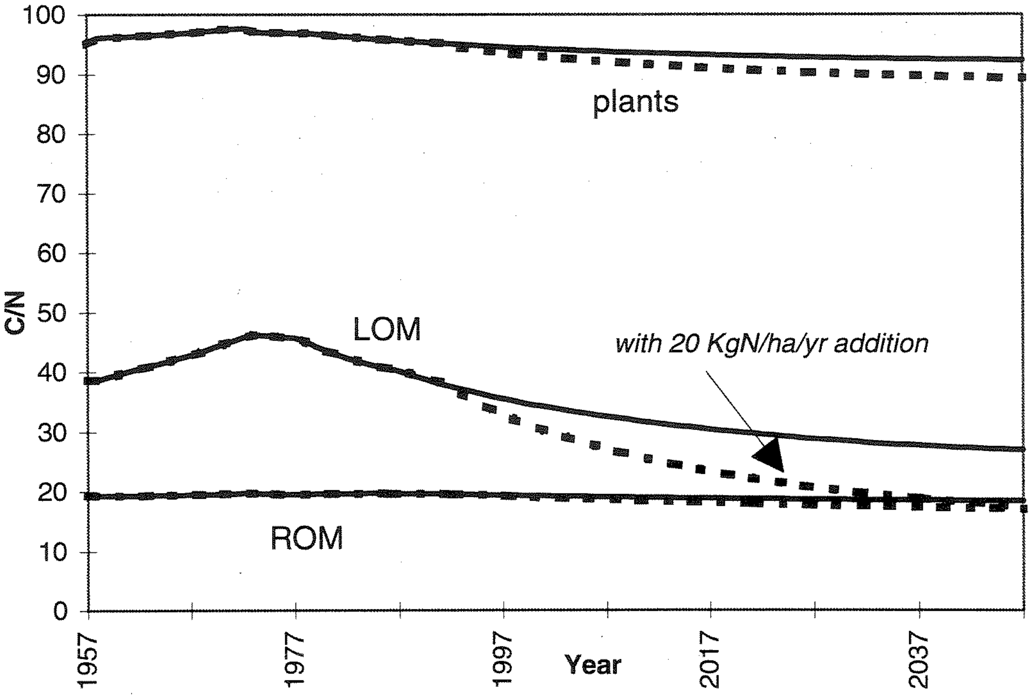
REPORT SNO 3844-98

The model MERLIN applied to Nordmoen, Norway

NATURENS TÅLEGRENSER

Miljøverndepartementet
Fagrapport nr. 95



C/N ratios

Naturens Tålegrenser

Programmet Naturens Tålegrenser ble satt igang i 1989 i regi av Miljøverndepartementet. Programmet skal blant annet gi innspill til arbeidet med Nordisk Handlingsplan mot Luftforurensninger og til pågående aktiviteter under Konvensjonen for Langtransporterte Grensoverskridende Luftforurensninger (Genevekonvensjonen). I arbeidet under Genevekonvensjonen er det vedtatt at kritiske belastningsgrenser skal legges til grunn ved utarbeidelse av nye avtaler om utslippsbegrensning av svovel, nitrogen og hydrokarboner.

En styringsgruppe i Miljøverndepartementet har det overordnete ansvar for programmet, mens ansvaret for den faglige oppfølgingen er overlatt en arbeidsgruppe bestående av representanter fra Direktoratet for naturforvaltning (DN), Norsk polarinstitutt (NP) og Statens forurensningstilsyn (SFT).

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REPORT

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Title The model MERLIN applied to Nordmoen, Norway	Serial No. 3844-98	Date 25. March 1998
	Report No. Sub-No. O-95173	Pages Price 41
Author(s) Sogn, Trine A. (IJVF, NLH) Wright, Richard F.	Topic group acid precipitation	Distribution
	Geographical area Norway	Printed NIVA

Client(s) Naturens tålegrense (Statens forurensningstilsyn) European Commission	Client ref.

Abstract

The process-oriented dynamic model, MERLIN, is been used to predict N leaching and risk of «N saturation» at the experimental field at Nordmoen, Norway. The model was calibrated to the period 1957 to 1987, and then compared to observed data from 4 years of experimental addition of N at 20 kg N ha^{-2} yr^{-1} (above ambient 11 kg N ha^{-2} yr^{-1}). The calibrated model was used to predict future trends in N leaching. MERLIN gave acceptable simulation of the increased N leaching observed in the N addition experiment. The model predicts that with ambient deposition there will be no significant leaching of N within the next 60 years; the forest is not at risk for N saturation. With ambient N load the model predicted the C:N ratio in forest floor to remain above 30. The enhanced deposition, on the other hand, is predicted to lead to significant increased NO_3 in leachate and a drop in the C:N ratio to below 25 after about 30 years. The critical load for nitrogen for this ecosystem is thus predicted to lie between 11 and 31 kg N ha^{-2} yr^{-1}.

4 keywords, Norwegian		4 keywords, English	
1.	sur nedbør	1.	acid precipitation
2.	nitrogen	2.	nitrogen
3.	modell	3.	model
4.	skog	4.	forest

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ISBN 82-577-3424-1

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Preface

This project came about as a result of interest in applying the new MERLIN model with data from the experimental field at Nordmoen, Norway. The project was supported by Naturens Tålegrense (Statens forurensningstilsyn contract 971800) and European Commission (Contract ENV4-CT95-0030, DYNAMO project).

Oslo, November 1997

Richard F. Wright

Contents

1. Summary

Atmospheric N deposition, in excess of plant requirements, is likely to lead to changes in forest ecosystem structure and function. Continuos input of N from the atmosphere may in the long-term produce «N-saturation», which among other things, is characterised by increased leaching of inorganic N below the rooting zone. Increased leaching leads to acidification of soils and waters. MERLIN (Model of Ecosystem Retention and Loss of Inorganic Nitrogen) is a potential tool for modelling the dynamics of N leaching, and can in the future be combined with MAGIC to model the dynamics of acidification of soils and waters and thus predict future exceedence of critical loads. Here MERLIN has been applied to the experimental field at Nordmoen, Norway.

The forest stand at Nordmoen (R1 and R2 plots) is a mixture of Scots pine and Norway spruce, 40 to 50 years old. The site was intensively investigated in the period 1986-1988 as part of the Integrated Forest Study (Johnson and Lindberg 1991). Since 1992 the plots have been added extra doses of N at 20 kg N ha^{-2} yr^{-1} in addition to ambient 11 kg N ha^{-1} yr^{-1} (I. Røsberg, pers. comm.).

MERLIN describes C and N cycles, and is comprised of 2 plant and 2 soil compartments (labile (LOM) and refractory (ROM) organic matter). Transfers between compartments occur by means of processes such as plant uptake, litter production, immobilisation, mineralization, nitrification and denitrification. Rates of plant uptake and cycling between pools are governed by the C:N ratios of the plant and soil pools.

The model was calibrated to match the C and N content of the different forest ecosystem compartments in the R1 and R2 plots at Nordmoen. The year 1957 was chosen as the starting point for the hindcast simulation. At this time the N deposition was significantly lower than today. A C and N cycle for the period 1957-1987 was reconstructed. Some historical information of changes in C and N content in different compartments of the young forest at Nordmoen is published, but the paucity of good historical information is a major source of uncertainty in the present model study. The N required to stand development and humus build-up, as well as loss of N in runoff, were assumed to come from deposition of N and «mining» of N from the soil ROM compartment.

The simulated leaching of N was compared to the N leakage measured after 4 years of N addition.

Two different scenarios were simulated. Scenario 1 assumes constant deposition at present-day levels. MERLIN simulated only a small increase in N leaching, and the C:N ratio did not decrease to less than 30 during the 60-year simulation period (1987-2047). For scenario 2 the extra N deposition of 20 kg ha^{-1}yr^{-1} was assumed to continue for 60 years. MERLIN simulated a significant increase in N leaching, and the C:N ratio in forest floor dropped below 25 around the year 2020. With this N load the time needed for the system to switch from being N-limited to N-rich was approximately 30 years.

As emphasised by Kjønaas *et al*. (1997) in the closely related assessment of the MERLIN model to the NITREX field at Gårdsjön, Sweden, the processes which govern the transition of a forest ecosystem from being N-rich to N-limited are still inadequately known. The ability of MERLIN to predict the time needed for a forest system to be N saturated is still uncertain. MERLIN may be an important contribution to the further development of qualitative understanding of the N cycle in forests. In order to aid evaluation of the model an extensive sensitivity analysis of the different model parameters are needed, as well as more data on changes in the C and N content in different compartments during forest succession. More data from long-term N addition experiments is also urgently required in order to properly test the model dynamics and prediction ability.

Coupling of MERLIN with MAGIC may provide a mechanism by which the dynamics of N and S exceedences of critical loads for soil and waters in Norwegian forest ecosystems can be explored.

2. Introduction

During the past years, there has been an increasing number of suggestions that deposition of N compounds from the atmosphere may negatively affect forest ecosystems (e.g. Nihlgård 1985, Skeffington and Wilson 1988). Atmospheric N deposition, in excess of plant requirements, is likely to lead to changes in ecosystem structure and function as well as to increase the loss of inorganic N to runoff. In N limited forest ecosystems typical for the boreal zone, the internal N cycle is tight, and little NO_3^- is usually lost to the soil water below the rooting zone (e.g. Stuanes *et al.* 1995). Even in these N limited forests, continuos input of N from the atmosphere may in the long-term produce «N saturation». True N saturation occurs when N losses are equal to or greater than N inputs. Other definitions put forward have simply viewed N saturation as the availability of NH_4^+ and NO_3^- in excess of the total combined plant and microbial N demand (Aber *et al.* 1989).

Predictions of the amount and number of years of N deposition a given forest ecosystem can tolerate before N saturation occurs, are crucial for the determination of critical loads for N in forest ecosystems. In the present study the process-oriented dynamic model MERLIN (Model of Ecosystem Retention and Loss of Inorganic Nitrogen) (Cosby *et al.* 1997) is used to indicate the time required for a forest ecosystem to move from a N limited to a N saturated state under a given rate of N deposition, assuming N saturation to occur when the N losses are equal or greater than the N inputs. MERLIN describes C and N cycles and is comprised of two plant and two soil compartments (labile and refractory organic matter). Transfer between compartments in the model occurs by means of processes such as plant uptake and cycling by the C:N ratios of the plant and soil pools (Cosby *et al.* 1997).

Intensive investigations of the C and N content in different compartments of a 40 to 50 years forest stand at Nordmoen, south-east Norway, were carried out during the Integrated Forest Study (Johnson and Lindberg 1992). The natural N deposition in the area is 0.079 mmol N m^{-2} yr^{-1}. Since 1992 the forest have received extra N, as NH_4NO_3 (I. Røsberg , pers. comm.).

In the present study we describe the calibration of MERLIN to the data from Nordmoen. An attempt to test the model is also carried out. Simulated leaching of N is compared to observed data on soil water N content following enhanced N input. The time for increased N leaching and N saturation at higher N load at Nordmoen is predicted by MERLIN. The potential of MERLIN to predict ecosystem effects following increased N input in forest ecosystems is discussed.

1. Site description, methods and data sources

3.1 Site description

The experimental field station at Nordmoen is located about 60 km north of Oslo at an elevation of 200 m. The R1 and R2 plots, used in the present study were established in 1986 as part of the Integrated Forest Study programme (Johnson and Lindberg 1991) in pristine forest.

The site was located on a flat plain of glaciofluvial deposits partly covered by a sheet of eolian sand. The deposits are about 60 m deep, overlying Precambrian and Permian crystalline bedrocks. The soil in the area was classified as a Typic Udipsamment (Stuanes and Sveistrup 1979).

The mature vegetation in the plots was a mixture of Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.), 40-50 years old. The dominating vascular plants were *Vaccinium myrtillus* L. and *Deschampsia flexuosa* (L.) Trin. (*Aira flexuosa* L.). The forest floor layer was dominated by moss species such as *Pleurozium schreberi* (Brid.) Mitt., *Hylocomium splendens* (Hedw.) Br Eur., *Ptilium crista-castrensis* (Hedw.) De Not., and *Dicranum* (Hedw.) spp. (Johnson and Lindberg 1991).

3.2 **Experimental design**

The natural N deposition in this area is 0.079 mmol N m^{-2} yr^{-1} (11 kg N ha^{-1} yr^{-1}). In the period from 1992 to 1997 the R1 and R2 plots have been treated with extra doses of N, as NH_4NO_3, in doses of 1 and 2 g N m^{-2} yr^{-1} (10 and 20 kg N ha^{-1} yr^{-1}) (I. Røsberg, pers. comm.). The NH_4NO_3 solution was applied 4 to 6 times during the growing season by use of a hand-driven insects spray pump. Concentrations of N in the soil water below the BC horizon were measured in the late autumn 1995, after 4 years of treatment (I. Røsberg, pers.comm.).

3.3 Methods and data for Normoen forest site 1987 and 1957

The year 1957 was chosen as a starting point for this model application. At this time the N deposition was significantly lower than the present-day deposition, and the forest was 10 to 20 years old. We thus avoid uncertainties involved in modelling the clear-cut and replanting period.

Values for C og N pools and fluxes for the reference year 1987 were obtained from measurements of tree biomass, litterfall, and soil chemistry reported by Johnson and Lindberg (1991).

3.3.1 Pools 1987

Trees:
The total biomass in the R1 and R2 plots is reported in the Table NS-1 in Johnson and Lindberg (1992). The various components were divided into a structural «wood stock» compartment and an active «plants» component. By consulting the closely related work by Kjønaas *et al.* (1997) where the MERLIN model was applied to NITREX Gårdsjön, the active component was decided to be calculated as the sum of foliage, 33.3% of the total branch, understory and 86.5% of the roots. The part of the total branch included in the active compartment was based on the assumption that 33.3% of the branch consists of twigs, which are reconditioned different from the branches. As done by Kjønaas *et al.* (1997) the part of the root biomass considered active was the fine roots less than 5 mm in diameter, assumed to be 86.5% of the total root biomass. The structural «wood stock» component was calculated as the sum of bole, stump, the rest of the branch (total branch-twigs=66.7%) and the rest of the roots (total root biomass-fine roots<5mm=13.5%). Assuming C to be 50% of the organic matter measured, the C and N pools in the active component were 199.5 and 2.11 mol m^{-2}, respectively. In the «wood stock» pool 189 and 1.23 mol m^{-2}, respectively.

Since no functions describing yearly increments in structural and active tree compartments for young Norway spruce forest were found, the yearly increments («pool change») in the structural and active compartments in the 40 to 50 years old stand were estimated using a modified version of the «empirical stand development» curves of Scots pine proposed by Albrektson (1980).

Soil:

The soil organic matter consists of components with quite different decomposition rates, ranging from days to several thousands of years. In the MERLIN programme the organic matter is simplified to include two fractions only. The labile organic matter (LOM) represents a fraction with a rapid turnover time (0 to 10 years), while the refractory organic matter (ROM) represents the organic matter compartments with longer turnover time (10 to 100 years). Although the different types of organic matter are dispersed throughout the soil both vertically and horizontally, in general litter and forest floor consists of the more rapidly decomposed material, whereas the organic matter in the deeper soil horizons usually consists of older material with a slower turnover time. In the present model application, LOM was represented by the organic matter in the O-horizon, while ROM was taken to be the organic matter content of the deeper mineral horizons. The C and N contents in these two compartments were gained by using the data collected during the Integrated Forest Study programme, Table NS-1 in Johnson and Lindberg (1991). This resulted in C:N ratios of the LOM and ROM pools of 39 and 19, respectively.

Yearly changes («pool change») in the LOM and ROM pool were estimated by using data from Sogn *et al.* (In review), where changes in total content of C and N in the mor layer and mineral soil down to 60 cm have been investigated during a forest rotation (0-100 years) at Nordmoen.

3.3.2 Fluxes 1987

Input-output:
Atmospheric input, and the leaching of N at 60 cm soil depth (BC horizon) were measured in the period from October 1986 to October 1988 during the IFS programme (Table NS-2 in Johnson and Lindberg 1991). The mean deposition of N (sum of wet and dry deposition) in this period was 79 mmol m^{-2} yr^{-1}. The output of inorganic N at 60 cm soil depth was 1.7 mmol m^{-2} yr^{-1}.

Litterfall:
Litterfall was measured during the IFS-programme (Table NS-3 in Johnson and Lindberg 1991). The above-ground litterfall contained 12 mol C m^{-2} yr^{-1}. As model input litter flux includes both above and below-ground litterfall. By assuming a below ground yearly litter production equal to the fine roots biomass down to 60 cm depth, a total C litter flux of 32.4 mol m^{-2} yr^{-1} was estimated.

