsh	EW	.	.	20.0 g N m-2	SI78
640	.	Winter wheat	G	SC	0.0	7.8 g N m-2	RE92
641	.	Winter wheat	G	SC	18.5	17.9 g N m-2	RE92
642	.	Winter wheat	G	SC	18.5	16.8 g N m-2	RE92
643	.	Winter wheat	G	L	0.0	7.1 g N m-2	RE92
644	.	Winter wheat	G	L	18.5	14.2 g N m-2	RE92
645	.	Winter wheat	G	L	18.5	14.9 g N m-2	RE92
646	.	Winter wheat	G	.	0.0	6.3 g N m-2	RE92
647	.	Winter wheat	G	.	18.5	14.2 g N m-2	RE92
648	.	Winter wheat	G	.	18.5	15.9 g N m-2	RE92
649	.	Tobacco	A	SL	20.5	19.5 g N m-2	CA78

650	.	Tobacco	A	SL	22.0	16.0 g N m-2	CA78
651	.	Potato	A	SL	16.5	8.0 g N m-2	CA78
652	.	Soybeans	A	SL	0.0	30.5 g N m-2	CA78
653	.	Greenbeans	A	SL	3.0	11.7 g N m-2	CA78
654	WI	Rye	G	SIL	0.0	7.6 g N m-2	KE77
655	WI	Rye	G	SIL	9.5	8.5 g N m-2	KE77
656	WI	Rye	G	SIL	19.0	10.4 g N m-2	KE77
657	WI	Rye	G	SIL	38.0	10.6 g N m-2	KE77
658	WI	Rye	G	SIL	76.0	10.8 g N m-2	KE77
659	WI	Rye	G	SIL	152.0	10.0 g N m-2	KE77
660	WI	Sorghum-sudan	G	SIL	0.0	5.4 g N m-2	KE77
661	WI	Sorghum-sudan	G	SIL	9.5	9.9 g N m-2	KE77
662	WI	Sorghum-sudan	G	SIL	19.0	13.3 g N m-2	KE77
663	WI	Sorghum-sudan	G	SIL	38.0	12.1 g N m-2	KE77
664	WI	Sorghum-sudan	G	SIL	76.0	11.7 g N m-2	KE77
665	WI	Sorghum-sudan	G	SIL	152.0	11.6 g N m-2	KE77
666	WI	Corn	A	SIL	0.0	5.4 g N m-2	KE77
667	WI	Corn	A	SIL	9.5	7.6 g N m-2	KE77
668	WI	Corn	A	SIL	19.0	9.2 g N m-2	KE77
669	WI	Corn	A	SIL	38.0	11.1 g N m-2	KE77
670	WI	Corn	A	SIL	76.0	12.3 g N m-2	KE77
671	WI	Corn	A	SIL	152.0	14.5 g N m-2	KE77
672	WI	Rye	G	SL	0.0	2.0 g N m-2	KE77
673	WI	Rye	G	SL	9.5	2.8 g N m-2	KE77
674	WI	Rye	G	SL	19.0	4.3 g N m-2	KE77
675	WI	Rye	G	SL	38.0	5.3 g N m-2	KE77
676	WI	Rye	G	SL	76.0	6.9 g N m-2	KE77
677	WI	Rye	G	SL	152.0	7.8 g N m-2	KE77
678	WI	Sorghum-sudan	G	SL	0.0	3.3 g N m-2	KE77
679	WI	Sorghum-sudan	G	SL	9.5	8.4 g N m-2	KE77
680	WI	Sorghum-sudan	G	SL	19.0	11.9 g N m-2	KE77
681	WI	Sorghum-sudan	G	SL	38.0	13.7 g N m-2	KE77
682	WI	Sorghum-sudan	G	SL	76.0	13.7 g N m-2	KE77
683	WI	Sorghum-sudan	G	SL	152.0	12.4 g N m-2	KE77
684	WI	Corn	A	SL	0.0	4.4 g N m-2	KE77
685	WI	Corn	A	SL	9.5	6.0 g N m-2	KE77

686	WI	Corn	A	SL	19.0	6.9 g N m-2	KE77
687	WI	Corn	A	SL	38.0	7.7 g N m-2	KE77
688	WI	Corn	A	SL	76.0	9.2 g N m-2	KE77
689	WI	Corn	A	SL	152.0	11.6 g N m-2	KE77
		End of File					

APPENDIX II REFERENCES

AB83 Aber, J. D., J. M. Melillo, C. A. McClaugherty, and K. N. Eshleman. 1983. Potential sinks for mineralized nitrogen following disturbance in forest ecosystems. IN (R. Hallberg, ed.) Environmental Biogeochemistry, Ecological Bulletin (Stockholm) 35: 179-192.

