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QUANTIFICATION OF N-FLUXES IN THE ROOTZONE

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CONTENTS

1. INTRODUCTION

A Joint European Research Project on 'Nitrate in soils' started in January 1988. It is a co-ordinated study on the impact of agricultural practices on nitrate leaching from the soil rootzone and effects on groundwater quality. In the study emphasis is on development of models at field and regional level to optimise nitrogen fluxes for agricultural or environmental objectives. Collection of data for model testing is an essential part of the project.
At the start of the Joint Research Project attention must be paid to monitoring and sampling procedures for soil, fertilizers, water and crops. In this contribution data collection will be discussed for experiments aiming at a better understanding of nitrogen processes in the rootzone. Two types of field experiments may be distinguished with respect to data collection: small scale intensive experiments for studying N processes and extensive experiments at a regional level for policy analysis. In the second paragraph the quantification of inputs, outputs and soil storage changes of N will be discussed and possible measures are suggested which might reduce the problems of data collection and monitoring. Some of the experience collected in a nitrate leaching study performed by the UK Soil Survey can be found in the third paragraph. A listing of background and monitoring data is presented in the last paragraph.

2. QUANTIFICATION OF INPUTS AND OUTPUTS

Extrapolation of experimental data on nitrate leaching to other situations can only be carried out when the processes influencing nitrate leaching are understood. This means first of all that all relevant inputs and outputs of N should be quantified as accurately as possible. Some terms of the N-balance can be quantified rather easily. For other terms large efforts have to be made to have a reasonable estimate of their quantity (table 1).

Much time, skilled scientists and sometimes expensive instrumentation is needed for collection of experimental data on especially deposition, biological N-fixation, denitrification, volatilization, erosion, surface runoff and change in organic N.

It is impossible therefore to quantify all inputs and outputs in every experiment. In regional studies it is impossible but also not necessary to have detailed measurements. However some more intensive site studies are necessary to learn about N-processes in soil and to collect data for the testing of nitrogen models. Part of the quantification problem may be reduced or prevented by selection of specific experimental sites and by an appropriate experimental design (table 2).

Table 1. Inputs and outputs of the N-balance for the rootzone, an estimate for the complexity of quantification in fertilization experiments and some possibilities to prevent or reduce quantification problems (see table 2)

N-balance terms	Complexity	Measures
Input: deposition (dry, wet)	+++	5,6,7
fertilization	+	
biological N-fixation	+++	8
Output: crop, milk, meat	+	
denitrification (N_2O, N_2)	+++	6
volatilization (NH_3)	+++	9
leaching	++	3,10
erosion, surface runoff	+++	1,2
Soil storage change: extractable NH_4^+	+	
NO_3^-	+	
organic N	+++	4,7

Table 2. Important factors influencing the problems in quantification of some inputs and outputs in the N-balance

	Site selection
1	Slope of the field
2	Soil permeability and drainage situation
3	Soil heterogeneity
4	History of soil use
5	Farming practices on neighbouring fields and farms
6	Water holding capacity and organic matter content in the soil profile
	Experimental design
7	Non fertilized field in experiment
8	No N-fixing crops
9	Technique of slurry application
10	Studies with lysimeters

Losses by soil erosion will increase at steeper slopes. Surface runoff is an important phenomenon for soils with a low permeability and a poor drainage situation.