Soil N transformation processes:
A buried-bag incubation technique has been used at Nordmoen to measure the rate and amount of microbiological conversion of organic N to NH_4^+ (ammonification) and NH_4^+ to NO_3^- (nitrification) (Mahindan 1988). Incubations, made *in situ*, were conducted over 1 and 3 month during the growing season (May-August) and over 1 month in September and October. Based on this study the net N mineralization rate was estimated to be 10.8 mmol m^{-2} yr^{-1} , which was only 0.2% of the total N in LOM. In an assembly describing the nutrient cycling at the R1/R2 plots at Nordmoen, Kvindesland and Røsberg (In review) pointed out that a mineralization of all the N in the annual litterfall would still not satisfy the N uptake. Although the deficit could partly be compensated by draining N from the existing large pool of soil N, the study indicated a significantly higher N mineralization rate than found by Mahindan (1988). Using the figure estimated from the study by Mahindan (1988) as a staring value, the net N mineralization percent of the LOM N content was adjusted to be 0.6% (Appendix A) in order to obtain internal consistency in the N cycle (Appendix A) .

3.3.3 Changes in pools and fluxes from 1957 to 1987

The area where the R1 and R2 plots were situated, was after clear cutting replanted in 1937 and 1947. The stand age was in 1987 40 and 50 years old.

Data for variations in bole, active crown and litterfall C and N content within the 40 to 50 years of development are not available for this area. The yearly increments in the structural and active compartments in the 40 to 50 years old stand were estimated using a modified version of the «empirical stand development» curves of Scots pine proposed by Albrektson (1980). The following changes were assumed. As the forest at Nordmoen was growing from age 10 to 20 years in 1957 to age 40 to 50 years in 1987, only about 1 mol N m^{-2} was stored in the boles of the trees, and only about 0.05 mol N m^{-2} was lost to leachate (Appendix A). During the stand development the active plant compartment was assumed to increase the N storage by 1.8 mol N m^{-2}. Time trends in the C and N content of LOM and ROM were estimated using data from Sogn *et al.* (In review) where changes in total C and N in the mor layer and mineral soil down to 60 cm have been investigated during a forest rotation (0-100 years) at Nordmoen. The LOM pool the C content was estimated to increase by 0.24 mol m^{-2} yr^{-1} with a C:N ratio of the ambient LOM (Appendix A). A «mining» of ROM in order to supply the N necessary for growth of trees and build up of forest floor was assumed. Such «mining» has been reported in several studies (e.g. Johnson 1991, Emmett *et al.* 1996, Sogn *et al*. In review) and is probably a natural feature of boreal forests. Most probably N is translocated from ROM to LOM via the plants, initially by uptake and then litterfall. According to studies by Berg (1986) there is a higher net release of N during the mineralization of older organic matter (ROM) than in younger material. This net released N is then available for plant uptake. During the mineralization of litter in the mor layer, less decomposed litter may cause a net immobilization of N and thus a reimmobilization instead of uptake by roots. In this way a recycling of N within the soil is taken place. The wood pool C content was assumed to increase by 7.7 mol m^{-2} yr^{-1} with a C:N ratio of 154 (Appendix A).

4. Description of MERLIN

MERLIN is a simple process-oriented model focused on simulating and predicting concentrations of inorganic N in soil leachate and runoff in terrestrial ecosystems (Cosby *et al.* 1997). The model links C and N cycles. The ecosystem is simplified to 2 plant compartments (active biomass such as foliage and roots and structural woody biomass) and 2 soil compartments (labile and refractory organic matter) (Figure 1). The C pools and fluxes are set external to the model. N pools and fluxes are then linked to C by C:N ratios in the pools. Transfer between compartments occurs by processes such as plant uptake, litterfall, immobilisation, mineralization, nitrification and denitrification. There is no feedback between N status and C fluxes; this would be the next step in complexity. The key to MERLIN is that the rates of these processes are assumed to be governed by C:N ratios in the various pools. MERLIN is comprised of (1) a book-keeping procedure in which inputs and outputs of C and N to the ecosystem and between the 4 compartments are tallied, and (2) a series of simultaneously-operating processes that describe the transfer of C and N between the compartments and out of the ecosystem. The model is designed to function at annual time steps.

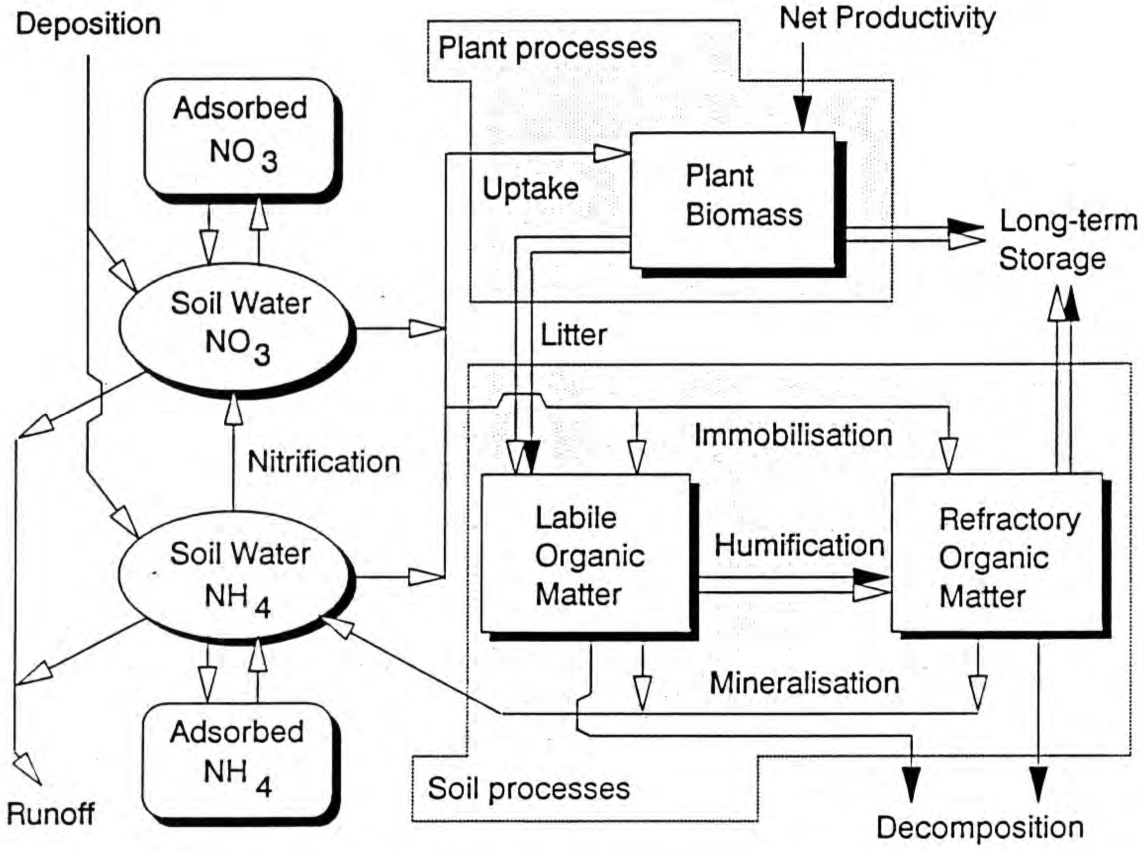


Figure 1. A schematic representation of the MERLIN model. Closed arrows represent fluxes of inorganic C; open arrows represent fluxes of inorganic N. Paired closed/open arrows represent fluxes of organic material containing both C and N (from Cosby *et al.* 1997.).

The model deals with NO_3, NH_4 and organic N. N inputs are as atmospheric deposition, fertilisers and N fixation. Time series of all inputs of inorganic N must be specified *a priori*. Nitrification, microbially-mediated transformation of NH_4 to NO_3, is represented in the model by a first-order reaction (1). The rate of loss of NH_4 is the product of a rate constant and the concentration of NH_4 at each time step:

$$FN_{nit} = NIT \times (NH_4)_{soil} \times SPV \qquad (1)$$

where FN_{nit} is the nitrifrication loss of NH_4 (mmol m^{-2} yr^{-1}), $(NH_4)_{soil}$ is the concentration of NH_4 in soil solution (mmol m^{-3}), NIT is the nitrification rate constant (yr^{-1}), and SPV is the pore volume per unit area of the soil (m). Adsorption of NH_4 on the soil matrix is modelled as a non-linear capacity-limited process using a Langmuir isotherm approach. N losses from the system are as inorganic in runoff and as gases (N_2O and N_2) from denitrification.

Plant biomass represents the aggregated pool of C and N present in the active portion of the ecosystem. The time series of net productivity is determined from specified time sequences of plant biomass, litter production and long-term storage such as wood production (Figure 1).

Plant growth requires N uptake from the soil as NH_4 and NO_3. Uptake is modelled as a non-linear Michaelis-Menten process that depends on the soil water concentration of NH_4 or NO_3 (2).

$$FNx_{upt,\,plt} = K_{mx,\,Nx,\,plt} \times \frac{(Nx)_{soil}}{(K_{hlf,\,Nx,\,plt} + (Nx)_{soil})} \qquad (2)$$

where $FNx_{upt,\,plt}$ is the uptake flux of inorganic N species by the plant compartment (mmol m^{-2} yr^{-1}), $(Nx)_{soil}$ is the concentration of inorganic N species in soil solution (mmol m^{-3}). $K_{mx,\,Nx,\,plt}$ is the maximum uptake rate (mmol m^{-2} yr^{-1}) which is calculated by the formula

$$K_{mx,Nx,plt} = FC_{npp} \times M_{Nx,plt} \qquad (3)$$

where FC_{npp} is the net primary production (mmol C m^{-2} yr^{-1}) and $M_{Nx,plt}$ is the maximum N element, Nx, uptake per unit of C production (mol N per mol C). $K_{hlf,\,Nx,\,plt}$ is the half-saturation constant (the concentration of inorganic N species at which plant uptake proceeds at half the maximum rate; mmol m^{-3}) calculated by the formula

$$K_{hlf,Nx,plt} = K_0 \times \exp\left(\frac{C{:}N_{0,plt} - C{:}N_{plt}}{S_{Nx,plt}}\right) \qquad (4)$$

where K_0 is the upper limit of uptake half saturation parameter as C:N's of biomass decrease (mmol m^{-3}), $C{:}N_{0,plt}$ the target C:N ration of the biomass compartment (mol C per mol N), $C{:}N_{plt}$ the C or N ratio of the biomass compartment (mol C per mol N) and $S_{Nx,plt}$ is the steepness of decline in uptake half-saturation parameter as C:N's of biomass increase (unitless). The maximum uptake rate is assumed to be proportional to the net primary productivity of the plants.

Soil organic material is divided into two compartments: labile organic matter (LOM) and refractory organic matter (ROM). Each is an aggregated pool of C and N representing accumulated organic compounds in the ecosystem. These materials provide the energy substrate for soil micro-organisms, which immobilise and mineralise C and N in soils (Figure 1). Similar to plant uptake the microbial immobilisation of inorganic N is modelled as a non-linear Michaelis-Menten process that depends on the concentration of NH_4 or NO_3 using the equations (2), (3) and (4). The maximum immobilisation rate is assumed proportional to microbial secondary productivity.

Litter from the plant compartment enters the LOM pool. C and N leave this pool by decomposition (transformation of organic C to CO_2) and decay (degradation of the quality of the organic material). The decay products are passed on to the next compartment (ROM). Decomposition also occurs in ROM. The model requires input information for litter production, size of the C pool stored in LOM, and decomposition of LOM at each time step. In addition the size of the C pool stored in ROM is required.

These compartments and fluxes are highly aggregated. Conceptually the LOM pool represents that fraction of soil organic matter with relatively short turnover time (0-10 years), whereas ROM represents the fraction of soil organic matter with longer turnover time. The LOM pool may be most readily identified with the forest floor, but organic matter such decaying roots are also LOM and are found in deeper soil layers. LOM provides a soil organic matter compartment that can respond rather quickly to changing external conditions and inputs. The ROM pool, on the other hand, represents the bulk of C and N present in the rest of the soil profile. The long-term storage losses from the ROM represent losses of organic matter through leaching of dissolved organic compounds in drainage waters or peat formation.

Inputs required for MERLIN are temporal sequences of: 1) C fluxes and pools, 2) hydrologic discharge, and 3) external sources of inorganic N. Initial conditions (amounts of C and N) must be specified for each compartment. A number of «constants» (e.g. uptake parameters) are needed to specify the N dynamics of the organic compartments, and characteristics of the soils must be given (depth, porosity, bulk density, anion/cation exchange characteristics).

Outputs from MERLIN include: 1) concentrations and fluxes of NH_4 and NO_3 in soil water and runoff; 2) total N contents of the various compartments; 3) the C:N ratios of the aggregated plant and soil compartments; and 4) estimates of important processes in the N cycle (i.e. uptake, gross and net mineralization and immobilisation).

5. Calibration procedure

The first step in the calibration of MERLIN to data from the Nordmoen field involved the compilation of C and N pool and flux data for reference year 1987 and for the year 1957 in the past (Appendix A). The necessary data were compiled in spreadsheets (Appendix A) and the complete C and N cycles are calculated and checked for internal consistency.

The next step was to define the time sequences of changes of pools and fluxes over the period 1957-87. In other words, how did the forest grow in terms of C and N. Although the history of the forest in the R1 and R2 plots at Nordmoen is relatively well known, no measurements of changes in C and N storage during the 40 to 50 years of forest growth are available. The following changes was assumed as basis for the calibration procedure. As the forest at Nordmoen was growing from age 10-20 years in 1957 to age 40-50 years in 1987, only about 1 mol N m^{-2} was stored in the boles of the trees, and only about 0.05 mol N m^{-2} was lost to leachate (Appendix A). During the stand development the active plant compartment was assumed to increase the N storage by 1.8 mol N m^{-2}. We assumed changes in the LOM pool (by an increase in C of 0.24 mol m^{-2} yr^{-1} with a C:N ratio of the ambient LOM, Appendix A) (Sogn *et al.* In review), the wood pool (by an increase in the C content of 7.7 mol m^{-2} yr^{-1} with a C:N ratio of 154, Appendix A), and the N deposition (increasing from 1957 to 1987 following estimates of A. Semb NILU, used by Kjønaas *et al.* 1997). Changes in ROM pool are calculated by MERLIN at each time step to balance the C budget.

Calibration of MERLIN then involved adjusting the parameters (see eq.(2), (3) and (4)) for the three N uptake/immobilization functions: plants, LOM and ROM. The maximum N uptake per unit of C production ($M_{x.plt}$, $M_{x.LOM}$ and $M_{x.ROM}$, in eq. (3)), the upper limit of uptake half-saturation parameter as C:N's of biomass decrease (K_0 in eq. (4)), the position of the Michaelis-Menten uptake curve (C:N reference, i.e the target C:N ratio of the biomass compartment ($C:N_{0,plt}$, $C:N_{0.LOM}$ and $C:N_{0,ROM}$, in eq. (4))) and the steepness of decline in uptake half-saturation parameter as C:N's of biomass increase ($S_{x.plt}$, $S_{x.LOM}$ and $S_{x.ROM}$, in eq. (4)) (Appendix B). For each trial the model was run from starting values in 1957 to 1987 and the suitability of the calibration was subjectively judged with respect to the best fit for:
(1) carbon pools in 1987 agree with observed;
(2) C:N ratios in the pools in 1987 agree with observed;
(3) Changes in C:N ratios over the 30-year period are acceptable;
(4) N output (leachate) in 1987 agree with the observed.

Tables of pools and fluxes for the Nordmoen calibration and a print-out of the parameter values are given in Appendix A and B.

The calibrated model was evaluated using results from I. Røsberg's N addition experiments. Finally the model was used to assess the future impact of 2 scenarios of N deposition. Scenario 1 was 60 years of constant N deposition (11 kg ha^{-1} yr^{-1}), while scenario 2 was 60 years of enhanced N depoisition (11+20 = 31 kg N ha^{-1} yr^{-1}).

