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CALCULATION OF CRITICAL LOADS OF NITROGEN AS A NUTRIENT

Summary report on the development of a library of default values */

I. INTRODUCTION

1. The recent workshop on calculation and mapping of critical loads of nitrogen held from 24 to 26 October 1994 at Grange-over-Sands (United Kingdom) proposed the following form of the simple mass balance equation :

$$CL_{(N)nut}=N_{l(crit)}+N_{i(crit)}+N_{u(crit)}+N_{de(crit)}-N_{fix(crit)}+N_{fire(crit)}+N_{erode(crit)}+N_{vol(crit)}$$

*/ Prepared by the secretariat with the assistance of Mr. M. Hornung (United Kingdom), consultant to the secretariat.

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where:

$CL_{(N)nut}$ = critical load for nutrient nitrogen;
$N_{l(crit)}$ = total annual N leaching (NO_3 + NH_4 - dissolved organic N) from the rooting zone under natural conditions in the absence of pollutant N inputs plus any enhanced leaching following forest harvesting, natural fires or fires used as part of traditional management regimes;
$N_{i(crit)}$ = an acceptable annual level of N immobilization in soil organic matter (including forest floor), at N inputs equal to the critical load, at which adverse ecosystem change will not take place;
$N_{u(crit)}$ = net annual removal of N in vegetation and harvested animals at N inputs equal to the critical load;
$N_{de(crit)}$ = annual flux of N to the atmosphere as a result of denitrification at N inputs equal to the critical load;
$N_{fire(crit)}$= N losses in smoke from natural wildfires or from fires used as part of traditional management regimes;
$N_{erode(crit)}$= annual N losses through erosion under natural conditions plus enhanced erosion losses following forest harvesting, natural fires or fires used as part of traditional management regimes;
$N_{vol(crit)}$ = annual N losses to the atmosphere from NH_4 volatilization.

2. National databases of measured values of the various input variables will rarely be available. As a result, recommended default values are likely to be used as input in the production of provisional national critical load maps. The workshop held at Lokeberg (Sweden) in 1993 1/ suggested a number of default values but also recommended that published data be brought together to provide the basis for the development of a matrix of values for the variables and a range of major ecosystem types. The workshop at Grange-over-Sands reiterated the need for such a review of available data. As a result of the recommendations of the workshop, the establishment of a database of default values was initiated by the joint effort of the United Kingdom Department of the Environment and the ECE secretariat.

II. OBJECTIVES AND METHOD OF WORK

3. The objectives of the work can be summarized as follows:

(a) To gather and critically assess available data quantifying the input variables to the simple mass balance equation for the calculation of critical loads of nitrogen as a nutrient;

(b) To develop a library of default values for each of the input variables to the simple mass balance equation and for a range of ecosystems.

4. Literature searches have been carried out, using computerized bibliographic databases in the United Kingdom and the United States of America, for combinations of relevant key words for each of the input variables to the simple mass balance equation. The resulting listings of titles were then searched manually to select subsets of relevant publications. Abstracts were then obtained from the bibliographies for the selected, relevant papers. Where necessary, copies of the full text of the relevant papers were obtained.

5. In parallel with the above procedure, a manual literature search was

carried out (i) to check the recovery by the key word combinations used in the searches of the computerized bibliographies and (ii) to access selected papers cited in publications identified from the computer searches.

III. DATA PRESENTATION

Data listing for each variable

6. The values for each input variable are being entered into a computer database, which also includes, where available, the following information: site name; site location (country and county, State, "land", district, etc.); latitude and longitude; altitude; area of site (where site is a stream catchment); habitat/ecosystem type (using descriptors used by the authors of the publication); metrology used to obtain the measurements; source of data (reference); general comments.

Summary data

7. A summary data file is being produced which contains: (a) the range of values for each variable - ecosystem combination; and (b) mean/recommended value for each variable - ecosystem combination.

Mapping manual

8. A condensed table and/or guidance for the calculation of default values will be prepared for inclusion in the mapping manual.