Heterogeneous soils, especially soils with deep cracks, give rise to problems with quantification of the amount of leachate and its nutrient concentrations. History of soil use is of importance for the magnitude and the balance between mineralisation and immobilisation and the resulting soil storage changes of especially organic N. The bigger the difference in C and N inputs between historic soil use and experiment soil use, the longer the experiment should run to reach a new equilibrium situation. Ammonia volatilization losses from slurry on neighbouring fields and farms within roughly 500 meters might cause differences in atmospheric deposition between N-treatments in the experiment. Denitrification losses can be reduced by selecting a soil with a low water holding capacity and a low organic matter content. This increases however the risk of crop wilting in dry periods. An estimate of mineral N from the soil store and from atmospheric deposition can be collected from N-uptake in the crop on non-fertilized fields. Introduction of N-fixing legumes will increase problems of quantification of N-inputs. In grassland fertilization experiments clover should therefore be removed at lower N-supplies to facilitate explanation of results at different levels of N-supply. Injection of slurry or a quick incorporation after surface spreading will prevent or minimize volatilization losses. Measurement of leachate volume and sampling of the leachate is easier in lysimeter studies than in field situations. Lysimeter experiments have some drawbacks (Appendix 2).

3. DATA COLLECTION IN A U.K. NITRATE LEACHING STUDY

An outline is given of what the U.K. Soil Survey measured and recorded during a recent nitrate-leaching study. The notes are arranged to answer the questions of why, what, how, where, when and who with respect to the project aims.

1. Why? The eventual models chosen will require numerical data. These data will be obtained by many different people in different laboratories, Institutes and countries. The data must, however, be of comparable quality and compatible with the model(s).
2. What? We measured/recorded the following:

   a. Soil

      i) Site (location, slope, aspect, height, land-use). We should also estimate erosion risk/rate.

      ii) Profile description (pit to 1.2 m). Can we agree a common soil classification?

      iii) Basic soil properties: particle size distribution
      organic carbon
      pH
      carbonate

      iv) Soil physical properties;
      Bulk density (undisturbed)-stone free.
      Water retention at several suctions.
      Hydraulic conductivity (undisturbed)
      Porosity (need to note large cracks, channels, earthworms etc.).

      v) Nitrate and ammonium contents (as kg N/ha/soil layer - however the latter is defined).

   b. Water

   Nitrate and ammonium as mg N/litre.

   c. Meterorology

   Precipitation
   Air Temperature

   d. Crops

   Crop type
   Mass of crop (oven dried) in kg/ha
   Total nitrogen in crop as kg/ha.

   e. Farm

3. How? This refers essentially to experimental and field procedures.

a. Soil

i) For basic soil properties samples are taken horizon-by-horizon from a conventional soil pit.

ii) For the nitrate leaching studies, soil samples are taken at 0-10 cm, 10-20 cm, 20-30 cm, 30-60 cm, 60-90 cm depths, as undisturbed cores using a gouge auger ca. 3 cm diameter. Samples are transferred, in the field, to a cold box (like a picnic-box) and sent to the laboratory by overnight rapid transport.

iii) Nitrate and ammonium are determined sequentially in a 2M KCl extract (40 g < 2 mm moist soil, 200 ml KCl, shake 2 hrs, filter through special grade nitrate-free paper). Determination by alkaline steam distillation using Devarda's alloy to reduce nitrate).

iv) Moisture content of soil determined and results calculated as Kg NO_3 or NH_4 as nitrogen, per hectare-layer (10 cm thick, or 30 cm thick) using the stone-free bulk density values.

v) These soil samples are taken:

a. Late autumn - soils just returned to field capacity.
b. Early spring - usually about mid-February.
c. Late spring - as soil moisture deficit begins to develop.

b. Water: samples taken from 1 metre depth using ceramic suction samplers (Soil Moisture Inc.). Maximum number of samplers is two per plot. Water samples kept cold (ca. 4°C), transported rapidly to laboratory and analysed immediately for nitrate and ammonium by alkaline distillation (a (iii)). The aim is to analyse water samples within 24 hr of sampling. Results are reported as mg NO_3 or NH_4 per litre, as nitrogen. Water samples are taken every two weeks.
(Note: the water from the two samplers in each plot is kept separate; we do not bulk samples).

c. Meteorology: These data (precipitation, potential transpiration, average weekly air temperature, calculated soil moisture deficit) are obtained from the National Meteorological Service Hydrometeorological Bulletin.