6. Results and discussion

The evaluation
After 4 years with addition of 2 g N m^{-2} yr^{-1} , a 4-fold increase in the soil water N concentration below the BC horizon was observed at the R1/R2 plot (I. Røsberg, pers. comm.). MERLIN simulated this increased N leaching (Figure 2). After 4 years with extra N addition MERLIN simulated the flux of N out of the system to be 4.6 mol N m^{-2} yr^{-1}. The simulated N flux was about 30 % lower than the observed flux after 4 years with enhanced N input. The discrepancy between simulated and observed is acceptable in that the observed value also is uncertain. This uncertainly stems from the fact that the soil water below the BC-horizon was only sampled occasionally during a limited period the autumn 1995 (I. Røsberg, pers. comm.), and thus seasonal variations are not included. Furthermore the increased N observed in the soil water the autumn 1995 does not necessarily reflect the real N status of the system. The forest system has had a limited time to respond to the sudden enhanced N deposition. On long-term basis, it is the changes in major processes such as the ratio of gross NH_4^+ and NO_3^- immobilization to gross mineralization, and the soil C:N ratio that is expected to determine the leaching level (Aber 1992). Additional years of N treatment and measurements are necessary in order to determine whether the increasing trend is correct, and to fully validate the predictive capacity of MERLIN.

The prediction
The calibrated model was used to assess 2 scenarios for future N deposition at Nordmoen. For scenario 1 (constant deposition) MERLIN simulated a small increase in N leaching from the forest at Nordmoen during the 60-year forecast period (Figure 2). A reduction in the LOM C:N ratio was simulated (Figure 3), but C:N ratio did not decrease below 30 within the 60 year-period. This suggests that this stand at Nordmoen is not at risk of N saturation under present-day levels of N deposition.

For scenario 2 the N deposition was increased by 20 kg N ha^{-1} yr^{-1} (total 31 kg N ha^{-1} yr$^{-1)}$ (Røsberg's experimental dose) for 60 years into the future (Figure 2). The N content in both the active plant pool and LOM were predicted to increase (Figure 3) as did N leaching during the 60-year simulation period (Figure 2). The C:N ratio of the LOM compartment was predicted to drop from around 40 before 1987 down to 25 around 2020, and then below 25 (Figure 3). With this N load the time needed for the system to switch from N-limited, indicated by high C:N ratio in LOM, to N-rich with a C:N ratio below 25, was estimated to be 25-30 years. Since MERLIN simulated the measured N leaching after 4 years of treatment relatively well, some confidence could be put into the results. However, both the rate and capacity of N assimilation, as well as the response of C dynamics to enhanced N deposition are inadequately understood.

The relationship between the C:N ratio and N leaching (Figure 4) corresponded with general results from the European forest stands and NITREX sites, at which significant N leaching appears at sites with low C:N ratios (Gundersen *et al.* 1998) (Figure 4). However, as emphasised by Kjønaas *et al.* (1997), the time needed for a system to change from being N limited, indicated by high C:N ratio in LOM, to a N-rich system, with a C:N ratio below 25, is uncertain, and the processes which govern the transition are not fully understood.

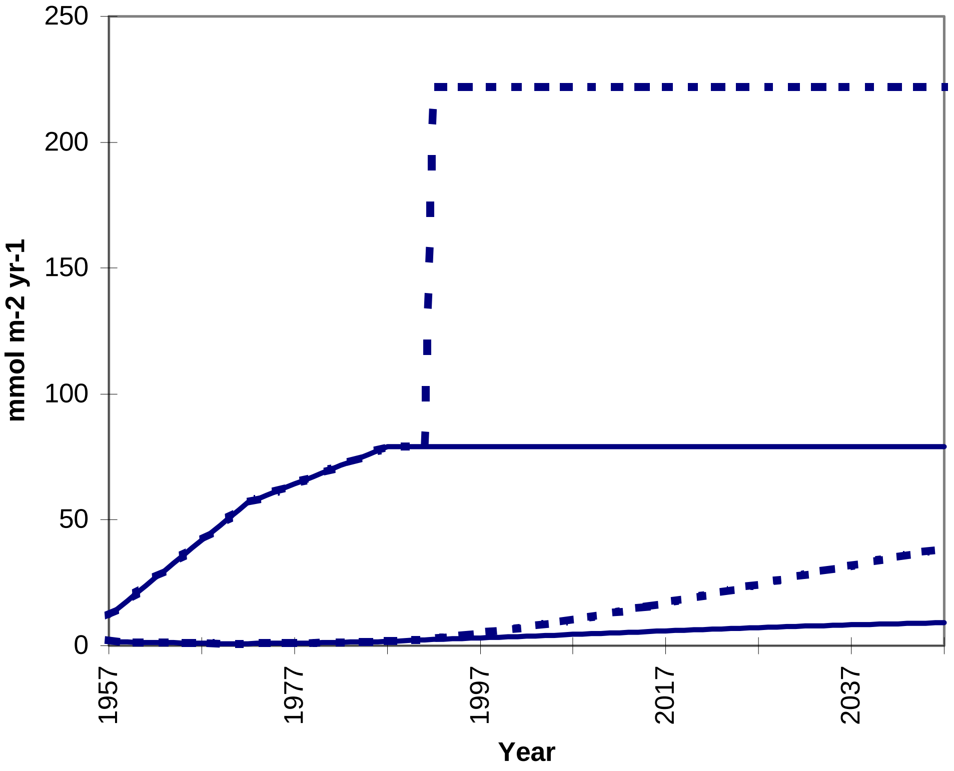


Figure 2. Results of MERLIN calibration and prediction for Nordmoen. Deposition and runoff. Solid line represents scenario 1 (constant N deposition at 1987 levels). Dotted line represents scenario 2 (with extra N addition).

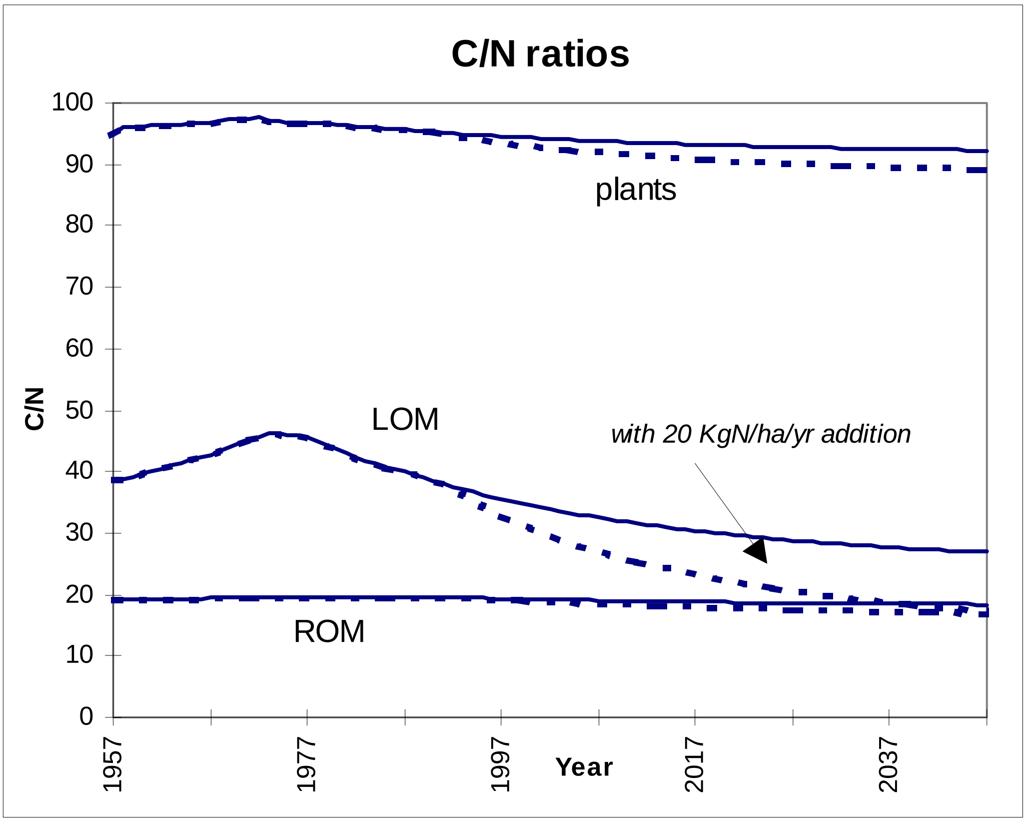


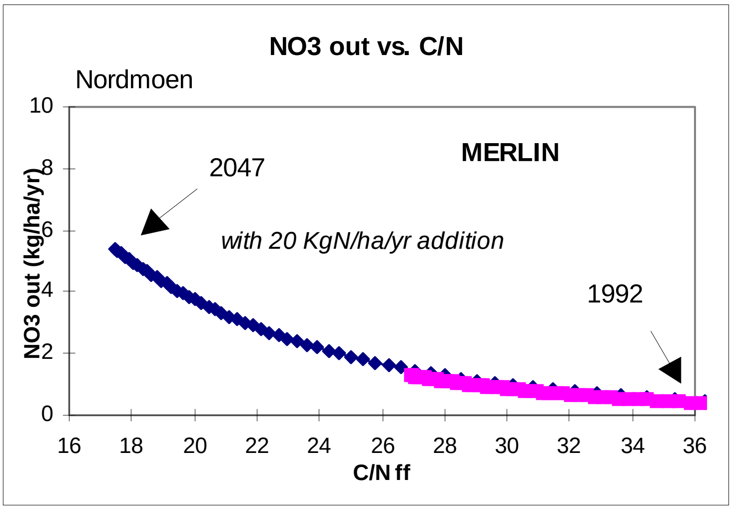
Figure 3. Results of MERLIN calibration and prediction for Nordmoen. C:N ratios in the three pools and gross mineralization and immobilisation in LOM and ROM. Solid line represents scenario 1 (constant N deposition at 1987 levels). Dotted line represents scenario 2 (with extra N addition).

General discussion

This application of MERLIN to Nordmoen corroborates applications of the model to NITREX sites at Aber, Wales, UK (Emmett *et al.* 1997) and Gårdsjön, Sweden (Kjønaas *et al.* 1997). In all cases the model calibrations suffer from inadequate data for C and N dynamics in forest ecosystems. In particular the changes in pools and fluxes during a forest rotation cycle are inadequately known. As pointed out by Kjønaas *et al.* (1997) there have been few studies of litter production, build-up of LOM and changes in ROM over a forest life cycle. Traditional forest studies focus mainly on wood production. Studies such as the survey of Sitka spruce stands of different ages in Wales (Emmett *et al.* 1993, Stevens *et al.* 1994) are urgently required for other major tree species such as Norway spruce and Scots pine. More background data regarding variations of C and N during forest succession are needed in order to increase the reliability of MERLIN predictions and those of any model in which N leaching is related to ecosystem N pools.

The application of the MERLIN model to Gårdsjön, Sweden, by Kjønaas *et al.* (1997) showed that MERLIN is a useful tool for bookkeeping of N pools and fluxes. This is also the case for our application to Nordmoen. The model may also be an important contribution to further development of qualitative understanding of the N cycle in forest ecosystems. However, the testing and application of the model is still too limited to generalise on its utility and robustness. Data to fully validate the model are scarce. An extensive sensitivity analysis of the key parameters is also urgently required. However, additional applications of MERLIN to sites such as Nordmoen may indicate whether a relatively narrow range of values for key parameters can satisfactorily explain observed ecosystem effects. Such model applications may also reveal whether major aspects of ecosystem behaviour following changes in N deposition can be accounted for by changes in mineralization and soil N accumulation rates.

This application of MERLIN to Nordmoen can be used to estimate critical load for N in the area. Critical loads for both water (groundwater) and soil at Nordmoen has been calculated previously by Wright et al. (1991) using the dynamic model MAGIC and several static models. These indicate that the critical load for acidity at Nordmoen is zero for both water and soil, largely because the growing forest depletes the soil of base cations faster that these are resupplied by weathering and deposition. More recently the nutrient cycling model NuCM (Liu *et al.*1992) has been assessed to the Nordmoen site (Kvindesland, In review). While the MAGIC simulations predicted a critical load of S < 0 mmol$_c$ SO_4^{2-} m^{-2} yr^{-1} to ensure that the molar Ca:Al ratio in soil solution does not fall below 1, NuCM predicted a load of approximately 70 mmol$_c$ SO_4^{2-} m^{-2} yr^{-1}. Historically and at present most of the acidification at Nordmoen has been due to S deposition. MERLIN indicates that at present-day N deposition there will be no appreciable N leaching and thus no acidity generated by N deposition in the next 60 years. This indicates that the critical load for N is greater than 11 kg N ha^{-1} yr^{-1} but less than 31 kg N ha^{-1} yr^{-1}.



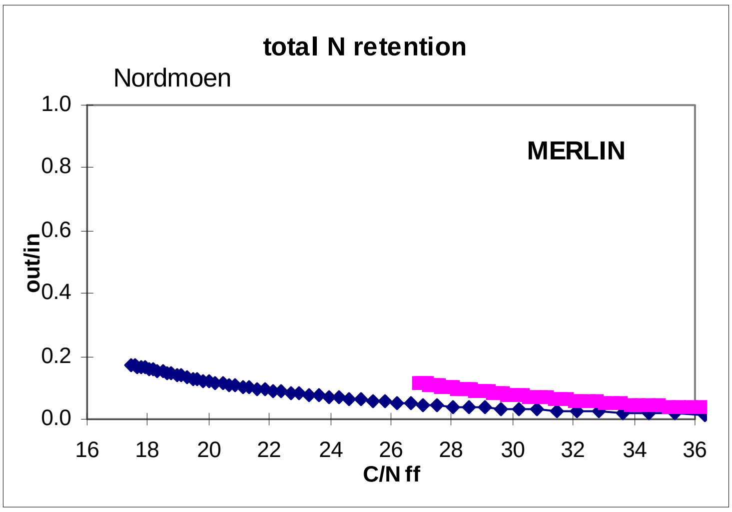


Figure 4. N flux out (top panel) and ratio of output to input of inorganic N (bottom panel) versus the C:N ratio in the forest floor (LOM). Solid diamonds: with 20 kg N ha^{-1} yr^{-1} addition; grey squares: with no N addition.

6. Acknowledgements

We thank O. Janne Kjønaas, Sheila Kvindesland and Ingvald Røsberg for professional assistance on selecting suitable data from Nordmoen, as well as how to prepare them for MERLIN application.

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Appendix A. C and N mass balances used in MERLIN

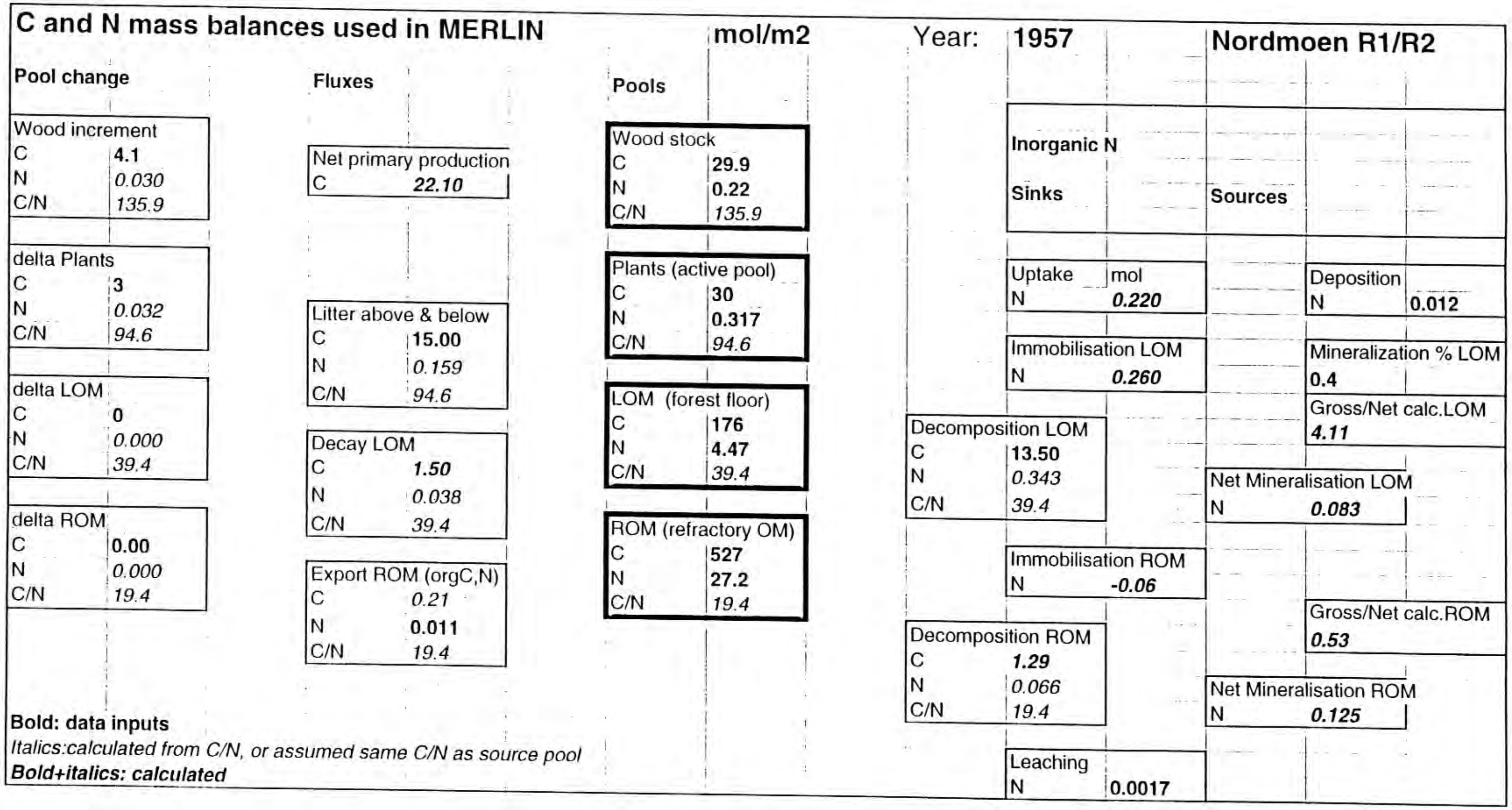
Shown are spreadsheets for 2 key years, 1957 and 1987.