IV. PROGRESS MADE AND RESULTS ACHIEVED

9. A large variation has been found in the number of published values recovered to date for the different variables. For example, there are more than 200 reliable values for N_l but, on the basis of current searches, only one or two reliable values for N_{vol} from soils; there are however a large number of values for N_{vol} from animal wastes. Some 40 reliable values for N_{de} have been identified to date. There are very few values for current rates of N_i and mean values are being calculated from data for accumulation of N in soil chronosequences and in disturbed systems, e.g. arable land allowed to revert to forest. (These values only provide extremes which can be used to scale and test other data.) Up to now, surprisingly few values have been found for N_{erode}; there are a large number of values for mass of material lost in erosion, but few publications give the chemical composition of the eroded material. The available data show that erosion losses following perturbations such as fire and clearcutting can be considerable for a number of years. Losses as smoke in fires can also be large; the best method of calculation may be from the proportion of the N content in the standing biomass lost. Net losses in grazing animals from extensively grazed semi-natural ecosystems can also be significant.

10. There is a clumping in the number of available values for variables in terms of the countries of origin and ecosystem type. Thus most of the available values for N_{de} originate from the United States, while the bulk of the values for N_l originate from north-west Europe. The available data are also heavily biased towards forest ecosystems, and particularly coniferous forests.

11. In an attempt to locate further data for those variables for which few

values have been found to date, larger bibliographic databases in the United States are now being accessed and relevant contacts have been established with the scientists from the eastern European countries.

12. The results of the work already done on assessing available data quantifying the input variables to the simple mass balance equation for the calculation of critical loads of nitrogen as nutrient, together with some preliminary conclusions, are presented in the following paragraphs.

Critical total annual leaching of nitrogen

13. Available data on total annual leaching of nitrogen from Europe has been brought together by Hauhs et al, 2/, Hornung et al 3/ and Dise and Wright 4/. The present exercise has drawn on these reviews, but has also brought together some data from North America.

14. The rates of loss are small for undisturbed natural systems but can increase for a number of years following disturbance, e.g. fire, windblow, and felling. The number of years of enhanced rates of loss depends on the rate of recolonization and this, in turn, depends on site fertility. The total losses over the period of enhanced leaching following disturbance should be divided by the period between disturbance events and the resultant value added to the background level of leaching.

15. The following ranges of values have been found in the literature:

(i) Boreal and temperate heaths and bogs: 0 - 0.5 kg ha^{-1} yr^{-1} (inorganic N); losses of organic N can be larger and data are being accumulated for these outputs. (There is, however, an urgent need for more data on organic N outputs from a range of ecosystems);

(ii) Managed coniferous forest: 0.5 - 1.0 kg ha^{-1} yr^{-1};

(iii) Coniferous plantations: 1 - 3 kg ha^{-1} yr^{-1}. (Can be significantly larger if open drains are dug prior to planting);

(iv) Temperate deciduous forests: 2 - 4 kg ha^{-1} yr^{-1};

(v) Temperate grasslands: 1 - 3 kg ha^{-1} yr^{-1};

(vi) Mediterranean forests: 1 - 2 kg ha^{-1} yr^{-1};

(vii) Temperate forests following felling: 5 - 25 kg ha^{-1} yr^{-1} for a period of ca. two years;

(viii) Heathland following fire: 2 - 10 kg ha^{-1} yr^{-1};

(ix) Temperate forest following fire: 5 - 20 kg ha^{-1} yr^{-1}.

Critical annual level of nitrogen immobilization

16. The annual level of nitrogen immobilization is the most difficult of the input variables to the N mass balance equation to parametrize. There are very few reported values for rates of immobilization but an increasing number of studies are applying ^{15}N techniques to determine rates over the short term.

17. Rates of N immobilization can be calculated from chronosequence studies.

The total amount of N accumulated in a soil is divided by the period of soil formation. Studies of this type on natural ecosystems, usually considering soils developed on glacial moraines or on sand-dunes, indicate rates of 0.5 - 1.0 kg ha^{-1} yr^{-1}.

18. Studies of aggrading systems where forest has developed on former agricultural land in temperate areas show values of 3 - 10 kg ha^{-1} yr^{-1}.

19. Alternative approaches to the calculation of immobilization rates are being explored as a matter of urgency.

Critical annual removal of nitrogen

20. Methods of calculation of net uptake by vegetation are outlined in the mapping manual. One method for forests divides the N in biomass by the age of the forest; in the absence of site-specific or national databases, the large number of published data noted in paragraph 25 below, dealing with nitrogen losses in smoke from fires N_{fire}, can be used. Net uptake from non-forest, natural or semi-natural ecosystems is insignificant unless the systems are used as extensive grazings for sheep, goats or cattle (or reindeer?). Net removal in sheep from extensive sheep grazings in the United Kingdom is between 0.5 and 2 kg ha^{-1} yr^{-1} depending on site fertility and grazing densities.

