Leaching of Nitrate from Arable Land into Groundwater in Sweden[1]

ARNE GUSTAFSON
Swedish University of Agricultural Sciences
Uppsala, Sweden

ABSTRACT / The agricultural influence on the quality of the groundwater in Sweden is mostly associated with infiltration areas. The local conditions here determine the extent of the nitrate leakage. It is evident that certain combinations of factors in normal cropping can give unduly high nitrate concentrations in the groundwater.

Introduction

During the last decade the impact of agriculture on groundwater has been discussed. Most of the interest has been focused on nitrate. At the Swedish University of Agricultural Sciences, investigations are in progress to determine the extent of and reasons for the leaching of nitrate. This represents a difficult problem because of the geohydrological complexity of the landscape. Nevertheless, it is possible to make a simple geohydrological model of a landscape to show where agricultural impact is and is not possible. From the standpoint of a specific geohydrological situation many factors, both inside and outside the agricultural area, will affect the extent of the nitrate leakage. The following factors will be discussed in this paper: climate, hydrodynamic pressure, type of soil, intensity of nitrogen dressing, type of crop, and chemical reduction of nitrate.

The results presented here are based on material from a network of experimental fields covering the whole country. The Division of Water Management is in charge of the investigations.

Geohydrological Conditions Preceding Agricultural Impact on Groundwater

Sweden has been glaciated. The country is therefore covered with Quaternary stratifications. A high proportion of the groundwater consumed thus derives from these stratifications which are thereby of great importance for the quantity of water available for consumption, for its age, and for its quality. A simple geohydrological model of a landscape in central Sweden can serve as a basis for estimates of where the risk of agricultural impact is great and where it is absent or small (Fig. 1). At bottom is the bedrock, followed by loose stratifications of permeable material such as moraine, gravel, and sand, and at the top in valleys and on plains an almost impervious layer of varying clay content.

This topography and succession of layers gives rise to specific geohydrological properties. Naturally only the groundwater in the permeable layers is of interest in terms of the water supply, since these can transmit enough water within a reasonable time. The head of the water pressure, which reflects the actual pressure at the depth of observation, will be established after drilling piezometric tubes down into the Quaternary layers. The observed groundwater pressures connected to one line show the pressure surface built up in the landscape at any given time.

Where the water is moving downward there is a decrease in the head with depth, and where it is ascending there is a corresponding increase. Thus, the head at some depth is likely to be lower than the water table in an intake area and higher in a discharge area. In consequences there is in a discharge area no possibility of agriculture affecting the deeper groundwater quality; this can only occur in intake areas. The magnitude of this impact on the groundwater quality is dependent on local conditions such as climate, type of soil, type of agricultural activities, and chemical conditions.

Climate Influence

Comparison

The great length of the country causes a considerable climate difference between northern and southern Sweden. For this reason the country was divided into three main regions, the northern, the central, and the southern, in order to differentiate and cover the most typical climatic zones. The bulk and distribution of the precipitation and runoff over the year, as well as the quality of the drainage water are included in this comparison. The experimental fields compared have soil types ranging from fine sand to clay.

Precipitation and Runoff

The bulk of the precipitation was lowest in the north and highest in the south. The months January, February, April, and May had, on average, lower precipitation than the remainder (Fig. 2). The total runoff averaged 90 mm, being heavier from the fields in the south compared with the other two

[1]Presented at the International Symposium, International Association of Hydrogeologists, "Impact of Agricultural Activities on Ground Water Quality and Quantity," Prague, Czechoslovakia, September, 1982