Table 1 shows year 1957, the start of the hindcast period at which time the forest was 10/20 years-old.

Table 2 shows the year 1987, the end of the hindcast period. Now the forest is 40/50 years old.

The C and N cycles are calculated from measured (or estimated) values for several parameters. These are shown in **bold** and include estimates for C and N contents of the 2 plant and 2 soil compartments outlined in bold at the centre, the annual C increment to these pools (left-hand column), and the deposition and leaching (right-hand column). In addition the fractions of total mineralisation occurring in LOM and ROM must be specified. All other values are calculated from these, either from mass-balance considerations or from assumptions about C:N ratios. The column at the left shows the annual incremental change in the pools, the next column gives the fluxes between the pools. The columns to the right of the pools show the sinks and sources. The details of the calculations are given in Table 3.

1957



C and N mass balances used in MERLIN

mol/m2

Year: **1957**

Nordmoen R1/R2

Pool change

Wood increment	
C	**4.1**
N	*0.030*
C/N	*135.9*

delta Plants	
C	**3**
N	*0.032*
C/N	*94.6*

delta LOM	
C	**0**
N	*0.000*
C/N	*39.4*

delta ROM	
C	**0.00**
N	*0.000*
C/N	*19.4*

Fluxes

Net primary production	
C	***22.10***

Litter above & below	
C	**15.00**
N	*0.159*
C/N	*94.6*

Decay LOM	
C	***1.50***
N	*0.038*
C/N	*39.4*

Export ROM (orgC,N)	
C	*0.21*
N	**0.011**
C/N	*19.4*

Pools

Wood stock	
C	**29.9**
N	**0.22**
C/N	*135.9*

Plants (active pool)	
C	**30**
N	**0.317**
C/N	*94.6*

LOM (forest floor)	
C	**176**
N	**4.47**
C/N	*39.4*

ROM (refractory OM)	
C	**527**
N	**27.2**
C/N	*19.4*

Inorganic N

Sinks

Uptake	mol
N	***0.220***

Immobilisation LOM	
N	***0.260***

Decomposition LOM	
C	**13.50**
N	*0.343*
C/N	*39.4*

Immobilisation ROM	
N	***-0.06***

Decomposition ROM	
C	***1.29***
N	*0.066*
C/N	*19.4*

Leaching	
N	**0.0017**

Sources

Deposition	
N	**0.012**

Mineralization % LOM
0.4

Gross/Net calc.LOM
4.11

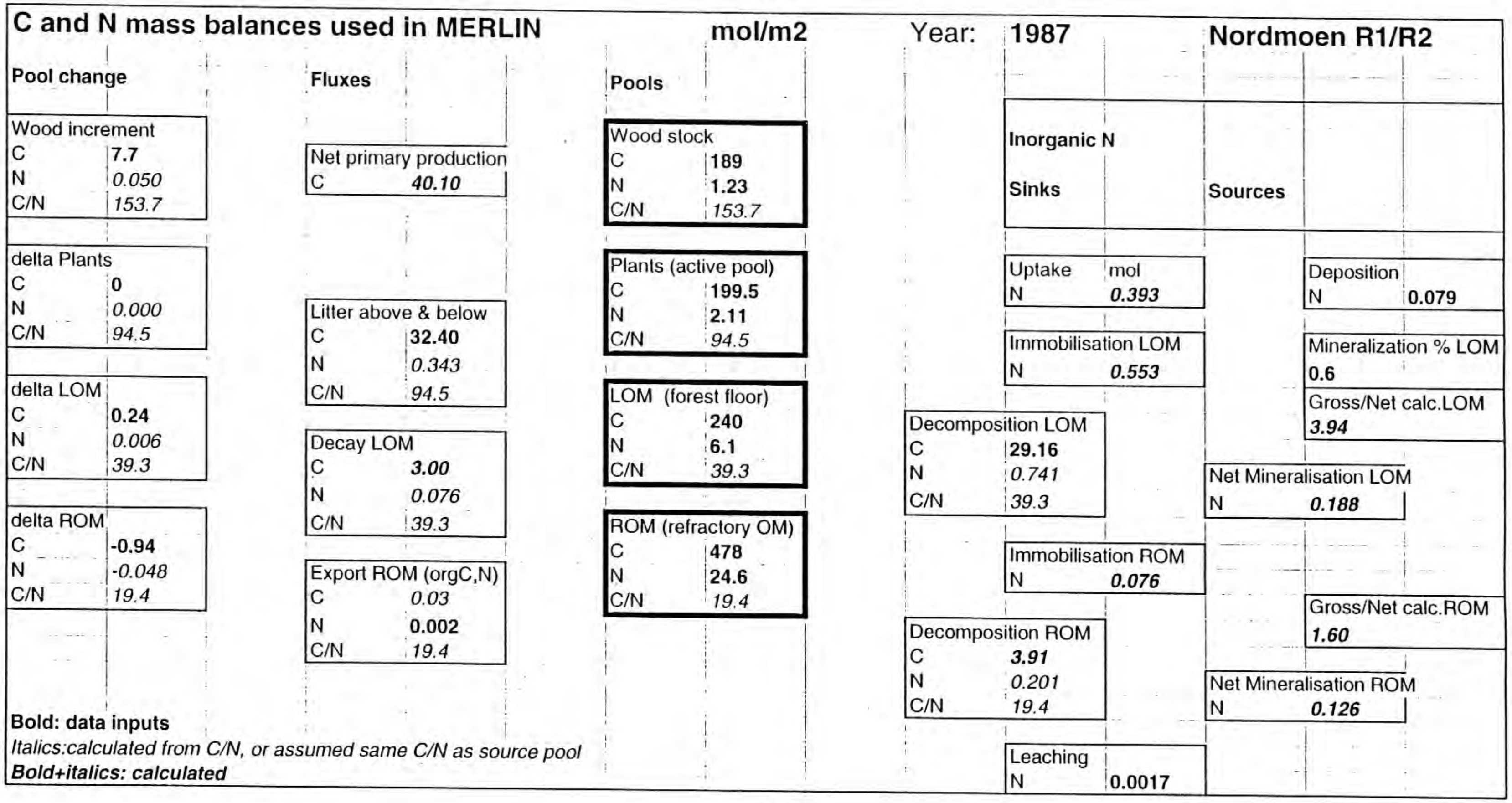
Net Mineralisation LOM	
N	***0.083***

Gross/Net calc.ROM
0.53

Net Mineralisation ROM	
N	***0.125***

Bold: data inputs
Italics:calculated from C/N, or assumed same C/N as source pool
Bold+italics: calculated

Balance_1987



C and N mass balances used in MERLIN **mol/m2** Year: **1987** **Nordmoen R1/R2**

Pool change

Wood increment
C **7.7**
N *0.050*
C/N *153.7*

delta Plants
C **0**
N *0.000*
C/N *94.5*

delta LOM
C **0.24**
N *0.006*
C/N *39.3*

delta ROM
C **-0.94**
N *-0.048*
C/N *19.4*

Fluxes

Net primary production
C ***40.10***

Litter above & below
C **32.40**
N *0.343*
C/N *94.5*

Decay LOM
C ***3.00***
N *0.076*
C/N *39.3*

Export ROM (orgC,N)
C *0.03*
N **0.002**
C/N *19.4*

Pools

Wood stock
C **189**
N **1.23**
C/N *153.7*

Plants (active pool)
C **199.5**
N **2.11**
C/N *94.5*

LOM (forest floor)
C **240**
N **6.1**
C/N *39.3*

ROM (refractory OM)
C **478**
N **24.6**
C/N *19.4*

Inorganic N

Sinks

Uptake mol
N ***0.393***

Immobilisation LOM
N ***0.553***

Decomposition LOM
C **29.16**
N *0.741*
C/N *39.3*

Immobilisation ROM
N ***0.076***

Decomposition ROM
C ***3.91***
N *0.201*
C/N *19.4*

Leaching
N **0.0017**

Sources

Deposition
N **0.079**

Mineralization % LOM
0.6

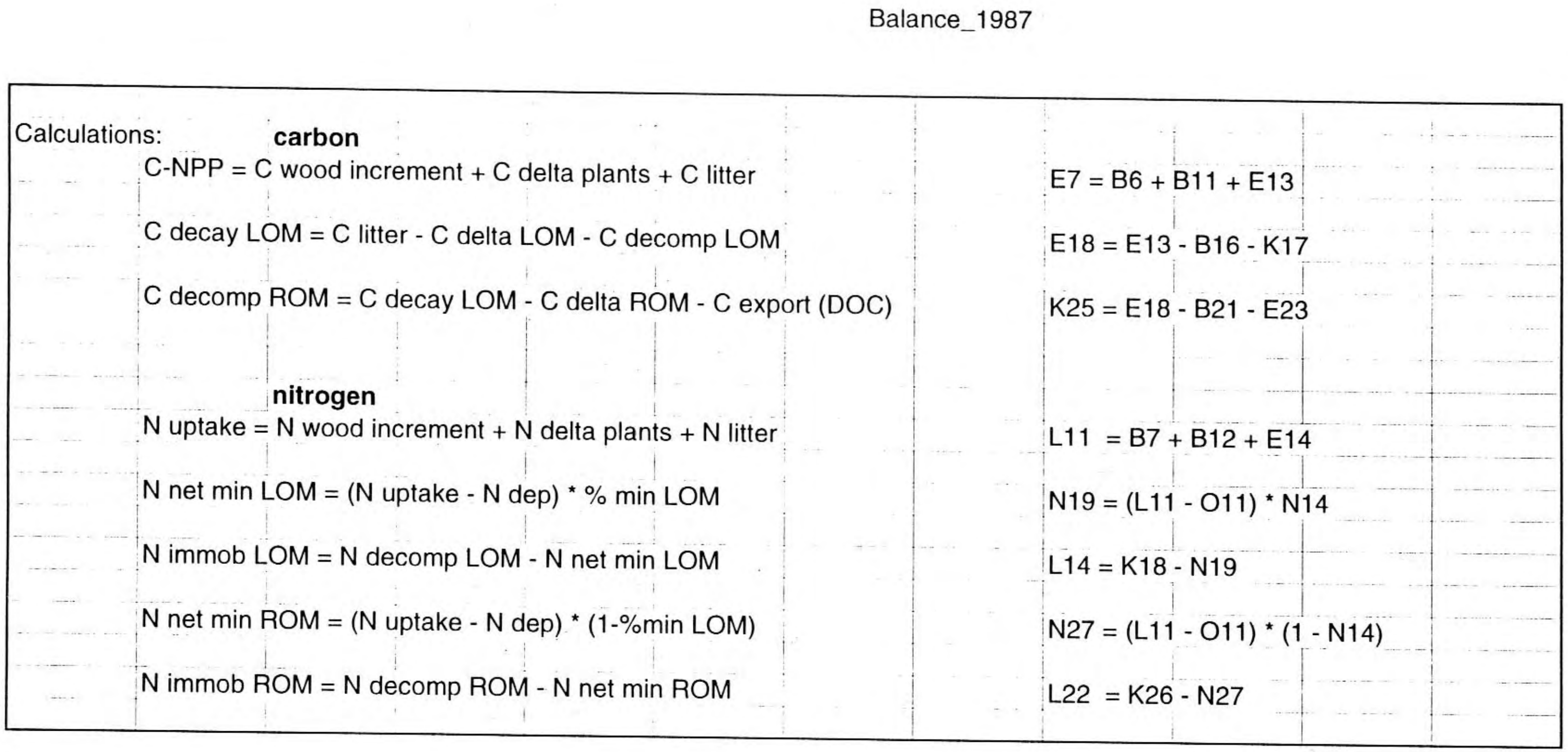
Gross/Net calc.LOM
3.94

Net Mineralisation LOM
N ***0.188***

Gross/Net calc.ROM
1.60

Net Mineralisation ROM
N ***0.126***

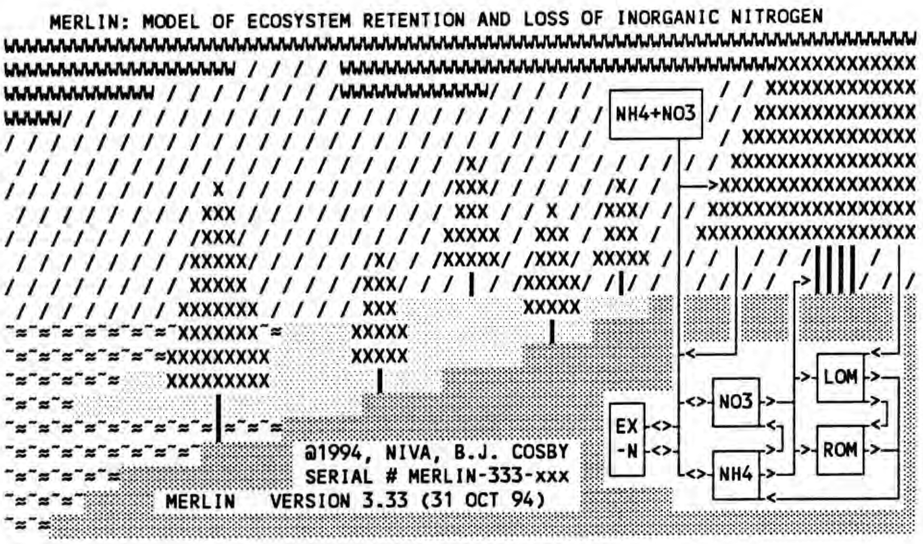
Bold: data inputs
Italics:calculated from C/N, or assumed same C/N as source pool
Bold+italics: calculated



Balance_1987

Calculations:	
carbon	
C-NPP = C wood increment + C delta plants + C litter	E7 = B6 + B11 + E13
C decay LOM = C litter - C delta LOM - C decomp LOM	E18 = E13 - B16 - K17
C decomp ROM = C decay LOM - C delta ROM - C export (DOC)	K25 = E18 - B21 - E23
nitrogen	
N uptake = N wood increment + N delta plants + N litter	L11 = B7 + B12 + E14
N net min LOM = (N uptake - N dep) * % min LOM	N19 = (L11 - O11) * N14
N immob LOM = N decomp LOM - N net min LOM	L14 = K18 - N19
N net min ROM = (N uptake - N dep) * (1-%min LOM)	N27 = (L11 - O11) * (1 - N14)
N immob ROM = N decomp ROM - N net min ROM	L22 = K26 - N27

Appendix B. Parameter values for calibration of MERLIN to Nordmoen



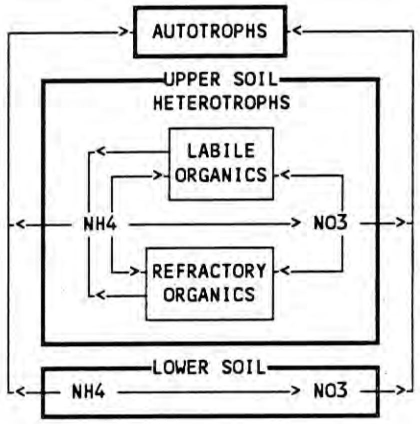
MERLIN: MODEL OF ECOSYSTEM RETENTION AND LOSS OF INORGANIC NITROGEN

@1994, NIVA, B.J. COSBY
SERIAL # MERLIN-333-xxx
MERLIN VERSION 3.33 (31 OCT 94)

FOUR PROCESSES CONTROL INORGANIC NITROGEN SPECIATION AND EXCHANGE BETWEEN BIOMASS POOLS AND THE SOILS.