AB84 Abshahi, A., F. J. Hills, and F. E. Broadbent. 1984. Nitrogen utilization by wheat from residual sugarbeet fertlizer and soil incorporated sugarbeet tops. Agronomy Journal 76: 954-958.

BU85 Burns, J. C., P. W. Westerman, L. D. King, G. A. Cummings, M. R. Overcash, and L. Goode. 1985. Swine lagoon effluent applied to "coastal" bermudagrass: I. Forage yield, quality, and element removal. Journal of Environmental Quality 14: 9-14.

BU93 Bundy, L. G., T. W. Andraski, and R. P. Wolkowski. 1993. Nitrogen credits in soybean-corn crop sequences on three soils. Agronomy Journal 85: 1061-1067.

CA78 Cameron, D. R., R. DeJong, and C. Chang. 1978. Nitrogen inputs and losses in tobacco, bean, and potato fields in a sandy loam watershed. Jounral of Environmental Quality 7: 545-550.

CO81 Cole, D. W., and M. Rapp. 1981. Elemental cycling in forest ecosystems, pp. 341-407. IN (D. E. Reichle, ed.) Dynamic Properties of Forest Ecosystems (IBP 23). Cambridge University Press, London.

CR98 Crozier, C. R., L. D. King, and R. J. Volk. 1998. Tracing nitrogen movement in corn production systems in the North Carolina Piedmont: A nitrogen-15 study. Agronomy Journal 90: 171-177.

CU81 Culley, J. L. B., P. A. Philliips, F. R. Hore, and N. K. Patni. 1981. Soil chemical properties and removal of nutrients by corn resulting from different rates and timing of liquid dairy manure applications. Canadian Journal of Soil Science 61: 35-46.

HA76 Halevy, J. 1976. Growth rate and nutrient uptake of two cotton cultivars grown under irrigation. Agronomy Journal 68: 701-705.

HA85 Hargrove, W. L. 1985. Influence of tillage on nutrient uptake and yield of corn. Agronomy Journal 77: 763-768.

IR97 Iragavarapu, T. K., G. W. Randall, and M. P. Russelle. 1997. Yield and nitrogen uptake of rotated corn in a ridge tillage system. Agronomy Journal 89: 397-403.

JO75 Johnson, J. W., L. F. Welch, and L. T. Kurtz. 1975. Environmental implications of N fixation by soybeans. Journal of Environmental Quality 4: 303-306.

JO89 Johnson, D. W., and R. I. Van Hook (eds.) 1989. Analysis of Biogeochemical Cycling Processes in Walker Branch Watershed. Springer-Verlag, New York.

JO92 Johnson, D. W., and S. E. Lindberg (eds.) 1992. Atmospheric Deposition and Forest Nutrient Cycling: A Synthesis of the Integrated Forest Study. Springer-Verlag, New York.

KA96 Kadlec, R. H., and R. L. Knight. 1996. Treatment Wetlands. Lewis Publishers, Boca Raton, Florida.

KE77 Kelling, K. A., A. E. Peterson, L. M. Walsh, J. A. Ryan, and D. R. Keeney. 1977. A field study of the agricultural use of sewage sludge: I. Effect on crop yield and uptake of N and P. Journal of Environmental Quality 6: 339-345.

KI85 King, L. D., P. W. Westerman, G. A. Cummings, M. R. Overcash, and J. C. Burns. 1985. Swine lagoon effluent applied to "coastal" bermudagrass: II. Effects on soil. Journal of Environmental Quality 14: 14-21.

KL75 Klopatek, J. M. 1975. The role of emergent macrophytes in mineral cycling in a freshwater marsh, pp. 367-393. IN (F. G. Howell, J. B. Gentry, and M. H. Smith, eds.) Mineral Cycling in Southeastern Ecosystems (US ERDA CONF-740513). National Technical Information Service, Springfield, VA.

LE79 Legg, J. O., G. Stanford, and O. L. Bennett. 1979. Utilization of labeled-N fertilizer by silage corn under conventional and no-till culture. Agronomy Journal 71: 1009-1015.

LE94 Leonardson, L., L. Bengtsson, T. Davidsson, T. Persson, and U. Emanuelsson. 1994. Nitrogen retention in artificially flooded meadows. Ambio 23: 332-341.