Environmental Geology, Vol. 5, No. 2, 65–71

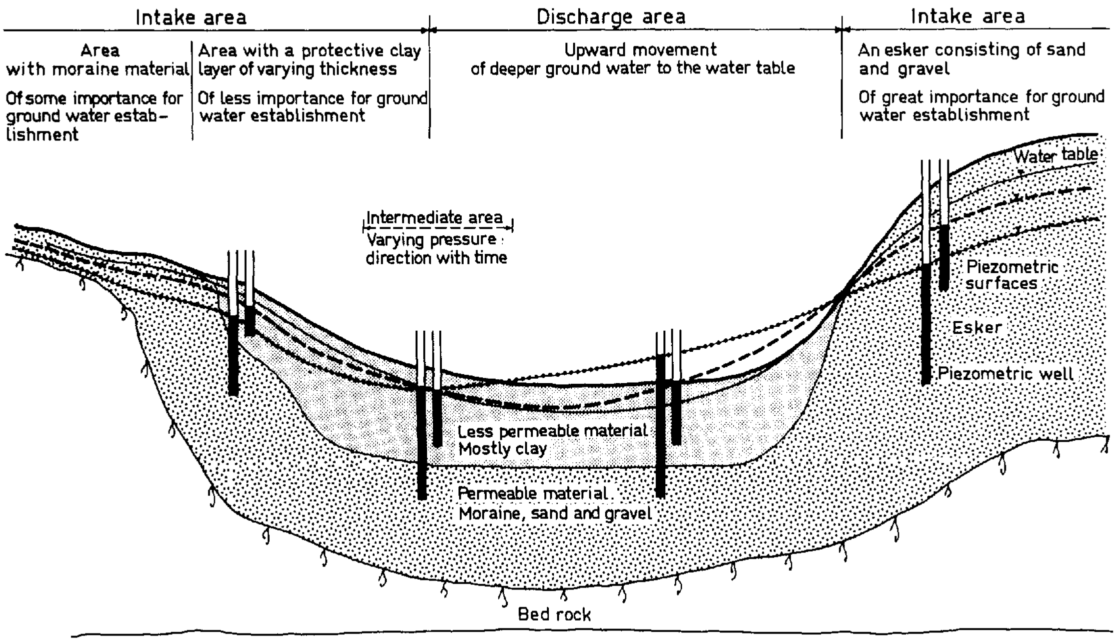

Figure 1. A geohydrological model of a landscape in central Sweden.

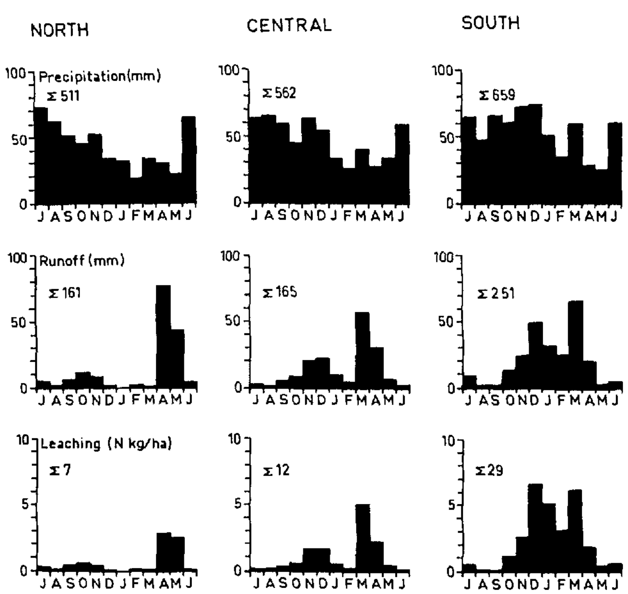

Figure 2. Precipitation, runoff, and leaching of nitrogen from experimental fields in three regions.

regions. The explanation primarily consists in the differing precipitation figures. The runoff during the summer months was normally low.

The winter runoff showed a clear climatic variation. In the northern area two very pronounced peaks were distinguished, in autumn and spring with, on average, a four-month period of frozen conditions in between (Dec.–Mar.). In the southern area, where the winter temperatures are normally higher, the runoff was considerable even during the winter. The runoff situation in the central area fell somewhere between those of the two other areas, as would be expected.

Table 1. Crop distribution (%) and nitrogen dressing with commercial fertilizers (N kg/ha per year) in three regions for counties and experimental fields represented

Area	Ley	Cereal crops	Rem. crops	Nitrogen dressing
North				
Counties	55	35	10	34
Experimental fields	50	40	10	56
Central				
Counties	23	64	13	85
Experimental fields	12	76	12	109
South				
Counties	21	55	24	113
Experimental fields	12	69	19	107

Nitrogen

The nitrogen transport was strictly correlated to the runoff. The difference in the total transport of nitrogen between the three regions was greater than the difference in runoff. This could be explained by consideration of how and when the runoff takes place. In the northern area most of the runoff occurs during the spring (80%), primarily as surface runoff, which decreases leaching of available nitrate in the soil profile. The apparent nitrogen transport during the spring was chiefly