UPTAKE: REMOVAL OF NO3 AND NH4 FROM SOIL
BY AUTOTROPHS (CAN BE FROM BOTH SOILS)
IMMOBILIZATION: REMOVAL OF NO3 AND NH4
BY HETEROTROPHS (FROM UPPER SOIL ONLY)
MINERALIZATION: RELEASE OF NH4 INTO SOIL
(TO THE UPPER SOIL ONLY)
NITRIFICATION: CONVERSION OF NH4 TO NO3
(CAN OCCUR IN BOTH SOILS)

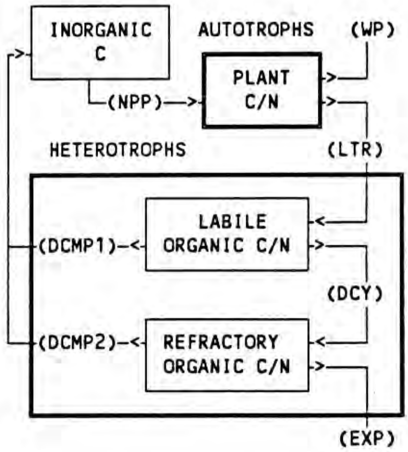
UPTAKE AND IMMOBILIZATION ARE NONLINEAR FUNCTIONS OF SOIL N CONCENTRATION, C/N OF BIOMASS, AND CARBON PRODUCTIVITY
MINERALIZATION IS A LINEAR FUNCTION OF DECOMPOSITION AND C/N OF BIOMASS



SEVEN FLUXES CONTROL THE CARBON CONTENT OF THE AGGREGATED BIOMASS POOLS.

- -(NPP) NET PRIMARY PRODUCTION
- -(WP) WOOD PRODUCTION
- -(LTR) LITTER PRODUCTION
- -(DCY) DECAY OF LABILE ORGANIC MATTER, CONVERTED TO REFRACTORY ORGANIC MATTER
- -(DCMP1 & DCMP2) DECOMPOSITION OF LABILE AND REFRACTORY ORGANIC MATTER
- -(EXP) ORGANIC MATTER EXPORT FROM SOIL

CARBON FLUXES (MOL/M2/T) AND/OR POOL SIZES (MOL/M2) MUST BE SPECIFIED.
CARBON FLUXES TRANSPORT NITROGEN BY MOVING ORGANIC-N ALONG WITH CARBON IN THE RATIO OF C/N IN THE SOURCE BIOMASS (OR BY USING A SPECIFIED C/N RATIO).



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CATCHMENT = Nordmoen R1/R2                               DATE = 11/17/97      TIME = 16:35:37        ** PAGE  2

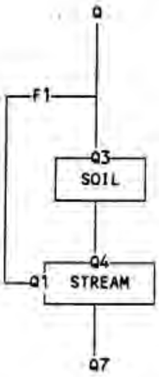
--------------- HINDCAST ---------------

 MERLIN   VERSION 3.33 (31 OCT 94)                    RUN DATE = 11/17/97               RUN TIME = 16:35:37

CATCHMENT = Nordmoen R1/R2

HINDCAST SIMULATION PERIOD =   30 YEARS       MONTHLY VARIATION = N        START YEAR = 1957        END YEAR = 1987

INTEGRATION TIME STEP =    0.0417 YEARS
```



```
ROUTING OF FLOW THROUGH THE CATCHMENT IS:

 F1 = % RUNOFF NOT CONTACTING TERRESTRIAL AREAS

                  --%-      -----------MM----------
                   F1      Q1      Q3      Q4      Q7
ANNUAL AVE         0.      0.    350.    350.    350.
```

```
    MEAN ANNUAL DISCHARGE =       0.350 M/YR


    MEAN ANNUAL PRECIPITATION =       1.000 M/YR

             -------- REFERENCE YEAR 1987                  ------- BACKGROUND YEAR 1957
              PRECIP CONC    DEPOSITION                     PRECIP CONC    DEPOSITION
               (MEQ/M3)        FACTOR                        (MEQ/M3)        FACTOR

NH4                38.0          1.0                             5.8           1.0
NO3                41.0          1.0                             6.1           1.0

THE FOLLOWING CONDITIONS ARE SET FOR Nordmoen R1/R2

    CONSTANT--------------------------STREAM        CONSTANT----------------------------SOIL
    RETENTION TIME (YR)                 0.00        SOIL DEPTH (M)                      0.45
    RELATIVE AREA (FRAC)                0.00        POROSITY (FRAC)                     0.45
    MEAN DEPTH (M)                      0.00        BULK DENSITY (KG/M3)             1021.00
                                                    NH4 MAX CAP (MEQ/KG)                0.00
                                                    NH4 HLF SAT (MEQ/M3)                0.00
                                                    NO3 MAX CAP (MEQ/KG)                0.00
                                                    NO3 HLF SAT (MEQ/M3)                0.00
                                                    PORE VOLUME (M)                     0.20
                                                    SOIL MASS (KG/M2)                 459.45

BIOLOGICAL PARAMETERS FOR NITROGEN ASSIMILATION

        AUTOTROPHS (PLANT BIOMASS)            HETEROTROPHS (LAB. ORGANIC)          HETEROTROPHS (REF. ORGANIC)
   NH4 UPT, OPTIMUM C/N       10.000     NH4 UPT, OPTIMUM C/N        1.000     NH4 UPT, OPTIMUM C/N        5.000
   NH4 UPT, REFERNC K2      1000.000     NH4 UPT, REFERNC K2      1000.000     NH4 UPT, REFERNC K2      1000.000
   NH4 UPT, REFERNC C/N       89.000     NH4 UPT, REFERNC C/N       25.000     NH4 UPT, REFERNC C/N       17.000
   NH4 UPT, C/N HFWD K2        1.500     NH4 UPT, C/N HFWD K2        8.000     NH4 UPT, C/N HFWD K2        0.550
   NO3 UPT, OPTIMUM C/N       10.000     NO3 UPT, OPTIMUM C/N        1.000     NO3 UPT, OPTIMUM C/N        5.000
   NO3 UPT, REFERNC K2      1000.000     NO3 UPT, REFERNC K2      1000.000     NO3 UPT, REFERNC K2      1000.000
   NO3 UPT, REFERNC C/N       89.000     NO3 UPT, REFERNC C/N       25.000     NO3 UPT, REFERNC C/N       17.000
   NO3 UPT, C/N HFWD K2        1.500     NO3 UPT, C/N HFWD K2        8.000     NO3 UPT, C/N HFWD K2        0.550
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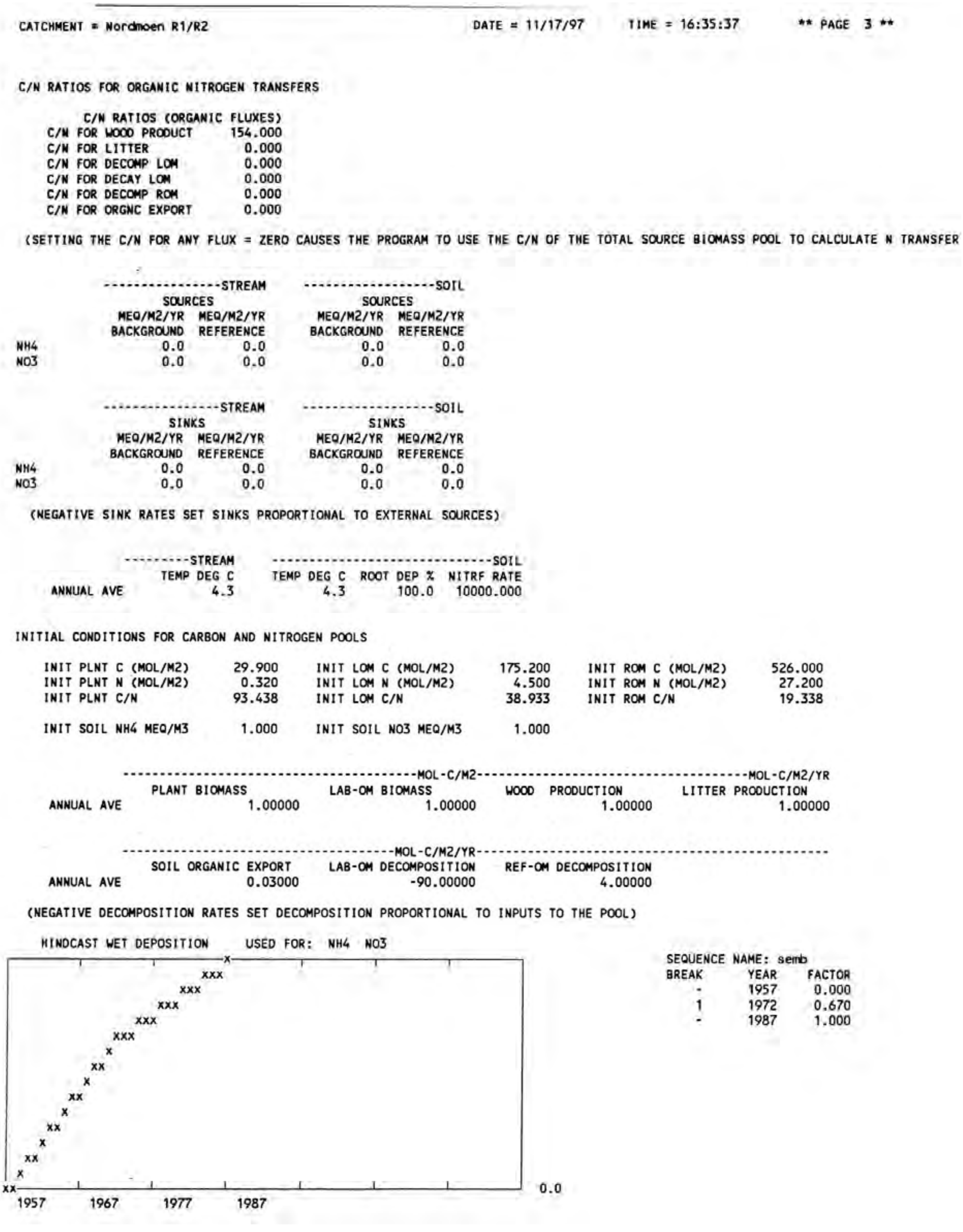

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CATCHMENT = Nordmoen R1/R2                                        DATE = 11/17/97     TIME = 16:35:37        ** PAGE  3 **


C/N RATIOS FOR ORGANIC NITROGEN TRANSFERS

         C/N RATIOS (ORGANIC FLUXES)
    C/N FOR WOOD PRODUCT      154.000
    C/N FOR LITTER              0.000
    C/N FOR DECOMP LOM          0.000
    C/N FOR DECAY LOM           0.000
    C/N FOR DECOMP ROM          0.000
    C/N FOR ORGNC EXPORT        0.000

 (SETTING THE C/N FOR ANY FLUX = ZERO CAUSES THE PROGRAM TO USE THE C/N OF THE TOTAL SOURCE BIOMASS POOL TO CALCULATE N TRANSFER


            ----------------STREAM    ------------------SOIL
                  SOURCES                   SOURCES
             MEQ/M2/YR  MEQ/M2/YR      MEQ/M2/YR  MEQ/M2/YR
            BACKGROUND  REFERENCE     BACKGROUND  REFERENCE
NH4               0.0         0.0           0.0         0.0
NO3               0.0         0.0           0.0         0.0


            ----------------STREAM    ------------------SOIL
                  SINKS                     SINKS
             MEQ/M2/YR  MEQ/M2/YR      MEQ/M2/YR  MEQ/M2/YR
            BACKGROUND  REFERENCE     BACKGROUND  REFERENCE
NH4               0.0         0.0           0.0         0.0
NO3               0.0         0.0           0.0         0.0

 (NEGATIVE SINK RATES SET SINKS PROPORTIONAL TO EXTERNAL SOURCES)


              ---------STREAM    -----------------------------SOIL
                  TEMP DEG C    TEMP DEG C  ROOT DEP %  NITRF RATE
    ANNUAL AVE           4.3           4.3       100.0   10000.000

INITIAL CONDITIONS FOR CARBON AND NITROGEN POOLS

    INIT PLNT C (MOL/M2)      29.900    INIT LOM C (MOL/M2)       175.200    INIT ROM C (MOL/M2)       526.000
    INIT PLNT N (MOL/M2)       0.320    INIT LOM N (MOL/M2)         4.500    INIT ROM N (MOL/M2)        27.200
    INIT PLNT C/N             93.438    INIT LOM C/N               38.933    INIT ROM C/N               19.338

    INIT SOIL NH4 MEQ/M3       1.000    INIT SOIL NO3 MEQ/M3        1.000


              ---------------------------------------MOL-C/M2-----------------------------------MOL-C/M2/YR
                  PLANT BIOMASS          LAB-OM BIOMASS          WOOD  PRODUCTION        LITTER PRODUCTION
    ANNUAL AVE               1.00000                1.00000                1.00000                  1.00000

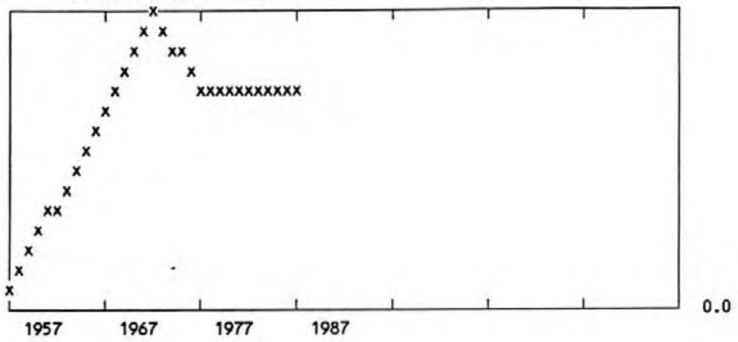

              ------------------------------------MOL-C/M2/YR---------------------------------------------
                  SOIL ORGANIC EXPORT    LAB-OM DECOMPOSITION    REF-OM DECOMPOSITION
    ANNUAL AVE               0.03000              -90.00000                4.00000

  (NEGATIVE DECOMPOSITION RATES SET DECOMPOSITION PROPORTIONAL TO INPUTS TO THE POOL)