LI97 Liu, F., C. C. Mitchell, J. W. Odom, D. T. Hill, and E. W. Rochester. 1997. Swine lagoon effluent disposal by overland flow: effects on forage production and uptake of nitrogen and phosphorus. Agronomy Journal 89: 900-904.

LO88 Lowrance, R., and D. Smittle. 1988. Nitrogen cycling in a multiple-crop vegetable production system. Journal of Environmental Quality 17: 158-162.

LO98 Lowrance, R., J. C. Johnson, Jr., G. L. Newton, and R. G. Williams. 1998. Denitrification from soils of a year-round forage production system fertilized with liquid dairy manure. Journal of Environmental Quality 27: 1504-1511.

MC98 McGuire, A. M., D. C. Bryant, and R. F. Denison. 1998. Wheat yields, nitrogen uptake, and soil moisture following winter legume cover crop vs. fallow. Agronomy Journal 90: 404-410.

ME85 Meisinger, J. J., V. A. Bandel, G. Standford, and J. O. Legg. 1985. Nitrogen utilization of corn under minimal tillage and moldboard plow tillage. I. Four-year results using labeled N fertilizer on an Atlantic coastal plain soil. Agronomy Journal 77: 602-611.

MI92 Mitchell, M. J., N. W. Foster, J. P. Shepard, and I. K. Morrison. 1992. Nutrient cycling in Huntington Forest and Turkey Lakes deciduous stands: nitrogen and sulfur. Canadian Journal of Forest Research 22: 457-464.

MO96 Moraghan, J. T., and L. J. Smith. 1996. Nitrogen in sugarbeet tops and the growth of a subsequent wheat crop. Agronomy Journal 88: 521-526.

NA83 Nadelhoffer, K. J., J. D. Aber, and J. M. Melillo. 1983. Leaf-litter production and soil organic matter dynamics along a nitrogen-availability gradient in Southern Wisconsin (U.S.A.). Canadian Journal of Forest Research 13: 12-21.

NA84 Nadelhoffer, K. J., J. D. Aber, and J. M. Melillo. 1984. Seasonal patterns of ammonium and nitrate uptake in nine temperate forest ecosystems. Plant and Soil 80: 321-335.

NA85 Nadelhoffer, K. J., J. D. Aber, and J. M. Melillo. 1985. Fine roots, net primary production, and nitrogen availability: a new hypothesis. Ecology 66: 1377-1390.

OL80 Olson, R. V. 1980. Fate of tagged nitrogen fertilizer applied to irrigated corn. Soil Science Society America Journal 44: 514-517.

OV94 Overman, A. R., D. M. Wilson, and E. J. Kamprath. 1994. Estimation of yield and nitrogen removal by corn. Agronomy Journal 86: 1012-1016.

PR84 Pratt, D. C., D. R. Dubbe, E. G. Garver, and P. J. Linton. 1984. Wetland Biomass Production: Emergent Aquatic Management Options and Evaluations: A Final Subcontract Report (SERI/STR-231-2383). Solar Energy Research Institute, Golden, Colorado.

RE87 Reddy, K. R., and W. F. DeBusk. 1987. Nutrient storage capabilities of aquatic and wetland plants, pp. 337-357. IN (K. R. Reddy and W. H. Smith, eds.) Aquatic Plants for Water Treatment and Resource Recovery. Magnolia Publishing,

RE92 Recous, S., J. M. Machet, and B. Mary. 1992. The partitioning of fertilizer-N between soil and crop: comparison of ammonium and nitrate applications. Plant and Soil 144: 101-111.

RI96 Richter, D. D., and D. Markewitz. 1996. Atmospheric deposition and soil resources of the southern pine forest, pp. 315-336. IN (S. FOX, and R. A. MICKLER, eds.) Impact of Air Pollutants on Southern Pine Forests. Springer-Verlag, New York.

SH88 Sharpe, R. R., L. A. Harper, J. E. Giddens, and G. W. Langdale. 1988. Nitrogen use efficiency and nitrogen budget for conservation tilled wheat. Soil Science Society America Journal 52: 1394-1398.

SI78 Simpson, R. L., D. F. Whigham, and R. Walker. 1978. Seasonal patterns of nutrient movement in a freshwater tidal marsh, pp. 243-257. IN (R. E. Good, D. F. Whigham, R. L. Simpson, and C. G. Jackson, Jr., eds.) Freshwater Wetlands: Ecological Processes and Management Potential. Academic Press, New York.

ST91 Staley, T. E., W. L. Stout, and G. A. Jung. 1991. Nitrogen use by tall fescue and switchgrass on acidic soils of varying water holding capacity. Agronomy Journal 83: 732-738.