d. Crops: Crop type is noted at each site. Crops are sampled at the same time as the soils are sampled. The samples are taken by hand-cutting all the crop to ground surface level in three randomly selected quadrats (50 cm x 50 cm). These samples are either dried on the day of collection, or kept frozen (-18°C) until drying is possible. Crop weights are calculated as kg/ha. Roots (for cereals and brassicas) are assumed to be 25% of shoot weight. Total nitrogen is measured in crop samples by a Kjeldahl procedure and nitrogen reported as kg/hectare (corrected for estimated root weight).

e. Farm: If experimental plots are on commercial farms there has to be a very clear arrangement with the farmer about:

i) access to site
ii) crops/sowing dates
iii) fencing or similar plot protection
iv) management (fertilisers, sprays, slurry/sludge spreading etc.)
v) record keeping.

4. Where? Sites in England were chosen to be representative of:

a. major climatic zones

b. soils which are freely-drained and extensive over aquifers. (The main problem for us is inorganic fertiliser nitrogen. Animal slurry is less of a problem). Initially we had 21 sites, but this is now reduced to 12, however, 6 sites have 3 crops on each site.

5. When? This has been partly covered by How?, but we have confined our measurement programme to, essentially, the period when our soils are at field capacity. This is usually between (approximately) mid/late October to late March/April.

6. Who? Perhaps not a very necessary question, but we did find that if several people are involved in the field programme it is very necessary to:

a. have an overall co-ordinator who checks regularly on sampling progress, and collects and collates all the data as the project progresses;

b. have a very clear set of guidelines (or even a training course) to show people exactly what is required (graduates are no better than assistants in this respect);

c. it is very, very preferable to send all material for analysis to one laboratory. It may be necessary to have agreed priorities for analysis of your material by your method.

4. DATA COLLECTION

Two types of studies may be distinguished with respect to data collection:

- more intensive studies involving detailed measurements at a limited number of sites
- less intensive studies at a larger number of sites (regional studies)

The more intensive studies yield detailed information about processes such as mineralisation, volatilization, leaching and denitrification. The results indicate the minimum amount of data required from less intensive studies and enhance the interpretation of these data.
In Appendix 1 a package for background and monitoring data is presented. When all data are available then the information can be used for the testing of more sophisticated models like the Agricultural Nitrogen Model (ANIMO) of the Institute of Land and Water Management Research. No suggestions will be made for the measurements to quantify ammonia volatilization, denitrification, immobilisation and mineralisation as quantification of these terms requires a large research effort. Incorporation of available knowledge may proceed with assistence of specialists from various countries. Net mineralisation (mineralisation - immobilisation) is being dealt with in the proposal.

APPENDIX 1: BACKGROUND DATA AND MONITORING DATA FOR FIELD EXPERIMENTS

A: Background data

1. Site (location, slope, height)
2. Profile description (till 1.2 m), including macroporosity (cracks, etc.)
3. Land use (cropping system: e.g. long term grass, cereals + potatoes, etc.)
4. History of land use and fertilization for the preceeding 10 years if possible, 5 years is essential

   For each soil horizon till roughly 1.2 m depth information is needed on:

5. Water retention characteristic (undisturbed samples)
   a minimum is: moisture fraction at wilting point (pF = 4.2)
   moisture fraction at field capacity (pF = 2.0)
   moisture fraction at saturation (pF = 0.0)
6. Hydraulic conductivity (undisturbed)
7. Organic N and organic matter content, pH
8. Bulk density (undisturbed)

B. Monitoring data

1. Climate:
   1.1. precipitation per day
   1.2. evapotranspiration per 10-day periods
   1.3. irrigation per day
   1.4. air temperature (mean per day), or soil temp. (see 5.4)
2. Crop:
   2.1. Crop type and variety
   2.2. date of sowing
   2.3. date of harvest
   2.4. N-content in crop fractions at harvest (e.g. for cereals: grain, straw, roots in kg N per ha). Indicate what residues are left on the fields (in kg N per ha)