     HINDCAST WET DEPOSITION      USED FOR:  NH4  NO3
                              x                                                         SEQUENCE NAME: semb
                           xxx                                                          BREAK      YEAR    FACTOR
                        xxx                                                               -        1957     0.000
                     xxx                                                                  1        1972     0.670
                  xxx                                                                     -        1987     1.000
               xxx
              x
            xx
           x
         xx
        x
      xx
     x
   xx
  x
xx                                                                     0.0
  1957     1967     1977     1987
```

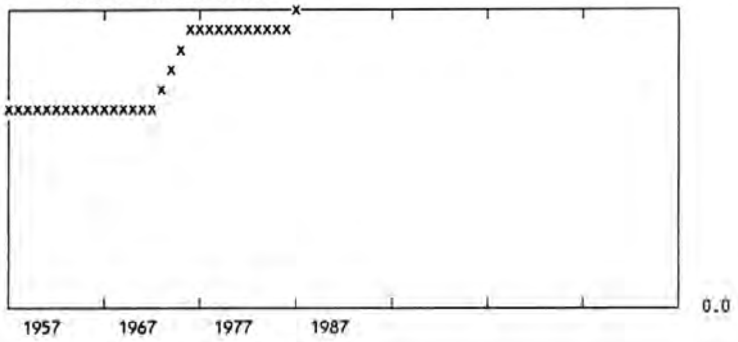
```
CATCHMENT = Nordmoen R1/R2                        DATE = 11/17/97      TIME = 16:35:37        ** PAGE  4 **
```

HINDCAST PLANT BIOMASS



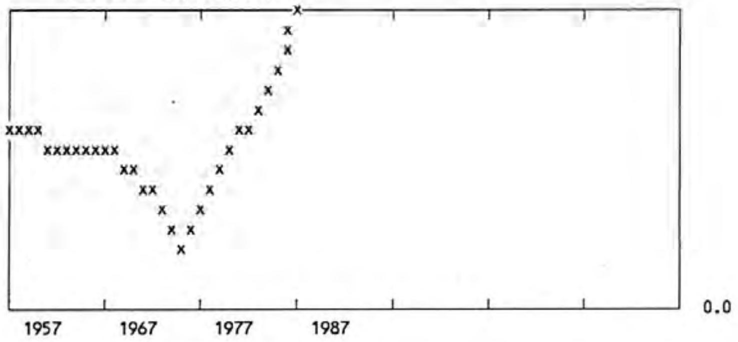
```
SEQUENCE NAME: simple2
BREAK        YEAR    FACTOR
  -          1957     1.000
  1          1957    29.900
  2          1967   169.600
  3          1972   249.400
  4          1977   199.500
  5          1987   199.500
  -          1987     1.000
```

HINDCAST LAB-OM BIOMASS



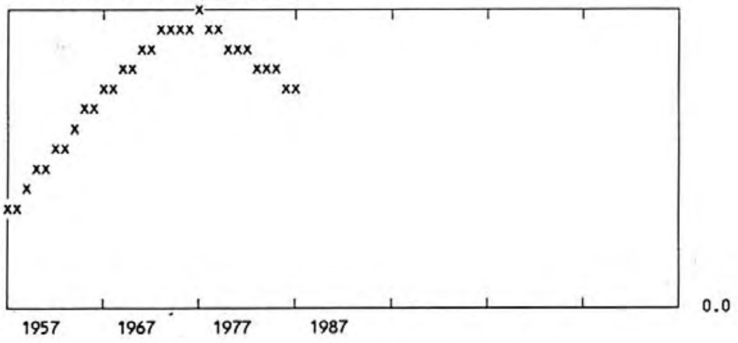
```
SEQUENCE NAME: simple2
BREAK        YEAR    FACTOR
  -          1957     1.000
  1          1957   175.200
  2          1967   175.200
  3          1972   175.200
  4          1977   240.000
  5          1987   242.400
  -          1987     1.000
```

HINDCAST WOOD PRODUCTION



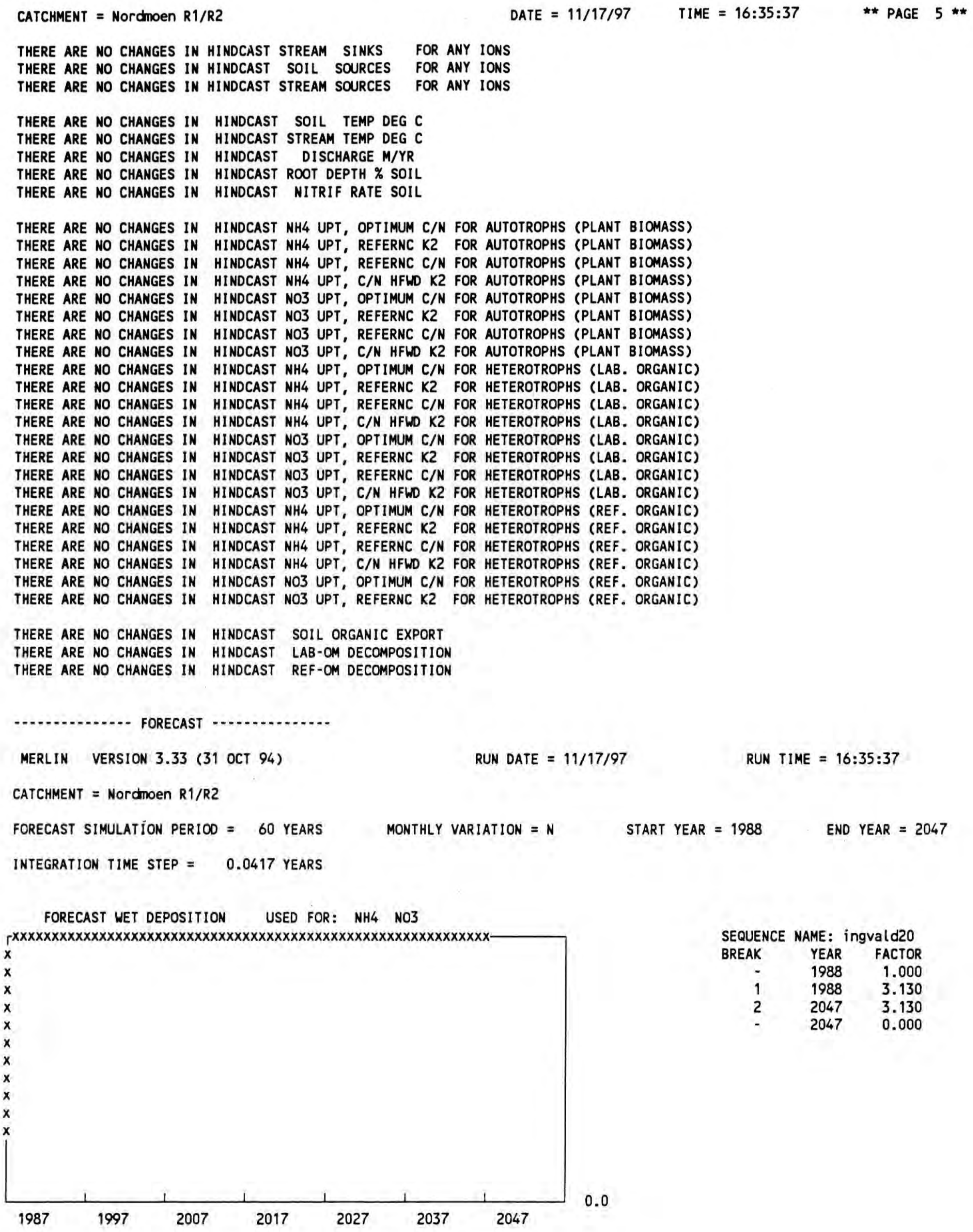
```
SEQUENCE NAME: simple4
BREAK        YEAR    FACTOR
  -          1957     1.000
  1          1957     5.000
  2          1962     4.500
  3          1970     4.000
  4          1975     1.900
  5          1982     5.100
  6          1987     7.700
  -          1987     1.000
```

HINDCAST LITTER PRODUCTION



```
SEQUENCE NAME: simple3
BREAK        YEAR    FACTOR
  -          1957     1.000
  1          1957    15.000
  2          1967    32.400
  3          1972    39.400
  4          1977    42.400
  5          1987    32.400
  -          1987     1.000
```

```
THERE ARE NO CHANGES IN HINDCAST DRY-DEP FACTOR   FOR ANY IONS
THERE ARE NO CHANGES IN HINDCAST  SOIL   SINKS    FOR ANY IONS
```



```
CATCHMENT = Nordmoen R1/R2                          DATE = 11/17/97      TIME = 16:35:37        ** PAGE  5 **

THERE ARE NO CHANGES IN HINDCAST STREAM  SINKS    FOR ANY IONS
THERE ARE NO CHANGES IN HINDCAST  SOIL  SOURCES   FOR ANY IONS
THERE ARE NO CHANGES IN HINDCAST STREAM SOURCES   FOR ANY IONS

THERE ARE NO CHANGES IN  HINDCAST  SOIL  TEMP DEG C
THERE ARE NO CHANGES IN  HINDCAST STREAM TEMP DEG C
THERE ARE NO CHANGES IN  HINDCAST   DISCHARGE M/YR
THERE ARE NO CHANGES IN  HINDCAST ROOT DEPTH % SOIL
THERE ARE NO CHANGES IN  HINDCAST  NITRIF RATE SOIL

THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, OPTIMUM C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, REFERNC K2  FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, REFERNC C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, C/N HFWD K2 FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, OPTIMUM C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, REFERNC K2  FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, REFERNC C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, C/N HFWD K2 FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, OPTIMUM C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, REFERNC K2  FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, REFERNC C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, C/N HFWD K2 FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, OPTIMUM C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, REFERNC K2  FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, REFERNC C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, C/N HFWD K2 FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, OPTIMUM C/N FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, REFERNC K2  FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, REFERNC C/N FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NH4 UPT, C/N HFWD K2 FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, OPTIMUM C/N FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  HINDCAST NO3 UPT, REFERNC K2  FOR HETEROTROPHS (REF. ORGANIC)

THERE ARE NO CHANGES IN  HINDCAST  SOIL ORGANIC EXPORT
THERE ARE NO CHANGES IN  HINDCAST  LAB-OM DECOMPOSITION
THERE ARE NO CHANGES IN  HINDCAST  REF-OM DECOMPOSITION


--------------- FORECAST ---------------

 MERLIN   VERSION 3.33 (31 OCT 94)                  RUN DATE = 11/17/97              RUN TIME = 16:35:37

CATCHMENT = Nordmoen R1/R2

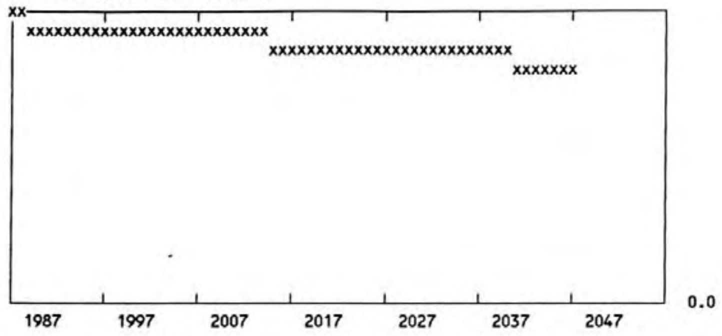
FORECAST SIMULATION PERIOD =   60 YEARS       MONTHLY VARIATION = N        START YEAR = 1988        END YEAR = 2047

INTEGRATION TIME STEP =     0.0417 YEARS


    FORECAST WET DEPOSITION      USED FOR:  NH4  NO3
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx-----------            SEQUENCE NAME: ingvald20
x                                                           |            BREAK      YEAR     FACTOR
x                                                           |              -        1988      1.000
x                                                           |              1        1988      3.130
x                                                           |              2        2047      3.130
x                                                           |              -        2047      0.000
x                                                           |
x                                                           |
x                                                           |
x                                                           |
x                                                           |
x                                                           |
|                                                           |
|                                                           |
|                                                           |
|________|_________|_________|_________|_________|_________|__|   0.0
 1987      1997      2007      2017      2027      2037      2047
```

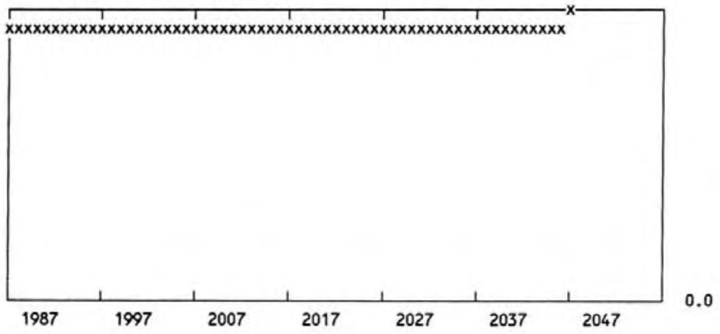
```
CATCHMENT = Nordmoen R1/R2                    DATE = 11/17/97     TIME = 16:35:37      ** PAGE  6
```

FORECAST PLANT BIOMASS



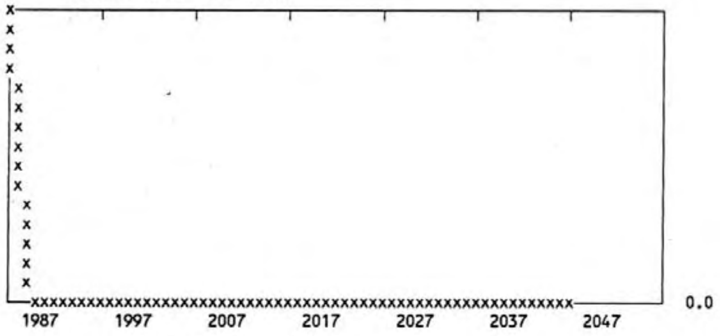
```
SEQUENCE NAME: simple1
BREAK      YEAR     FACTOR
  -        1988      1.000
  1        1988    199.500
  2        2047    169.600
  -        2047      1.000
```

FORECAST LAB-OM BIOMASS



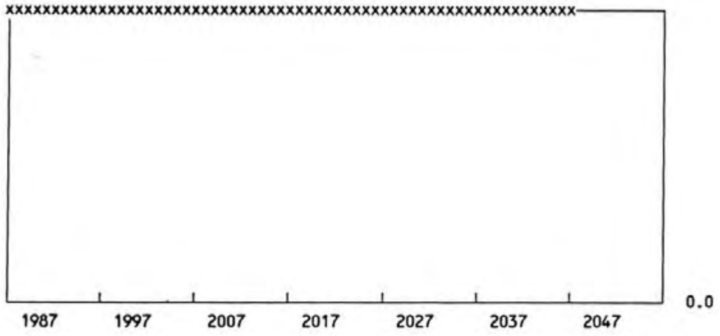
```
SEQUENCE NAME: simple1
BREAK      YEAR     FACTOR
  -        1988      1.000
  1        1988    242.400
  2        2047    249.600
  -        2047      1.000
```

FORECAST WOOD PRODUCTION



```
SEQUENCE NAME: simple1
BREAK      YEAR     FACTOR
  -        1988      1.000
  1        1988      5.800
  2        1990      0.000
  3        2047      0.100
  -        2047      1.000
```

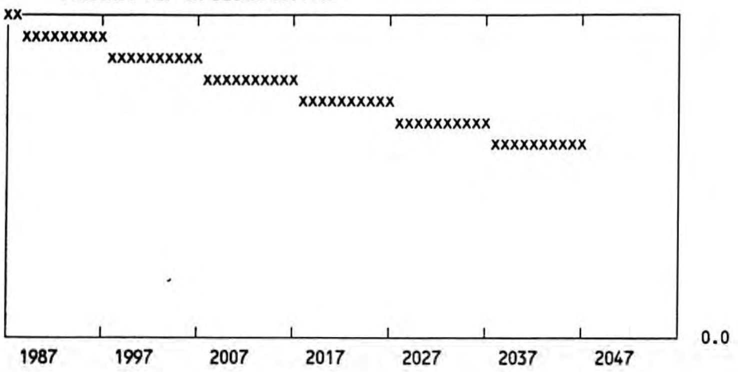
FORECAST LITTER PRODUCTION



```
SEQUENCE NAME: simple1
BREAK      YEAR     FACTOR
  -        1988      1.000
  1        1988     32.400
  2        2047     32.400
  -        2047      1.000
```

```
CATCHMENT = Nordmoen R1/R2                                  DATE = 11/17/97       TIME = 16:35:37         ** PAGE  7 **

     FORECAST REF-OM DECOMPOSITION
```



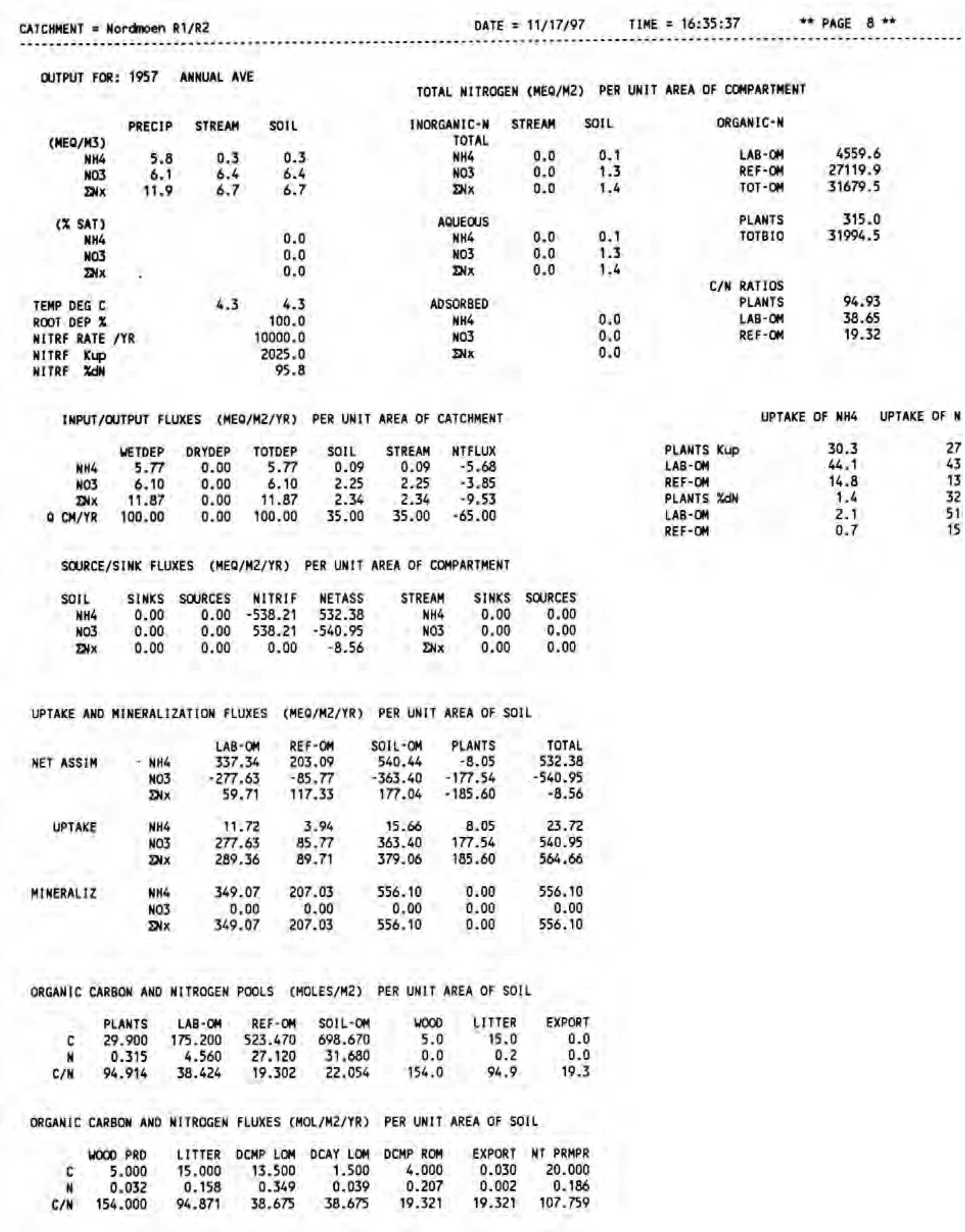
```
SEQUENCE NAME: simple1
BREAK      YEAR     FACTOR
  -        1988      1.000
  1        1988      1.000
  2        2047      0.600
  -        2047      1.000