ST95 Staley, T. E., and H. D. Perry. 1995. Maize silage utilization of fertilizer and soil nitrogen on a hill-land Ultisol relative to tillage method. Agronomy Journal 87: 835-842.

ST96 Stevens, W. E., J. J. Varco, and J. R. Johnson. 1996. Evaluating cotton nitrogen dynamics in the GOSSYM Simulation Model. Agronomy Journal 88: 127-132.

SW72 Switzer, G. L., and L. E. Nelson. 1972. Nutrient accumulation and cycling in loblolly pine (P. taeda) plantation ecosystems: first twenty years. Soil Science Society America Journal 36: 143-147.

WI80 Wittwer, R. F., M. J. Immel, and F. R. Ellingsworth. 1980. Nutrient uptake in fertilized plantations of American sycamore. Soil Science Society America Journal 44: 606-610.

ZA76 Zartman, R. E., R. E. Phillips, and J. E. Leggett. 1976. Comparison of simulated and measured nitrogen accumulation in burley tobacco. Agronomy Journal 68: 406-410.

APPENDIX III. Literature review of annual soil denitrification rates. RN = record number; SITE = state abbreviation or other geographic location; BRIEF DESCRIPTION = vegetation cover; LULC = forest (F), agriculture (A), herbaceous (G), emergent wetland (EW), woody wetland (WW); FERT = fertilized (Y) or not fertilized (N); HYD = hydric soil (Y) or not hydric soil (N); D = annual denitrification; REF = reference source.

RN	SITE	BRIEF DESCRIPTION	LULC	FERT	HYD	D	UNITS	REF
1	Can.	Fallow-Wheat	A	N	.	0.69	g N m-2	AU84
2	Can.	Fallow-Wheat	A	N	.	1.22	g N m-2	AU84
3	Can.	Wheat-Fallow	A	Y	.	0.33	g N m-2	AU84
4	Can.	Wheat-Fallow	A	Y	.	1.43	g N m-2	AU84
5	Can.	Wheat-Fallow	A	N	.	1.52	g N m-2	AU84
6	Can.	Wheat-Fallow	A	N	.	3.36	g N m-2	AU84
7	Can.	Wheat-Wheat	A	Y	.	1.17	g N m-2	AU84
8	Can.	Wheat-Wheat	A	Y	.	1.58	g N m-2	AU84
9	NC	Corn	A	Y	Y	6.00	g N m-2	GA75
12	MI	Deciduous Forest	F	.	Y	2.40	g N m-2	GR89
13	MI	Deciduous Forest	F	.	Y	4.00	g N m-2	GR89
14	MI	Deciduous Forest	F	.	Y	0.05	g N m-2	GR89
15	MI	Deciduous Forest	F	.	N	1.10	g N m-2	GR89
16	MI	Deciduous Forest	F	.	N	1.70	g N m-2	GR89
17	MI	Deciduous Forest	F	.	N	0.08	g N m-2	GR89
18	MI	Deciduous Forest	F	.	N	1.00	g N m-2	GR89
19	MI	Deciduous Forest	F	.	N	1.80	g N m-2	GR89
20	MI	Deciduous Forest	F	.	N	0.06	g N m-2	GR89
21	RI	Deciduous Forest	F	.	N	0.48	g N m-2	HA94
22	RI	Deciduous Forest	F	.	Y	0.63	g N m-2	HA94
23	RI	Deciduous Forest	F	.	N	0.57	g N m-2	HA94
24	RI	Deciduous Forest	F	.	Y	1.63	g N m-2	HA94
25	RI	Residential	G	.	N	0.71	g N m-2	HA94
26	RI	Residential	G	.	Y	2.14	g N m-2	HA94
27	RI	Residential	G	.	N	1.59	g N m-2	HA94
28	RI	Residential	G	.	Y	3.85	g N m-2	HA94
29	.	Meadow (Flooded)	EW	.	Y	19.00	g N m-2	LE94
30	.	Meadow (Flooded)	EW	.	Y	22.00	g N m-2	LE94

