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# Nitrogen Balance in Fertilizer Application and Plant Production

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The investigation comprises several agricultural crops, a Karup locality (56°16' N, 9°9' E) with an average annual precipitation of 775 mm and coarse sand (soil 1), and a Tåstrup locality (55°40' N, 12°18' E) with an average precipitation of 600 mm and clay with fine sand (soil 6). Soils 1 and 6 have 5 and 8 t N/ha in organic matter, respectively, to 50 cm soil depth and an average effective root zone capacity for available water of 60 and 170 mm.

Data for soils 1 and 6 in kg N/ha as average (with great annual variation) were for spring barley found to be around the following: mineralization 75 and 135, denitrification 5 and 20, uptake in·harvest 105 and 155, leaching 65 and 40, and spring storage 10 and 60, respectively. Wintering and late growing crops reduce the leaching by around 20 kg N/ha. The nitrogen leaching from sandy soil is clearly influenced by variation in fertilization whereas the leaching from clay soil is only a little affected.

## Introduction

Aslyng and Hansen (1982) have described the root zone water balance and crop dry matter production simulation model WATCROS based on climate, soil and plant parameters and variables. See also S. Hansen, page 205-212 in this publication. In addition to the WATCROS model, Hansen and Aslyng (1984) have developed the nitrogen balance in crop production simulation model NITCROS. Both models operate with a time step of one day.

In the root zone inorganic nitrogen balance is considered:

| Source | Sink |
|---|---|
| 1. Mineralization | 4. Denitrification |
| 2. Atm. fall-out and microbial assimilation | 5. Uptake by plants |
| 3. Fertilization | 6. Leaching by percolation from the root zone |
| 7. Root zone balance (root zone storage) | |

The following short presentation is mainly on mineralization and leaching of nitrogen.

## Mineralization

$K$ is a rate constant and $N_0$ is the total organic $N$ in the soil down to 50 cm depth. The rate constant $K$ is assumed to depend on soil temperature and soil moisture content. That is

$$K = K' f_t(T_s) f_\theta(\theta) \quad (1)$$

where $K'$ is the mineralization rate at 10°C and field capacity, $FC$; $f_t(T_s)$ describes the effect of soil temperature $T_s$, and $f_\theta(\theta)$ describes the effect of soil moisture content $\theta$.

Addiscott (1983) adjusted for temperature effect on $N$ mineralization by using an Arrhenius type equation $K = A\ e^{-B/T}$, where $K$ is the mineralization rate, $A$ and $B$ constants and $T$ the temperature in $K$. He recommended $B = 7{,}000\ K$ by which the equation yields relatively high values at low temperatures, Fig. 1. We assume that the mineralization almost ceases when the temperature approaches zero, therefore Eq. (2) has been selected (Fig. 1)

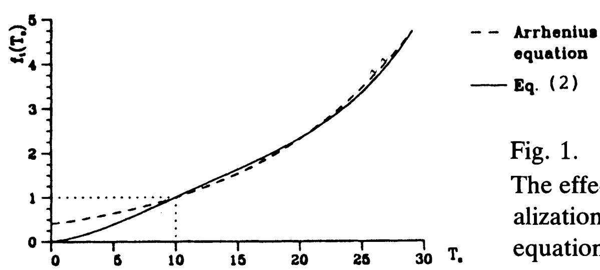



Fig. 1.
The effect of soil temperature $T_s$ on mineralization according to the Arrhenius Type equation and Eq. (2).

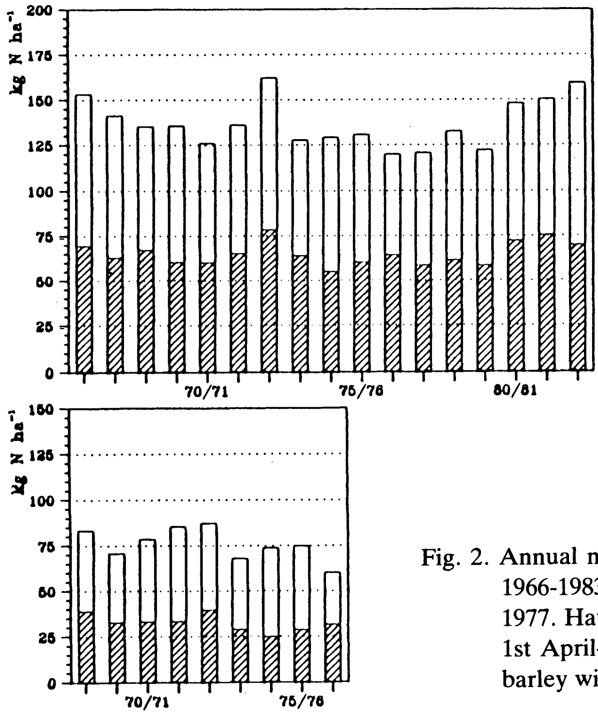



Fig. 2. Annual mineralization in soil 6 at Tåstrup 1966-1983, and in soil 1 at Karup 1968-1977. Hatched 1st April-31st July and total 1st April-31st March when growing spring barley with 110/140 kg N/ha, respectively.