3. Mineral fertilizers:
   3.1. amount of N, P, K (in kg per ha)
   3.2. date of application
   3.3. N-form in N-fertilizers (NH_4, NO_3, urea)
   3.4. slow release fertilizers, type and amount

4. Animal manure and slurry[1]:
   4.1. amount and type (cattle, pig, etc.) (in m^3 per ha)
   4.2. date of application
   4.3. technique of application (injection, surface application)
   4.4. date of incorporation in soil in case of surface application
   4.5. analyses in manure: dry matter, organic matter, K, total N, NH_4, total P (in % of total weight)
   4.6. number of animals and grazing days in grassland experiments
   4.7. Nitrification inhibitor applied, type and amount

5. Soil data[2]:
   5.1. Sampling dates of mineral N (NH_4, NO_3) per layer (in kg N per ha per layer)
   5.2. number of subsamples per soil layer per field, size of subsamples
   5.3. soil moisture per layer of 20 cm (in soil samples taken for mineral N) (in % of dry weight)
   5.4. soil temperature (once a week at roughly 5, 15, 30, 60 cm depth) or air temp. (see 1.4)

6. Groundwatertable:
   6.1. groundwatertable depth (once a week; when groundwater influences water content in rootzone)

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1) Large errors may be introduced by poorly mixing irregular spreading, uncorrect sampling and storage of slurry samples

2) Care should be taken that correct soil sampling procedures are being used (number of subsamples, mixing) and attention should be paid to cooling during storage and to a rapid drying and analyzing

7. Leaching[3]:

7.1. amount of drainage water (in mm) in a defined time

7.2. nutrient concentrations in drainage water (NO_3, and NH_4) (in g per m^3, as N)

7.3. N leached (in kg per ha, as N)

APPENDIX 2: Methods to assess nitrogen losses to ground and surface waters

(From: Steenvoorden, J.H.A.M., H. Fonck and H.P. Oosterom, 1986. Losses of nitrogen from intensive grassland systems by leaching and surface runoff. Techn. Bull. n.s. 53. Institute for Land and Water Management Research, Wageningen, 13 pp.)

Methods to assess nitrogen losses to ground and surface waters

Quantification of N losses to ground and surface waters requires data about the amount of drainage or runoff water and its chemical composition. Different techniques are available to quantify water movement and accompanying N loss. Each technique has its own merits depending on the problem to be assessed and technical constraints imposed by the field site in question. The range of techniques available is summarised in Table 1. The principle difference between techniques relates to the depth of sampling involved.

Analysis of soil mineral N (technique 1) in the upper metre in autumn gives only an estimate of the potential loss of nitrate through leaching. The actual amount of N leached also depends on the amount of excess precipitation and changes in the mineral N content of soil brought about by microbiological processes which occur between the time of soil sampling and the end of the leaching season.

Soil water samples can be collected from below the root zone by using ceramic cups (technique 2). The leachate is sampled by creating a vacuum in the cup which exceeds soil water tension in the surrounding soil. The ceramic cups are connected to a vessel on the soil surface, under vacuum during sampling, in which the leachate is collected. For experiments on cut grassland with an even distribution of fertilizers and animal manures, four cups per field are sufficient to produce reliable data (Table 2).