THERE ARE NO CHANGES IN FORECAST DRY-DEP FACTOR   FOR ANY IONS
THERE ARE NO CHANGES IN FORECAST  SOIL   SINKS    FOR ANY IONS
THERE ARE NO CHANGES IN FORECAST STREAM  SINKS    FOR ANY IONS
THERE ARE NO CHANGES IN FORECAST  SOIL  SOURCES   FOR ANY IONS
THERE ARE NO CHANGES IN FORECAST STREAM SOURCES   FOR ANY IONS

THERE ARE NO CHANGES IN  FORECAST  SOIL  TEMP DEG C
THERE ARE NO CHANGES IN  FORECAST STREAM TEMP DEG C
THERE ARE NO CHANGES IN  FORECAST   DISCHARGE M/YR
THERE ARE NO CHANGES IN  FORECAST ROOT DEPTH % SOIL
THERE ARE NO CHANGES IN  FORECAST  NITRIF RATE SOIL

THERE ARE NO CHANGES IN  FORECAST NH4 UPT, OPTIMUM C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, REFERNC K2  FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, REFERNC C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, C/N HFWD K2 FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, OPTIMUM C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, REFERNC K2  FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, REFERNC C/N FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, C/N HFWD K2 FOR AUTOTROPHS (PLANT BIOMASS)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, OPTIMUM C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, REFERNC K2  FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, REFERNC C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, C/N HFWD K2 FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, OPTIMUM C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, REFERNC K2  FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, REFERNC C/N FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, C/N HFWD K2 FOR HETEROTROPHS (LAB. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, OPTIMUM C/N FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, REFERNC K2  FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, REFERNC C/N FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NH4 UPT, C/N HFWD K2 FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, OPTIMUM C/N FOR HETEROTROPHS (REF. ORGANIC)
THERE ARE NO CHANGES IN  FORECAST NO3 UPT, REFERNC K2  FOR HETEROTROPHS (REF. ORGANIC)

THERE ARE NO CHANGES IN  FORECAST  SOIL ORGANIC EXPORT
THERE ARE NO CHANGES IN  FORECAST  LAB-OM DECOMPOSITION
```



```
CATCHMENT = Nordmoen R1/R2                          DATE = 11/17/97     TIME = 16:35:37       ** PAGE  8 **
-----------------------------------------------------------------------------------------------------------

  OUTPUT FOR: 1957   ANNUAL AVE
                                                 TOTAL NITROGEN (MEQ/M2)  PER UNIT AREA OF COMPARTMENT

               PRECIP   STREAM     SOIL          INORGANIC-N  STREAM    SOIL          ORGANIC-N
   (MEQ/M3)                                            TOTAL
         NH4      5.8      0.3      0.3                NH4       0.0     0.1             LAB-OM      4559.6
         NO3      6.1      6.4      6.4                NO3       0.0     1.3             REF-OM     27119.9
         ΣNx     11.9      6.7      6.7                ΣNx       0.0     1.4             TOT-OM     31679.5

    (% SAT)                                          AQUEOUS                             PLANTS       315.0
         NH4                        0.0                NH4       0.0     0.1             TOTBIO     31994.5
         NO3                        0.0                NO3       0.0     1.3
         ΣNx                        0.0                ΣNx       0.0     1.4
                                                                                     C/N RATIOS
 TEMP DEG C                4.3      4.3             ADSORBED                             PLANTS       94.93
 ROOT DEP %                       100.0                NH4               0.0             LAB-OM       38.65
 NITRF RATE /YR                 10000.0                NO3               0.0             REF-OM       19.32
 NITRF  Kup                      2025.0                ΣNx               0.0
 NITRF  %dN                        95.8


    INPUT/OUTPUT FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF CATCHMENT                         UPTAKE OF NH4   UPTAKE OF N

           WETDEP   DRYDEP   TOTDEP     SOIL   STREAM   NTFLUX                PLANTS Kup            30.3            27
      NH4    5.77     0.00     5.77     0.09     0.09    -5.68                LAB-OM                44.1            43
      NO3    6.10     0.00     6.10     2.25     2.25    -3.85                REF-OM                14.8            13
      ΣNx   11.87     0.00    11.87     2.34     2.34    -9.53                PLANTS %dN             1.4            32
 Q CM/YR  100.00     0.00   100.00    35.00    35.00   -65.00                LAB-OM                 2.1            51
                                                                              REF-OM                 0.7            15

    SOURCE/SINK FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF COMPARTMENT

    SOIL     SINKS  SOURCES   NITRIF   NETASS     STREAM   SINKS  SOURCES
      NH4     0.00     0.00  -538.21   532.38        NH4    0.00     0.00
      NO3     0.00     0.00   538.21  -540.95        NO3    0.00     0.00
      ΣNx     0.00     0.00     0.00    -8.56        ΣNx    0.00     0.00


 UPTAKE AND MINERALIZATION FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF SOIL

                         LAB-OM    REF-OM     SOIL-OM    PLANTS      TOTAL
 NET ASSIM       NH4     337.34    203.09      540.44     -8.05     532.38
                 NO3    -277.63    -85.77     -363.40   -177.54    -540.95
                 ΣNx      59.71    117.33      177.04   -185.60      -8.56

    UPTAKE       NH4      11.72      3.94       15.66      8.05      23.72
                 NO3     277.63     85.77      363.40    177.54     540.95
                 ΣNx     289.36     89.71      379.06    185.60     564.66

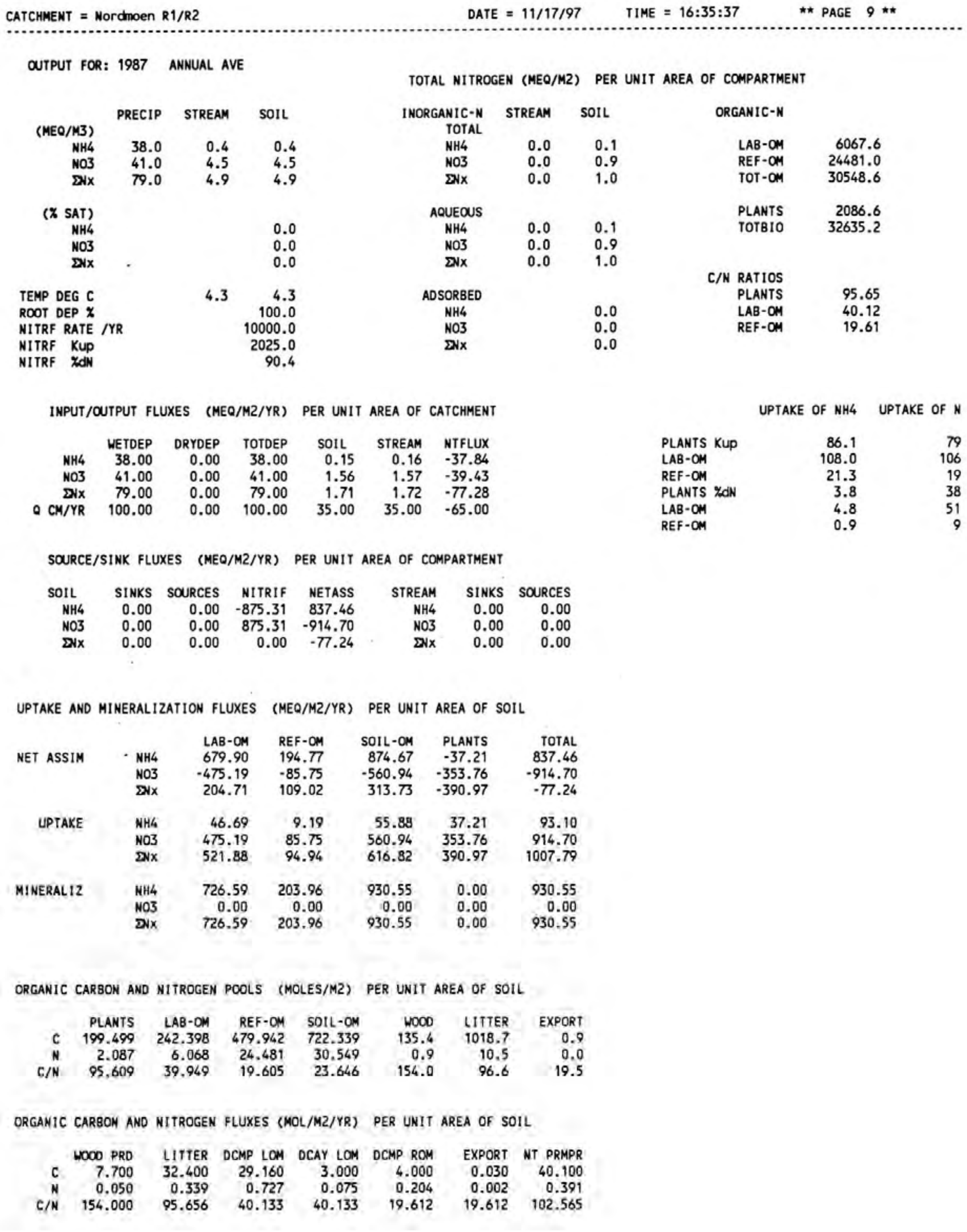
 MINERALIZ       NH4     349.07    207.03      556.10      0.00     556.10
                 NO3       0.00      0.00        0.00      0.00       0.00
                 ΣNx     349.07    207.03      556.10      0.00     556.10


 ORGANIC CARBON AND NITROGEN POOLS  (MOLES/M2)  PER UNIT AREA OF SOIL

           PLANTS    LAB-OM    REF-OM    SOIL-OM       WOOD    LITTER    EXPORT
      C    29.900   175.200   523.470   698.670        5.0      15.0       0.0
      N     0.315     4.560    27.120    31.680        0.0       0.2       0.0
    C/N    94.914    38.424    19.302    22.054      154.0      94.9      19.3