$$f_t(T_s) = \{\exp(0.57 - 0.024T_s + 0.0020T_s^2) - \\ - \exp(0{:}57 - 0.042T_s - 0.0051T_s^2)\} \qquad (2)$$

Stanford and Epstein (1974) found a lineary relation in the interval dry soil to soil at optimum soil water content. As a reasonable approximation they recommend

$$f_\theta(\theta) \equiv \frac{\theta}{\theta_{FC}} \; ; \quad \theta \leq \theta_{FC} \qquad (3)$$

where $\theta_{FC}$ is field capacity (= optimum).

Stanford and Epstein found that the mineralization declined when the moisture exceeded the optimum content, but they gave no quantitative measure of this. We have assumed a linear relationship in the region between optimum moisture content and water saturation when the soil pores are water filled. This is expressed by the equation

$$f_\theta(\theta) = 1 - \frac{\theta - \theta_{FC}}{\theta_s - \theta_{FC}} \; ; \quad \theta > \theta_{FC} \qquad (4)$$

where $\theta_s$ is the moisture content at saturation.

From field experiments we have found $K' = 0.8\ 10^{-4}\ \text{day}^{-1}$ satisfactory when applied to the total content of organic nitrogen in the upper 50 cm soil.

Fig. 2 shows the simulated mineralization in soils 6 and 1 for a number of years.

## Atmospheric Fall-Out and Microbial Assimilation

Based on literature information we have calculated with 1.5 kg N/ha for each month of the year.

## Fertilization

Applied nitrogen is considered available to plants when the soil moisture has been above 80% of the available capacity or the precipitation has been at least 7 mm in 3 days or 12 mm in 7 days after application.

## Denitrification

A model has been developed based upon the assumption that from zero to 10% of the applied nitrogen (depending on soil type) is lost over a short period. In addition to this a diffuse loss occurs when the soil temperature is at least 5°C, the soil moisture at least 90% of available capacity and the nitrogen content larger than 0.6 kg N/ha/cm depth.

## Uptake by Plants

The maximum uptake determined by the nitrogen content in the crop $N_c$ is calculated as

$$U_c^* = \frac{N_c^* - N_c}{\Delta t} \qquad (5)$$

where $N_c^*$ is the maximum nitrogen content in the crop at the present time step, $N_c$ is the actual content in the crop at the end of the previous time step, and $\Delta t$ is the time step of the model, which is one day.

The maximum uptake determined by the available nitrogen in the root zone is calculated as

$$U_s^* = \frac{N_i - N_i'}{\Delta t} \qquad (6)$$

where $N_i$ is the total inorganic nitrogen content in the root zone and $N_i'$ is the inorganic nitrogen content in the root zone not available to plants.

The uptake is then calculated as

$$U = \mathrm{MIN}(U_c^*, U_s^*) \qquad (7)$$

Fig. 3 shows – as an example – the simulated and experimentally determined nitrogen content in harvest of winter wheat.

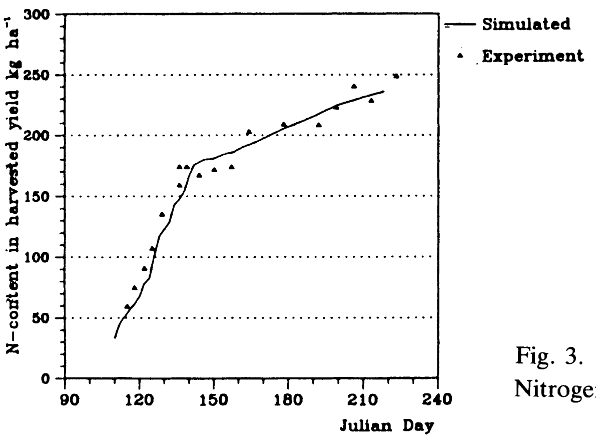



Fig. 3.
Nitrogen in harvest of winter wheat 1983.