Table 1. Techniques for quantification of N losses from soils to ground and surface waters[a]

Technique	Water quantity	N concentration	Total load
Leaching			
1. Soil mineral N	–	–	±
2. Soil moisture analysis at roughly 1 meter below soil surface	–	+	–
3. Borehole water from shallow groundwater	–	+	–
4. Lysimeter effluent	+	+	+
5. Drainage effluent	+	+	+
Surface runoff			
6. Gutter	+	+	+

[a] +, direct measurement possible
–, direct measurement not possible
±, provides only an estimate

Table 2. Comparison of nitrate N concentrations in leachate ($g\ m^{-3}$) from two sampling sets in one experimental field, each set consisting of four ceramic cups at one metre below soil surface. The experiment is on cut grassland; cattle slurry was injected in early spring. The water samples were taken in the drainage period after the growing season in 1984

N application ($kg\ ha^{-1}\ yr^{-1}$)		Nitrate N concentration in leachate ($g\ m^{-3}$)	
slurry	mineral fertilizer	set 1	set 2
143	600	36	35
143	400	13	9
143	0	2.5	2.3
283	600	83	87
283	400	25	25
283	0	3.2	5.5

At sites with a shallow groundwater table, leachate samples can also be collected from borehole water (technique 3). When information is required on N leaching from the preceding growing season, the borehole water should be sampled when water movement through the profile ceases. This is normally the beginning of April in the Netherlands. The depth of the borehole should approximate the percolation depth of excess precipitation during the wet period. Percolation depth can be estimated from soil water balance calculations and physical data for the soil. On grazed fields attention should be paid to the number of boreholes per field as a wide variation in concentration might occur (Table 3). In this case, more than 24 boreholes may be required to obtain reliable results. The high nitrate concentrations below these fields may partly be caused by the low grass production in the very dry summer of 1976.

Table 3. Variation of nitrate N concentrations in the upper metre of the groundwater below grazed fields. Results are based on separate analyses of groundwater from 15 or 24 boreholes per field early in the spring of 1977
$\bar{x}$ = mean nitrate N concentration
S_x = standard deviation of the 15 or 24 analyses
$S_{\bar{x}}$ = standard deviation of the mean ($S_x/\sqrt{n}$)

Field	Number of boreholes	Nitrate N ($g\ m^{-3}$)			
		$\bar{x}$	S_x	$S_{\bar{x}}$	$S_{\bar{x}}$ (% of $\bar{x}$)
1	24	80	47	9.6	12.0
2	24	111	57	11.6	10.5
3	24	95	56	11.4	12.0
4	15	137	58	15.0	10.9
5	15	137	68	17.6	12.8
6	15	65	48	12.4	19.1
7	15	80	27	7.0	8.7

Results from lysimeter experiments (technique 4) will only be applicable to field situations if the soil moisture regime within the root zone is the same as that in the undisturbed soil in the field. Comparability is often poor due to the fixed groundwater level in lysimeters, physical disturbance during installation of lysimeters and absence of surface runoff in lysimeter experiments. It is impossible to assess the effects of grazing in lysimeter studies.

Samples collected from field drains (technique 5) can also reflect the influence of soil use. It should be noted, however, that field drain effluents are a mixture of water with different residence times in the subsoil. Precipitation on soil immediately above a drain may be discharged in the same year. In contrast, the residence time of water in subsoil between two drains may be several years depending on the hydrological situation [4]. Conse--ntly, the concentration of nitrate in field drain effluents may reflect not only the influence of land use during the preceding growing season, but also that in previous years as well as the effects of microbiological processes occurring during transport through the subsoil.

The disadvantages of water quality measurements using lysimeters and drains are balanced to some extent by the ease of water quantity measurements. In experiments using soil moisture and borehole techniques, water fluxes can only be estimated from soil water balance calculations. The choice between the available techniques will be influenced not only by considerations of the reliability of estimates of water quality or quantity, but also by other factors. The borehole technique, which results in considerable structural damage to the soil, is not applicable to small experimental plots if the experiment is to be continued for some years. Soil water analysis (technique 2) requires frequent sampling during the drainage season and is more labour intensive than the borehole technique.

Surface runoff is the excess precipitation which is transported over the soil surface to surface waters. Measurement of the amount of surface runoff and reliable sampling of its nutrient content can only be achieved by installation of a gutter at the edge of a field (technique 6).