Critical annual flux of nitrogen to the atmosphere

21. The annual flux of nitrogen to the atmosphere can be calculated using approaches developed by Sverdrup and Ineson and by de Vries. In the absence of the necessary input data required by these methodologies, a default value can be used. Dutch and Ineson 5/ reviewed the available data on rates of denitrification and the present exercise used their study as a starting-point. Some 40 separate values have been collected from the literature, mainly for North American sites but also covering a range of European studies. The studies include both direct field measurement of denitrification, usually for short intervals, which are then extrapolated to longer periods, and laboratory measurements. They also include measurements of actual rates and potential rates. The latter values are generally higher than actual measured field rates.

22. Losses of N by denitrification are generally small in undisturbed natural systems with low, background levels of N inputs. However, rates of denitrification can increase following disturbance. The increased rates will last for only one to three years. The total enhanced losses following the disturbance should be divided by the period of time between disturbance events and added to the background rates.

23. The following values have been considered:

(i) Boreal and temperate ecosystems: 0.1 to 3.0 kg ha^{-1} yr^{-1} with the majority of reported values, especially for forest systems, below 1 kg $ha^{-1}yr^{-1}$; the upper values apply to wet soils; rates for well drained soils are generally less than 0.5 kg ha^{-1} yr^{-1};

(ii) Following felling: 2.0 to 30.0 kg ha^{-1} yr^{-1} for a two-year period following felling; the upper values apply to nutrient-rich sites with large nitrate concentrations in soil solution, the lower to acid soils with low nitrate concentrations. The value of 30 kg ha^{-1}

yr^{-1} is a potential rate.

Critical nitrogen losses in smoke from fires

24. Nitrogen losses in smoke and gases are only significant in a few natural ecosystems (e.g. in maquis and boreal forests), and in semi-natural systems where fire is a normal part of management used to maintain the ecosystem (e.g. Calluna heathland in the United Kingdom). (Fire is also being used increasingly in boreal and temperate forest management in North America to maintain diversity.)

25. There are published data on outputs at fire but examination of the data suggests that the losses should be calculated from the N content of the above ground biomass and litter layers. Between 60 and 80% of the N will be lost, the percentage varying with the temperature of the fire; ca. 60% losses from "cool" fires and ca. 80% losses from "hot" fires. There may also be some loss of soil N from the surface organic horizons in the hot fires. The losses in fires should be divided by the time interval between the occurrence of the fires. Return time for fires in Mediterranean maquis vegetation is ca. 20 years (R. Guardans, pers. comm.) and for boreal forest 100 - 200 years.

26. There are many published data on the N content in biomass of different ecosystems and forest types and a sample of these will be included in the database. The values below give an indication of the median content and the range of contents in major forest types:

(i) Boreal forest: 447 kg ha^{-1} (174 - 1915 kg ha^{-1});

(ii) Temperate coniferous: 664 kg ha^{-1} (375 - 1327 kg ha^{-1});

(iii) Temperate broad-leaved: 1085 kg ha^{-1} (406 - 1608 kg ha^{-1});

(iv) Fire losses from Calluna heathland of 20 - 45 kg ha^{-1} have been reported.

Critical annual nitrogen losses through erosion

27. There are relatively few published rates of N loss by erosion but many more data on total mass loss and these data can be used to calculate approximate rates of N loss.

28. Losses by erosion are very small from undisturbed natural ecosystems but these losses can increase dramatically following disturbance, e.g. windblow, fire, and/or clearcutting. The increased rates of loss will last for only a small number of years after disturbance, the length of time depending on the rates of recolonization by vegetation: this is rapid, up to one year, on nutrient-rich sites and slow, two to five years (or more in tundra systems), on nutrient-poor sites. The total losses resulting from the period of enhanced erosion following disturbance should be divided by the time interval between disturbance events and the resultant value added to the background rate of loss.

29. Ranges of losses following disturbance are listed below for a few ecosystems:

(i) Undisturbed natural systems: < 0.5 kg ha^{-1} yr^{-1};

(ii) Temperate plantations: 1 - 3 kg ha^{-1} yr^{-1};

(iii) Heathland following fire: 80 - 150 kg ha^{-1} yr^{-1} for a period of one to three years; the variation is related to differences in slope and rainfall;

(iv) Boreal and temperate forest following fire: 50 - 200 kg ha^{-1} yr^{-1}; the rate for a given site is determined by fire intensity, slope and climate (mainly rainfall amount and intensity);

(v) Temperate forest following clearcutting: 5 - 10 kg ha^{-1} yr^{-1} for a period of two to five years.

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