31	.	Meadow (Flooded)	EW	.	Y	43.00 g N m-2	LE94
32	.	Meadow (Flooded)	EW	.	Y	46.00 g N m-2	LE94
33	GA	Row Crop-Cover Crop	A	.	.	0.50 g N m-2	LO92
34	GA	Row Crop-Cover Crop	A	.	.	0.78 g N m-2	LO92
35	GA	Row Crop-Cover Crop	A	.	.	0.78 g N m-2	LO92
36	GA	Row Crop-Cover Crop	A	.	.	1.06 g N m-2	LO92
47	NC	Loblolly Pine	F	.	.	0.07 g N m-2	RO87
48	NC	Loblolly Pine (Clearcut)	F	.	.	0.60 g N m-2	RO87
49	CA	Vegetable Prod Unit	A	Y	.	18.40 g N m-2	RY80
50	CA	Vegetable Prod Unit	A	Y	.	22.30 g N m-2	RY80
51	CA	Vegetable Prod Unit	A	Y	.	13.20 g N m-2	RY80
52	CA	Vegetable Prod Unit	A	Y	.	9.50 g N m-2	RY80
53	CA	Vegetable Prod Unit	A	Y	.	14.20 g N m-2	RY80
54	CA	Vegetable Prod Unit	A	Y	.	15.50 g N m-2	RY80
55	CA	Vegetable Prod Unit	A	Y	.	17.20 g N m-2	RY80
65	Denmark	Alder Stand	F	N	Y	0.18 g N m-2	ST90
66	Denmark	Alder Stand	F	N	Y	0.49 g N m-2	ST90
67	Denmark	Alder Stand	F	Y	Y	1.62 g N m-2	ST90
68	Denmark	Alder Stand	F	Y	Y	2.60 g N m-2	ST90
69	Denmark	Alder Stand	F	Y	Y	4.21 g N m-2	ST90
70	Berkshire	Ryegrass pasture	G	N	.	0.16 g N m-2	RY83
71	Berkshire	Ryegrass pasture	G	Y	.	1.11 g N m-2	RY83
72	Berkshire	Ryegrass pasture	G	Y	.	2.91 g N m-2	RY83
73	NC	Hardwood forest	F	N	.	1.46 g N m-2	TO75
74	KS	Tallgrass prairie	G	N	.	0.90 g N m-2	GR95
75	KS	Tallgrass prairie	G	N	.	0.53 g N m-2	GR95
76	KS	Tallgrass prairie	G	N	.	0.59 g N m-2	GR95
77	KS	Tallgrass prairie	G	N	.	0.30 g N m-2	GR95
78	KS	Tallgrass prairie	G	N	.	0.02 g N m-2	GR95
79	KS	Tallgrass prairie	G	N	.	0.27 g N m-2	GR95
80	KS	Tallgrass prairie	G	N	.	0.00 g N m-2	GR95
81	KS	Tallgrass prairie	G	N	.	0.30 g N m-2	GR95
82	KS	Forest	F	N	.	0.52 g N m-2	GR95
83	.	Riparian forest	F	Y	Y	8.04 g N m-2	LO95
84	.	Riparian forest	F	Y	Y	5.63 g N m-2	LO95
85	GA	Forage production	G	Y	.	10.70 g N m-2	LO98

86	GA	Forage production	G	Y	.	24.70 g N m-2	LO98
87	GA	Forage production	G	Y	.	4.90 g N m-2	LO98
88	GA	Forage production	G	Y	.	5.10 g N m-2	LO98
89	Sweden	Flooded meadow	EW	N	Y	22.00 g N m-2	DA98
90	Sweden	Flooded meadow	EW	N	Y	43.00 g N m-2	DA98
91	Sweden	Flooded meadow	EW	N	Y	46.00 g N m-2	DA98
92	NY	Deciduous Forest	F	N	Y	0.20 g N m-2	AS98
93	NY	Deciduous Forest	F	N	Y	0.44 g N m-2	AS98
94	NY	Deciduous Forest	F	N	N	0.07 g N m-2	AS98
95	NY	Deciduous Forest	F	N	N	0.07 g N m-2	AS98
96	NY	Deciduous Forest	F	N	N	0.08 g N m-2	AS98
97	RI	Forest	F	N	N	0.32 g N m-2	GR97
98	RI	Forest	F	N	N	0.27 g N m-2	GR97
99	RI	Forest	F	N	Y	0.56 g N m-2	GR97
100	RI	Forest	F	N	Y	1.02 g N m-2	GR97
101	RI	Forest	F	N	Y	13.56 g N m-2	GR97
102	RI	Forest	F	N	N	0.17 g N m-2	GR97
103	RI	Forest	F	N	N	0.13 g N m-2	GR97
104	RI	Forest	F	N	Y	0.24 g N m-2	GR97
105	RI	Forest	F	N	Y	0.27 g N m-2	GR97
106	RI	Forest	F	N	Y	1.40 g N m-2	GR97
107	RI	Forest	F	N	N	0.53 g N m-2	GR97
108	RI	Forest	F	N	N	0.44 g N m-2	GR97
109	RI	Forest	F	N	Y	0.70 g N m-2	GR97
110	RI	Forest	F	N	Y	0.76 g N m-2	GR97
111	RI	Forest	F	N	Y	0.44 g N m-2	GR97
112	RI	Forest	F	N	N	0.26 g N m-2	GR97
113	RI	Forest	F	N	N	0.33 g N m-2	GR97
114	RI	Forest	F	N	Y	0.22 g N m-2	GR97
115	RI	Forest	F	N	Y	0.24 g N m-2	GR97
116	RI	Forest	F	N	Y	0.17 g N m-2	GR97
117	RI	Forest	F	N	N	0.24 g N m-2	GR97
118	RI	Forest	F	N	Y	0.32 g N m-2	GR97
119	RI	Forest	F	N	Y	0.25 g N m-2	GR97
120	RI	Forest	F	N	Y	3.36 g N m-2	GR97
121	RI	Forest	F	N	N	0.12 g N m-2	GR97