 ORGANIC CARBON AND NITROGEN FLUXES (MOL/M2/YR)  PER UNIT AREA OF SOIL

          WOOD PRD    LITTER  DCMP LOM  DCAY LOM  DCMP ROM    EXPORT  NT PRMPR
      C      5.000    15.000    13.500     1.500     4.000     0.030    20.000
      N      0.032     0.158     0.349     0.039     0.207     0.002     0.186
    C/N    154.000    94.871    38.675    38.675    19.321    19.321   107.759
```



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CATCHMENT = Nordmoen R1/R2                                   DATE = 11/17/97     TIME = 16:35:37       ** PAGE  9 **
----------------------------------------------------------------------------------------------------------------------

  OUTPUT FOR: 1987   ANNUAL AVE
                                                         TOTAL NITROGEN (MEQ/M2)  PER UNIT AREA OF COMPARTMENT

              PRECIP   STREAM    SOIL              INORGANIC-N  STREAM    SOIL            ORGANIC-N
    (MEQ/M3)                                             TOTAL
         NH4    38.0      0.4     0.4                    NH4      0.0      0.1               LAB-OM      6067.6
         NO3    41.0      4.5     4.5                    NO3      0.0      0.9               REF-OM     24481.0
         ΣNx    79.0      4.9     4.9                    ΣNx      0.0      1.0               TOT-OM     30548.6

     (% SAT)                                           AQUEOUS                               PLANTS      2086.6
         NH4                      0.0                    NH4      0.0      0.1               TOTBIO     32635.2
         NO3                      0.0                    NO3      0.0      0.9
         ΣNx                      0.0                    ΣNx      0.0      1.0
                                                                                          C/N RATIOS
   TEMP DEG C             4.3     4.3                 ADSORBED                               PLANTS       95.65
   ROOT DEP %                   100.0                    NH4               0.0               LAB-OM       40.12
   NITRF RATE /YR             10000.0                    NO3               0.0               REF-OM       19.61
   NITRF  Kup                  2025.0                    ΣNx               0.0
   NITRF  %dN                    90.4

     INPUT/OUTPUT FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF CATCHMENT                          UPTAKE OF NH4   UPTAKE OF N

            WETDEP   DRYDEP   TOTDEP     SOIL    STREAM   NTFLUX                    PLANTS Kup          86.1            79
       NH4   38.00     0.00    38.00     0.15      0.16   -37.84                    LAB-OM             108.0           106
       NO3   41.00     0.00    41.00     1.56      1.57   -39.43                    REF-OM              21.3            19
       ΣNx   79.00     0.00    79.00     1.71      1.72   -77.28                    PLANTS %dN           3.8            38
    Q CM/YR 100.00     0.00   100.00    35.00     35.00   -65.00                    LAB-OM               4.8            51
                                                                                    REF-OM               0.9             9

     SOURCE/SINK FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF COMPARTMENT

     SOIL     SINKS  SOURCES   NITRIF   NETASS     STREAM    SINKS  SOURCES
       NH4     0.00     0.00  -875.31   837.46        NH4     0.00     0.00
       NO3     0.00     0.00   875.31  -914.70        NO3     0.00     0.00
       ΣNx     0.00     0.00     0.00   -77.24        ΣNx     0.00     0.00


   UPTAKE AND MINERALIZATION FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF SOIL

                           LAB-OM     REF-OM     SOIL-OM    PLANTS      TOTAL
   NET ASSIM       NH4     679.90     194.77     874.67    -37.21     837.46
                   NO3    -475.19     -85.75    -560.94   -353.76    -914.70
                   ΣNx     204.71     109.02     313.73   -390.97     -77.24

     UPTAKE        NH4      46.69       9.19      55.88     37.21      93.10
                   NO3     475.19      85.75     560.94    353.76     914.70
                   ΣNx     521.88      94.94     616.82    390.97    1007.79

   MINERALIZ       NH4     726.59     203.96     930.55      0.00     930.55
                   NO3       0.00       0.00       0.00      0.00       0.00
                   ΣNx     726.59     203.96     930.55      0.00     930.55


   ORGANIC CARBON AND NITROGEN POOLS  (MOLES/M2)  PER UNIT AREA OF SOIL

            PLANTS    LAB-OM    REF-OM    SOIL-OM       WOOD    LITTER    EXPORT
       C   199.499   242.398   479.942    722.339      135.4    1018.7       0.9
       N     2.087     6.068    24.481     30.549        0.9      10.5       0.0
     C/N    95.609    39.949    19.605     23.646      154.0      96.6      19.5

   ORGANIC CARBON AND NITROGEN FLUXES (MOL/M2/YR)  PER UNIT AREA OF SOIL

          WOOD PRD    LITTER  DCMP LOM  DCAY LOM  DCMP ROM    EXPORT  NT PRMPR
       C     7.700    32.400    29.160     3.000     4.000     0.030    40.100
       N     0.050     0.339     0.727     0.075     0.204     0.002     0.391
     C/N   154.000    95.656    40.133    40.133    19.612    19.612   102.565
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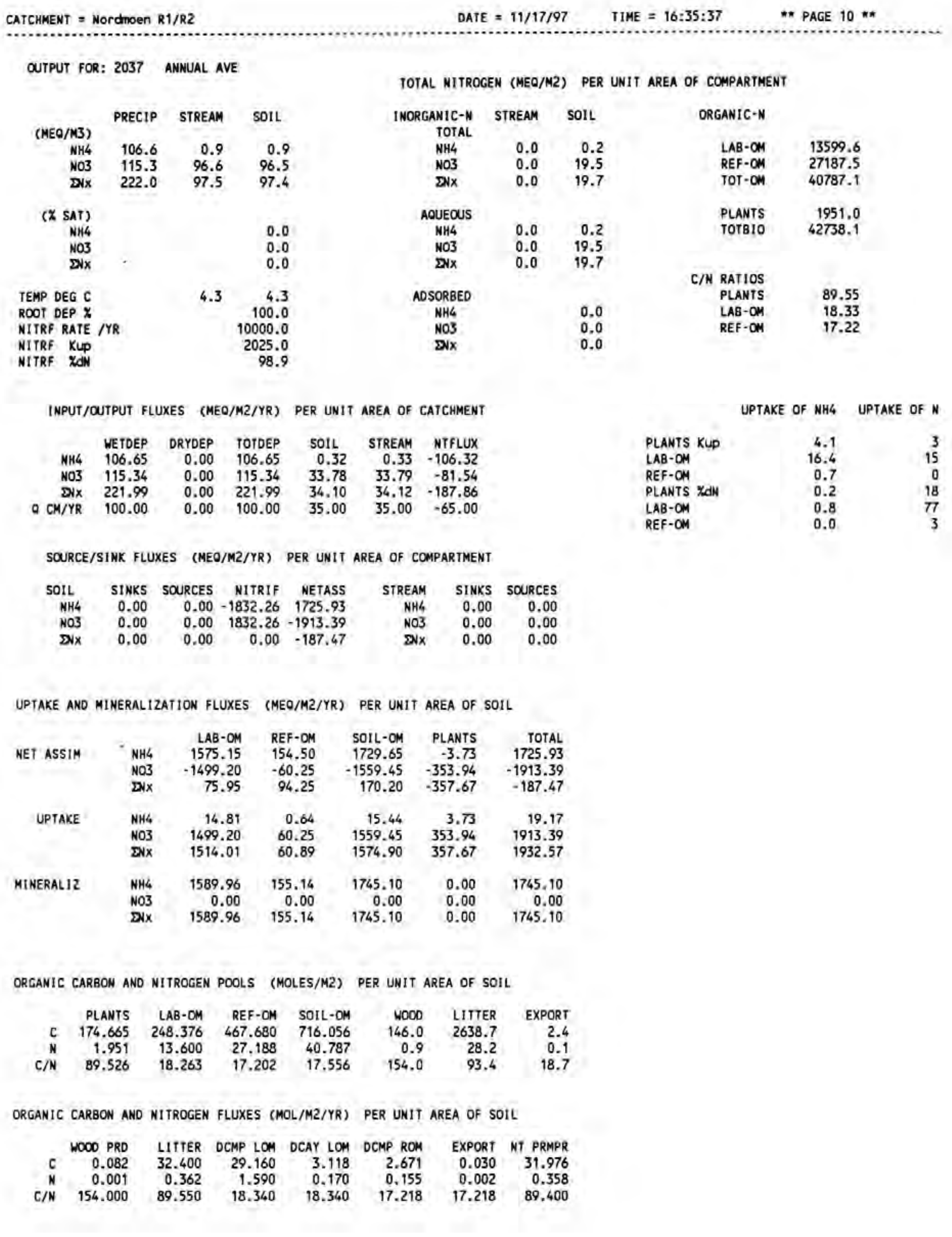

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CATCHMENT = Nordmoen R1/R2                                        DATE = 11/17/97     TIME = 16:35:37       ** PAGE 10 **
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  OUTPUT FOR: 2037   ANNUAL AVE
                                                          TOTAL NITROGEN (MEQ/M2)  PER UNIT AREA OF COMPARTMENT

              PRECIP   STREAM    SOIL                     INORGANIC-N  STREAM    SOIL             ORGANIC-N
    (MEQ/M3)                                                    TOTAL
         NH4   106.6      0.9     0.9                             NH4     0.0     0.2                LAB-OM     13599.6
         NO3   115.3     96.6    96.5                             NO3     0.0    19.5                REF-OM     27187.5
         ΣNx   222.0     97.5    97.4                             ΣNx     0.0    19.7                TOT-OM     40787.1

     (% SAT)                                                  AQUEOUS                                PLANTS      1951.0
         NH4                      0.0                             NH4     0.0     0.2                TOTBIO     42738.1
         NO3                      0.0                             NO3     0.0    19.5
         ΣNx                      0.0                             ΣNx     0.0    19.7
                                                                                                C/N RATIOS
  TEMP DEG C              4.3     4.3                        ADSORBED                                PLANTS       89.55
  ROOT DEP %                    100.0                             NH4             0.0                LAB-OM       18.33
  NITRF RATE /YR              10000.0                             NO3             0.0                REF-OM       17.22
  NITRF  Kup                   2025.0                             ΣNx             0.0
  NITRF  %dN                     98.9


      INPUT/OUTPUT FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF CATCHMENT                             UPTAKE OF NH4   UPTAKE OF N

              WETDEP   DRYDEP   TOTDEP    SOIL   STREAM   NTFLUX                       PLANTS Kup          4.1            3
         NH4  106.65     0.00   106.65    0.32     0.33  -106.32                       LAB-OM             16.4           15
         NO3  115.34     0.00   115.34   33.78    33.79   -81.54                       REF-OM              0.7            0
         ΣNx  221.99     0.00   221.99   34.10    34.12  -187.86                       PLANTS %dN          0.2           18
    Q CM/YR   100.00     0.00   100.00   35.00    35.00   -65.00                       LAB-OM              0.8           77
                                                                                       REF-OM              0.0            3

      SOURCE/SINK FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF COMPARTMENT

      SOIL    SINKS  SOURCES   NITRIF   NETASS     STREAM   SINKS  SOURCES
        NH4    0.00     0.00 -1832.26  1725.93        NH4    0.00     0.00
        NO3    0.00     0.00  1832.26 -1913.39        NO3    0.00     0.00
        ΣNx    0.00     0.00     0.00  -187.47        ΣNx    0.00     0.00


  UPTAKE AND MINERALIZATION FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF SOIL

                           LAB-OM    REF-OM     SOIL-OM    PLANTS      TOTAL
  NET ASSIM        NH4    1575.15    154.50     1729.65     -3.73    1725.93
                   NO3   -1499.20    -60.25    -1559.45   -353.94   -1913.39
                   ΣNx      75.95     94.25      170.20   -357.67    -187.47

     UPTAKE        NH4      14.81      0.64       15.44      3.73      19.17
                   NO3    1499.20     60.25     1559.45    353.94    1913.39
                   ΣNx    1514.01     60.89     1574.90    357.67    1932.57

  MINERALIZ        NH4    1589.96    155.14     1745.10      0.00    1745.10
                   NO3       0.00      0.00        0.00      0.00       0.00
                   ΣNx    1589.96    155.14     1745.10      0.00    1745.10


  ORGANIC CARBON AND NITROGEN POOLS  (MOLES/M2)  PER UNIT AREA OF SOIL

           PLANTS    LAB-OM    REF-OM   SOIL-OM      WOOD    LITTER    EXPORT
       C  174.665   248.376   467.680   716.056     146.0    2638.7       2.4
       N    1.951    13.600    27.188    40.787       0.9      28.2       0.1
     C/N   89.526    18.263    17.202    17.556     154.0      93.4      18.7

  ORGANIC CARBON AND NITROGEN FLUXES (MOL/M2/YR)  PER UNIT AREA OF SOIL

         WOOD PRD    LITTER  DCMP LOM  DCAY LOM  DCMP ROM    EXPORT  NT PRMPR
       C    0.082    32.400    29.160     3.118     2.671     0.030    31.976
       N    0.001     0.362     1.590     0.170     0.155     0.002     0.358
     C/N  154.000    89.550    18.340    18.340    17.218    17.218    89.400
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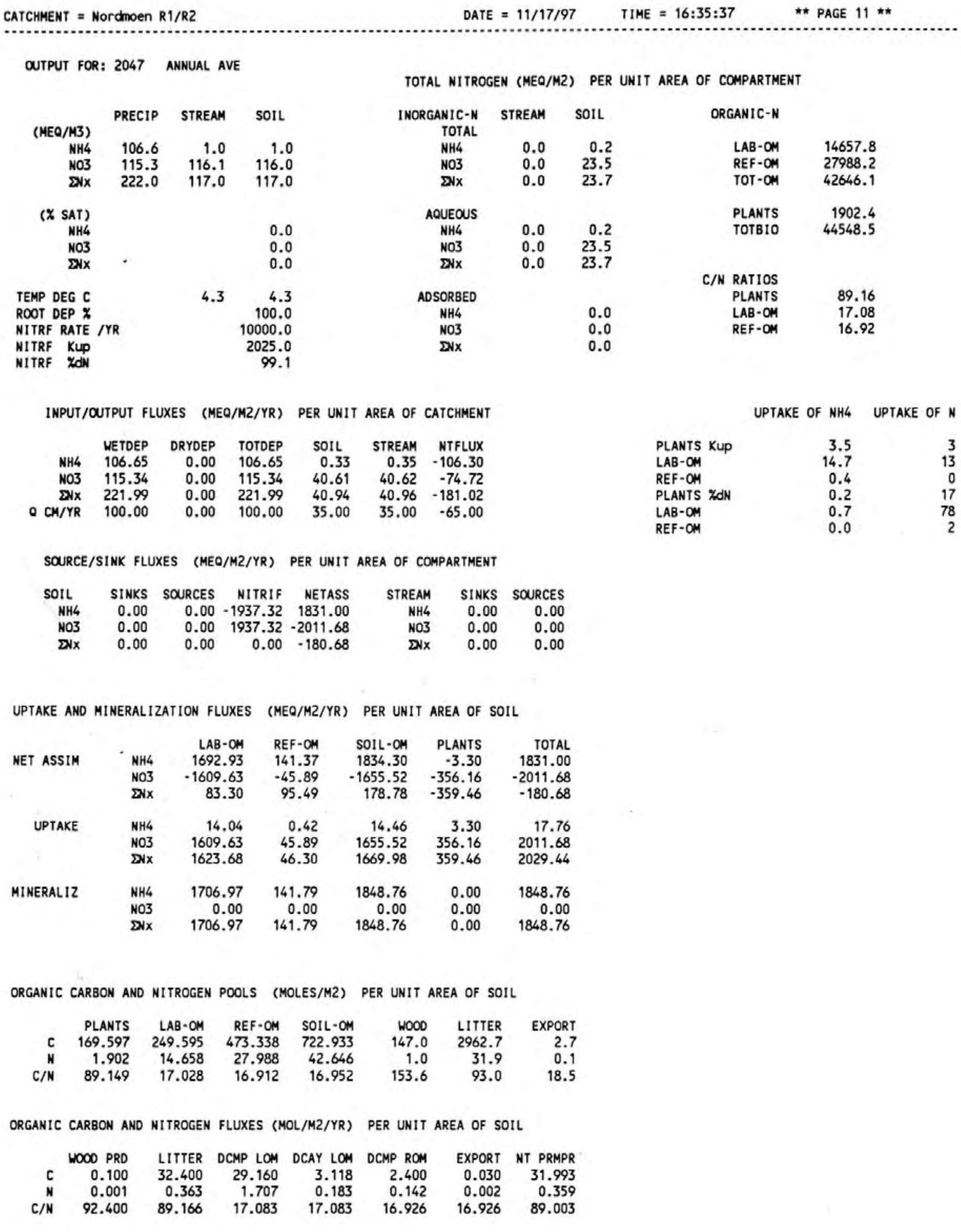

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CATCHMENT = Nordmoen R1/R2                                   DATE = 11/17/97     TIME = 16:35:37        ** PAGE 11 **
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   OUTPUT FOR: 2047   ANNUAL AVE
                                                      TOTAL NITROGEN (MEQ/M2)  PER UNIT AREA OF COMPARTMENT

               PRECIP   STREAM    SOIL                INORGANIC-N  STREAM    SOIL               ORGANIC-N
    (MEQ/M3)                                                TOTAL
         NH4    106.6      1.0     1.0                      NH4       0.0     0.2                  LAB-OM     14657.8
         NO3    115.3    116.1   116.0                      NO3       0.0    23.5                  REF-OM     27988.2
         ΣNx    222.0    117.0   117.0                      ΣNx       0.0    23.7                  TOT-OM     42646.1

      (% SAT)                                             AQUEOUS                                  PLANTS      1902.4
         NH4                       0.0                      NH4       0.0     0.2                  TOTBIO     44548.5
         NO3                       0.0                      NO3       0.0    23.5
         ΣNx                       0.0                      ΣNx       0.0    23.7
                                                                                                C/N RATIOS
  TEMP DEG C                4.3     4.3                  ADSORBED                                  PLANTS       89.16
  ROOT DEP %                      100.0                     NH4               0.0                  LAB-OM       17.08
  NITRF RATE /YR                10000.0                     NO3               0.0                  REF-OM       16.92
  NITRF  Kup                     2025.0                     ΣNx               0.0
  NITRF  %dN                       99.1


      INPUT/OUTPUT FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF CATCHMENT                                   UPTAKE OF NH4  UPTAKE OF N

             WETDEP   DRYDEP   TOTDEP     SOIL   STREAM   NTFLUX                 PLANTS Kup               3.5             3
        NH4  106.65     0.00   106.65     0.33     0.35  -106.30                 LAB-OM                  14.7            13
        NO3  115.34     0.00   115.34    40.61    40.62   -74.72                 REF-OM                   0.4             0
        ΣNx  221.99     0.00   221.99    40.94    40.96  -181.02                 PLANTS %dN               0.2            17
   Q CM/YR   100.00     0.00   100.00    35.00    35.00   -65.00                 LAB-OM                   0.7            78
                                                                                 REF-OM                   0.0             2

      SOURCE/SINK FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF COMPARTMENT

      SOIL     SINKS  SOURCES   NITRIF   NETASS      STREAM    SINKS  SOURCES
       NH4      0.00     0.00 -1937.32  1831.00         NH4     0.00     0.00
       NO3      0.00     0.00  1937.32 -2011.68         NO3     0.00     0.00
       ΣNx      0.00     0.00     0.00  -180.68         ΣNx     0.00     0.00


  UPTAKE AND MINERALIZATION FLUXES  (MEQ/M2/YR)  PER UNIT AREA OF SOIL

                             LAB-OM    REF-OM    SOIL-OM    PLANTS      TOTAL
  NET ASSIM         NH4     1692.93    141.37    1834.30     -3.30    1831.00
                    NO3    -1609.63    -45.89   -1655.52   -356.16   -2011.68
                    ΣNx       83.30     95.49     178.78   -359.46    -180.68

     UPTAKE         NH4       14.04      0.42      14.46      3.30      17.76
                    NO3     1609.63     45.89    1655.52    356.16    2011.68
                    ΣNx     1623.68     46.30    1669.98    359.46    2029.44

  MINERALIZ         NH4     1706.97    141.79    1848.76      0.00    1848.76
                    NO3        0.00      0.00       0.00      0.00       0.00
                    ΣNx     1706.97    141.79    1848.76      0.00    1848.76


  ORGANIC CARBON AND NITROGEN POOLS  (MOLES/M2)  PER UNIT AREA OF SOIL

            PLANTS    LAB-OM    REF-OM   SOIL-OM      WOOD    LITTER    EXPORT
       C   169.597   249.595   473.338   722.933     147.0    2962.7       2.7
       N     1.902    14.658    27.988    42.646       1.0      31.9       0.1
     C/N    89.149    17.028    16.912    16.952     153.6      93.0      18.5

  ORGANIC CARBON AND NITROGEN FLUXES (MOL/M2/YR)  PER UNIT AREA OF SOIL

          WOOD PRD    LITTER  DCMP LOM  DCAY LOM  DCMP ROM    EXPORT  NT PRMPR
       C     0.100    32.400    29.160     3.118     2.400     0.030    31.993
       N     0.001     0.363     1.707     0.183     0.142     0.002     0.359
     C/N    92.400    89.166    17.083    17.083    16.926    16.926    89.003
```

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