## Leaching

We have applied a slightly modified version of the leaching model proposed by Addiscott (1977). This model has been especially developed for leaching in structured soils. It is a layer model in which transport of nitrogen between layers only takes place as solute in percolating water.

The soil solution is partitioned into a mobile (*MW*) and a retained (*RW*) fraction. The *RW* represents water held in 'dead end' and very small pores. The model permits displacement of the mobile solution through an indefinite number of layers when large flows occur (piston flow).

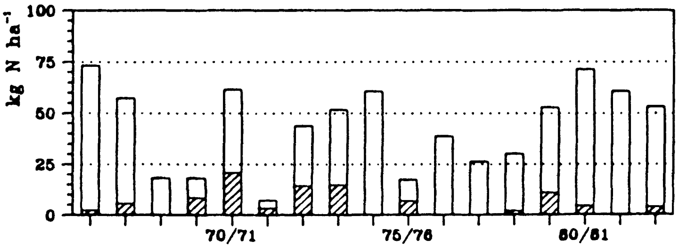
The *MW* and *RW* values in each layer are important parameters in the Addiscott model. The allocation of values to *MW* and *RW* is essentially arbitrary because of the nature of the working approximation. Addiscott proposed the upper limit of the *MW* to be pF 1.7 (field capacity) and the lower limit of the *RW* to be half-way (on moisture basis) between pF 4.2 (wilting point) and dryness. The division between *MW* and *RW* is at pF 3.3.

In our version of the Addiscott model the uppermost layer is treated separately. The underlying layers, each of the thickness of 5 cm, are treated as proposed by Addiscott (1977). In spring before onset of growth the uppermost layer has a thickness of 25 cm but when the roots, after onset of growth, penetrate into the layers below the uppermost layer, these layers are included in the uppermost layer with the content of water and nitrogen.

When soil water content $\theta$ in the uppermost layer exceeds the threshold value $\theta_{FC}$ (field capacity) the percolation is

$$q \equiv K_q(\theta - \theta_{FC})\Delta z \tag{8}$$

where $K_q$ is a reservoir constant and $\triangle z$ the thickness of the layer.



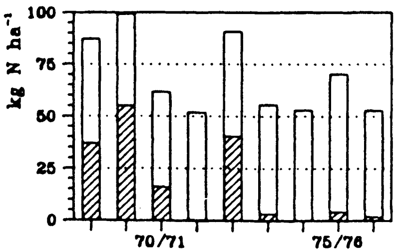




Fig. 4. Annual leaching from soil 6 at Tåstrup 1966-1983 and from soil 1 at Karup 1968-1977. Hatched 1st April-31st July and total 1st April-31st March when growing spring barley with 110/140 kg N/ha, respectively.

For layers below the uppermost layer, leaching is assumed to take place instantaneously when field capacity is reached (as in the Addiscott model). The water balance is run as a book-keeping system with input and output on a daily basis.

Figs. 4-5 show the simulated nitrogen leaching in kg N/ha for a number of years and the leaching as a function of nitrogen application and cropping of the land. The leaching of nitrogen is largest from sandy soil and when growing spring crops harvested early. Late crops and wintering crops reduce the nitrogen leaching.

## Storage

The possibility of storing $NO_3^-$ is greatest in clay soil but so is also the risk of denitrification. The risk of leaching is greatest from sandy soils. Not only the storage of $NO_3^-$ but also the mineralization are important factors in the nitrogen balance and crop production.

Two root zone storage quantities ($NO_3{-}N + NH_4{-}N$) are of specific interest:

1) Storage at onset of spring growth (spring storage)
2) Storage at end of growth or at harvest (harvest storage)

The spring storage is of importance in reducing winter leaching and to fertilizer application needed in the spring. The minimum harvest storage shows how efficient the crop can exhaust the root zone for inorganic nitrogen. The remaining amount of nitrogen is a soil characteristic when fertilizer has not been applied to excess.