122	RI	Forest	F	N	Y	0.12 g N m-2	GR97
123	RI	Forest	F	N	Y	0.17 g N m-2	GR97
124	RI	Forest	F	N	Y	0.93 g N m-2	GR97
125	RI	Forest	F	N	N	0.44 g N m-2	GR97
126	RI	Forest	F	N	N	1.17 g N m-2	GR97
127	RI	Forest	F	N	Y	0.38 g N m-2	GR97
128	RI	Forest	F	N	Y	1.99 g N m-2	GR97
129	RI	Forest	F	N	Y	3.21 g N m-2	GR97
130	RI	Forest	F	N	N	0.25 g N m-2	GR97
131	RI	Forest	F	N	N	0.30 g N m-2	GR97
132	RI	Forest	F	N	Y	0.25 g N m-2	GR97
133	RI	Forest	F	N	Y	0.26 g N m-2	GR97
134	RI	Forest	F	N	Y	0.41 g N m-2	GR97
135	Sweden	Barley	G	Y	.	0.12 g N m-2	SV91
136	Sweden	Barley	G	Y	.	0.32 g N m-2	SV91
137	Sweden	Grass ley	G	Y	.	0.36 g N m-2	SV91
138	Sweden	Grass ley	G	Y	.	1.98 g N m-2	SV91
139	Sweden	Lucerne	G	N	.	2.61 g N m-2	SV91
140	GA	Forage production	G	N	.	0.56 g N m-2	LO98
141	GA	Forage production	G	N	.	3.00 g N m-2	LO98
142	GA	Forage production	G	N	.	1.81 g N m-2	LO98
143	GA	Forage production	G	N	.	1.52 g N m-2	LO98
144	GA	Forage production	G	Y	.	5.59 g N m-2	LO98
145	GA	Forage production	G	Y	.	18.10 g N m-2	LO98
146	GA	Forage production	G	Y	.	4.20 g N m-2	LO98
147	GA	Forage production	G	Y	.	3.47 g N m-2	LO98
148	GA	Forage production	G	Y	.	15.80 g N m-2	LO98
149	GA	Forage production	G	Y	.	29.70 g N m-2	LO98
150	GA	Forage production	G	Y	.	5.57 g N m-2	LO98
151	GA	Forage production	G	Y	.	6.85 g N m-2	LO98
152	GA	Forage production	G	Y	.	10.70 g N m-2	LO98
153	GA	Forage production	G	Y	.	23.90 g N m-2	LO98
154	GA	Forage production	G	Y	.	4.90 g N m-2	LO98
155	GA	Forage production	G	Y	.	5.10 g N m-2	LO98
		End of File					

APPENDIX III REFERENCES

AS98 Ashby, J. A., W. B. Bowden, and P. S. Murdoch. 1998. Controls on denitrification in riparian soils in headwater catchments of a hardwood forest in the Catskill Mountains, USA. Soil Biology and Biochemistry 30: 853-864.

AU84 Aulakh, M. S., D. A. Rennie, and E. A. Paul. 1984. Gaseous nitrogen losses from soils under zero-till as compared with conventional-till management systems. Journal of Environmental Quality 13: 130-136.

DA98 Davidsson, T. E., and L. Leonardson. 1998. Seasonal dynamics of denitrification activity in two water meadows. Hydrobiologia 364: 189-198.

GA75 Gambrell, R. P., J. W. Gilliam, and S. B. Weed. 1975. Denitrification in subsoils of the North Carolina coastal plain as affected by soil drainage. Journal of Environmental Quality 4: 311-316.

GR89 Groffman, P. M., and J. M. Tiedje. 1989. Denitrification in north temperate forest soils: spatial and temporal patterns at the landscape and seasonal scales. Soil Biology and Biochemistry 21: 613-620.

GR95 Groffman, P. M., and C. L. Turner. 1995. Plant productivity and nitrogen gass fluxes in a tallgrass prairie landscape. Landscape Ecology 10: 255-266.

GR97 Groffman, P. M., and G. C. Hanson. 1997. Wetland denitrification: influence of site quality and relationships with wetland delineation protocols. Soil Science Society America Journal 61: 323-329.

HA94 Hanson, G. C., P. M. Groffman, and A. J. Gold. 1994. Denitrification in riparian wetlands receiving high and low groundwater nitrate inputs. Journal of Environmental Quality 23: 917-922.

LE94 Leonardson, L., L. Bengtsson, T. Davidsson, T. Persson, and U. Emanuelsson. 1994. Nitrogen retention in artificially flooded meadows. Ambio 23: 332-341.

LO92 Lowrance, R. 1992. Groundwater nitrate and denitrification in a coastal plain riparian forest. Journal of Environmental Quality 21: 401-405.

LO95 Lowrance, R., G. Vellidis, and R. K. Hubbard. 1995. Denitrification in a restored riparian forest wetland. Journal of Environmental Quality 24: 808-815.

LO98 Lowrance, R., J. C. Johnson, Jr., G. L. Newton, and R. G. Williams. 1998. Denitrification from soils of a year-round forage production system fertilized with liquid dairy manure. Journal of Environmental Quality 27: 1504-1511.

RO87 Robertson, G. P., P. M. Vitousek, P. A. Matson, and J. M. Tiedje. 1987. Denitrification in a clearcut Loblolly pine (Pinus taeda L.) plantation in the southeastern United States. Plant and Soil 97: 119-129.

RY80 Ryden, J. C., and L. J. Lund. 1980. Nature and extent of directly measured denitrification losses from some irrigated vegetable crop production units.

Soil Science Society America Journal 44: 505-511.

RY83 Ryden, J. C. 1983. Denitrification loss from a grassland soil in the field receiving different rates of nitrogen as ammonium nitrate. Journal of Soil Science 34: 355-365.

ST90 Struwe, S., and A. Kjoller. 1990. Seasonality of denitrification in water-logged alder stands. Plant and Soil 128: 109-113.

SV91 Svensson, B. H., L. Klemedtsson, S. Simkins, K. Paustian, and T. Rosswall. 1991. Soil denitrification in three cropping systems characterized by differences in nitrogen and carbon supply. Plant and Soil 138: 257-271.

TO75 Todd, R. L., J. B. Waide, and B. W. Cornaby. 1975. Significance of biological nitrogen fixation and denitrification in a deciduous forest ecosystem, pp. 729-735. IN (F. G. Howell, J. B. Gentry, and M. H. Smith, eds.) Mineral Cycling in Southeastern Ecosystems. National Technical Information Service, Springfield, Virginia.