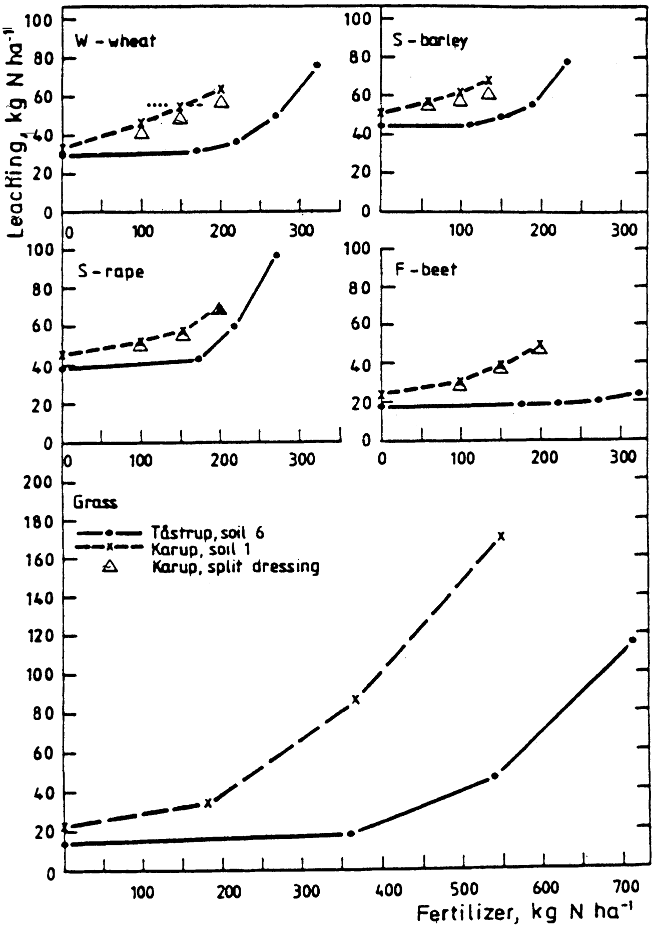



Fig. 5. Average leaching 1st April-31st March from soil 6 at Tåstrup 1966-1983 and from soil 1 at Karup 1968-1977, when growing different crops with different nitrogen fertilization. The grass had 25% of the fertilizer for each of the first four cuts (total 5 cuts). For split dressing at Karup half of the nitrogen is applied three weeks later than normal.

Independent of nitrogen application from zero to more than the normal amount, a given soil contains in the effective root zone an almost standard amount of inorganic nitrogen at the time of crop ripening or harvest if drought has not prevented the nitrogen uptake. We have assumed a minimum harvest storage for soil 1 to be 5 and for soil 6 to be 20 kg N/ha in a root zone of 50 and 100 cm depth, respectively. Spring storage is small in sandy soil and 25-90 kg N in clay soil, Fig 6.

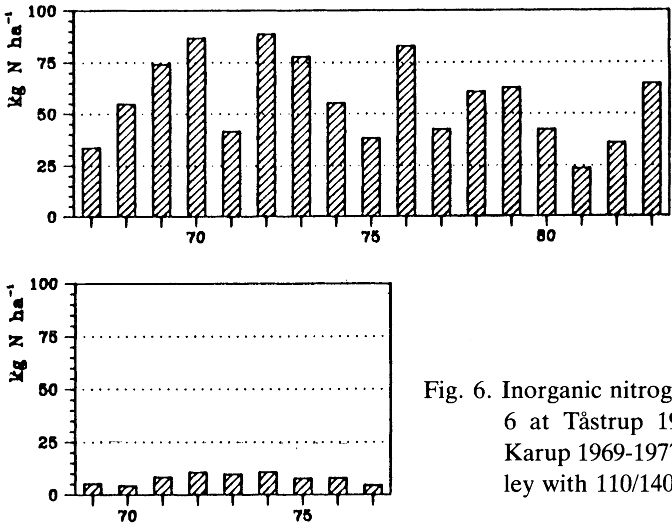



Fig. 6. Inorganic nitrogen storage 1st April in soil 6 at Tåstrup 1967-1983 and in soil 1 at Karup 1969-1977 when growing spring barley with 110/140 kg N/ha, respectively.

## References


Addiscott, T.M. (1977) A simple computer model for leaching in structured soils, *J. Soil Sci., vol 28,* 554-563.

Addiscott, T.M. (1983) Kinetics and temperature relationships of mineralization and nitrification in Rothamsted soil with differing histories, *J. Soil Sci., vol 34*, 343-353.

Aslyng, H.C., and Hansen, S. (1982) Water balance and crop production simulation. Model WATCROS for local and regional application, Hydrotechnical Laboratory. The Royal Vet. and Agric. Univ. Copenhagen, 200 pages.

Hansen, S., and Aslyng, H.C. (1984) Nitrogen balance in crop production simulation model NITCROS, Hydrotechnical Laboratory. The Royal Vet. and Agric. Univ. Copenhagen, 113 pages.

Stanford, G., and Epstein, E. (1974) Nitrogen mineralization-water relations in soils, *Soil Sci. Soc. Am. J., vol, 38*, 103-107.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