APPENDIX IV. Arc Macro Language (AML) script 1

```
/*N nmodel.aml
/*
/*P-------------------------------Purpose--------------------------------
/*
/*  Calculate potential excess nitrogen flux from each pixel in the Neuse
/*  River watershed for each of four seasons.  Also categorizes each pixel
/*  as a source of N, sink for N, or too close to call.
/*
/*A------------------------------Arguments-------------------------------
/*G---------------------------Global Variables---------------------------
/*L---------------------------Local Variables----------------------------
/*
/*  season = season being considered
/*
/*I----------------Input/Output Files, Coverages, etc.-------------------
/*
/*  Requires a grid called "landcover" which contains the landcover/land
/*  use categories and seasonal excess nitrogen values for each category.
/*  Assumes that there is a "boundary" coverage in the .. workspace.
/*  Creates two grids for each season.
/*
/*R----Other AML programs, Menus, or Programs Run by this AML program----
/*B---Other Aml programs, Menus, or Programs that run this AML program---
/*O---------------------Operating System dependencies--------------------
/*
/*  Must be run from within ARC GRID.  Developed with Arc/Info 7.2.1 on
/*  a Sun Ultra 5 running Solaris.
/*
/*H-------------------------------History--------------------------------
/*                         Original coding by:
/*                           Tom L. Ashwood
/*                    Environmental Sciences Division
/*                     Oak Ridge National Laboratory
/*                            P.O. Box 2008
/*                        Oak Ridge, TN 37831-6036
/*  Version 0, August 2000
/*E======================================================================
/*
&SEVERITY &ERROR &ROUTINE bailout
/*
/* Setup the basic GRID environment
/*
SETWINDOW ../boundary  /* Make sure window is set within Neuse boundary
SETCELL 15  /*  Uses 15-m pixels.
/*
/* Seasonal do-loop
/*
&DO season &LIST SPRING SUMMER FALL WINTER
  /*
  /*  Apply seasonal excess N values to each pixel based on landcover.
  /*  Convert g N/m^2 to g n/pixel by multiplying by 225 m^2/pixel
  /*
  %season%1grd = CON(landcover ne 0, INT(225 * landcover.%season% + .5))
  /*
  /*  Convert pixels to red-yellow-green schema based on excess N ranges
  /*  that correspond to <-225 (green or sink), >225 (red or source),
```

```
  /*  and >-225 <225 (yellow, too close to call).
  /*
  IF(%season%1grd lt -225) %season%grd = 3  /* Green
    ELSE IF(%season%1grd gt 225) %season%grd = 2  /* Red
    ELSE %season%grd = 7  /*  Yellow
  ENDIF
&END
&CALL exit
&RETURN
/*
/*------------------------------Routine Exit------------------------------
/* Exit Routine - Return to default GRID environment
/*
&ROUTINE exit
SETWINDOW maxof
SETCELL maxof
&RETURN
/*
/*------------------------------Routine Bailout---------------------------
/*
&ROUTINE bailout
&SEVERITY &ERROR &IGNORE
&CALL exit
&RETURN &ERROR Bailing out of nmodel.aml
/* End of AML
```

APPENDIX V. Arc Macro Language (AML) script 2

```
/*N nmodel_r1.aml
/*
/*P------------------------------Purpose------------------------------
/*
/*  This AML creates a revised set of seasonal excess N grids
/*  by summing the seasonal grids for each parameter.
/*
/*A------------------------------Arguments------------------------------
/*G--------------------------Global Variables--------------------------
/*L--------------------------Local Variables----------------------------
/*
/*  season = season being considered
/*  sname = first three letters of %season%
/*
/*I----------------Input/Output Files, Coverages, etc.-----------------
/*
/*  Requires individual grids for each model parameter (i.e., atmospheric
/*  deposition, fertilizer, mineralization, uptake, and denitrification).
/*  Assumes that there is a "boundary" coverage in the /usr5/neuse workspace.
/*  Creates two grids for each season.
/*
/*R---Other AML programs, Menus, or Programs Run by this AML program----
/*B---Other Aml programs, Menus, or Programs that run this AML program---
/*O--------------------Operating System dependencies--------------------
/*
/*  Must be run from within ARC GRID.  Developed with Arc/Info 7.2.1 on
/*  a Sun Ultra 5 running Solaris..
/*
/*H------------------------------History-------------------------------
/*                            Original coding by:
/*                              Tom L. Ashwood
/*                       Environmental Sciences Division
/*                        Oak Ridge National Laboratory
/*                               P.O. Box 2008
/*                          Oak Ridge, TN 37831-6036
/*  Version 0, August 2000
/*E====================================================================
/*
&SEVERITY &ERROR &ROUTINE bailout
/*
/* Setup the basic GRID environment
/*
SETWINDOW /usr5/neuse/boundary  /* Make sure window is set within Neuse
boundary
SETCELL 15  /*  Uses 15-m pixels.
/*
/*  Seasonal do loop
/*
&DO season &LIST spring summer fall winter
  &SETVAR sname = [SUBSTR %season% 1 3]
/*  %season%r1 = 225 + /usr5/neuse/nmodel/fer%sname%grd + min%sname%grd1 ~
/*   - /usr5/neuse/nmodel/den%sname%grd - /usr5/neuse/nmodel/upt%sname%grd
  IF(%season%r1 lt -225) %season%r1grd = 3
    ELSE IF(%season%r1 gt 225) %season%r1grd = 2
    ELSE %season%r1grd = 7
    ENDIF
```

```
  &END
&CALL exit
&RETURN
/*
/*-------------------------------Routine Exit-----------------------------
/* Exit Routine
/*
&ROUTINE exit
&RETURN
/*
/*-----------------------------Routine Bailout---------------------------
/*
&ROUTINE bailout
&SEVERITY &ERROR &IGNORE
&CALL exit
&RETURN &ERROR Bailing out of nmodel_r1.aml
/* End of AML
```

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