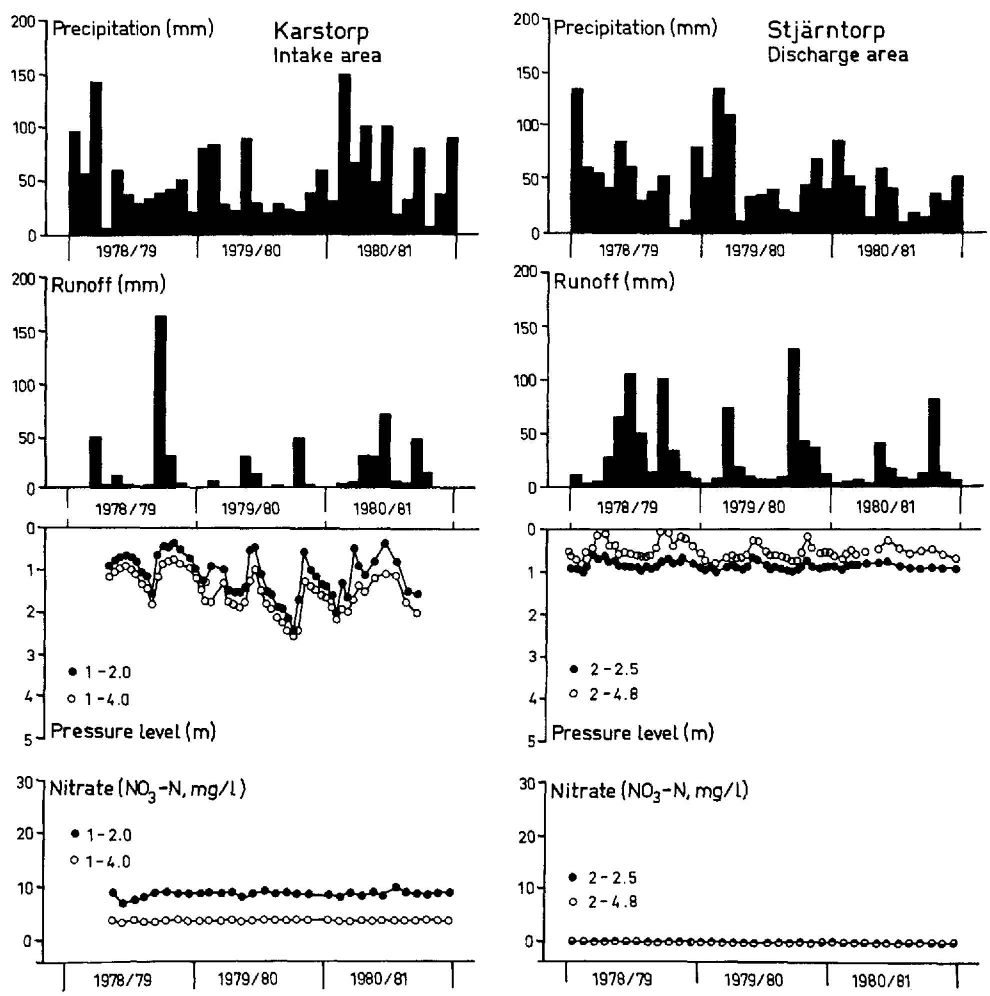

Figure 3. Precipitation, runoff, groundwater pressure, and content of nitrate in an intake area and a discharge area.

caused by spreading of manure on frozen ground. The manure disappeared with the surface runoff.

In the southern area the considerable winter runoff in combination with the limited time that the soil is frozen provokes heavy leaching of the soil profile. The mineralization of nitrogen during the autumn is also favored by the milder climate.

As a result of the climate, the proportion of the land used for cereal crops is increasing, from north to south, which means more crop residues available for mineralization. The amount of nitrogen dressing is also increasing (Table 1). All these facts combined explain why the leaching of nitrogen is much higher in the south than the north.

Hydrodynamic Pressure

The water from soils in intake areas originates in precipitation which infiltrates the field. In consequence the nitrate derives mainly from the surface. Many years may pass before the nitrate reaches deeper layers of the soil profile. The variation of the groundwater pressure is obvious during the year (Fig. 3).

The situation is different with soils in discharge areas. The water is usually of far distant origin. The conditions of the investigated field have no influence on the water quality at a depth somewhat deeper than the water table. The variation of the groundwater pressure is small (Fig. 3), and the nitrate content normally low. It has been established through tritium analysis that the groundwater from some fields, at a depth of 4 m, could be more than 30 years old.

If the groundwater reservoir is subjected to an excessive discharge of consumption water, the water emanating from the intake area is too slow in refilling the reservoir. The upward movement of deeper groundwater disappears and limited intake areas around the water wells are created. Strictly local pollution could influence the groundwater, and thereby cause a

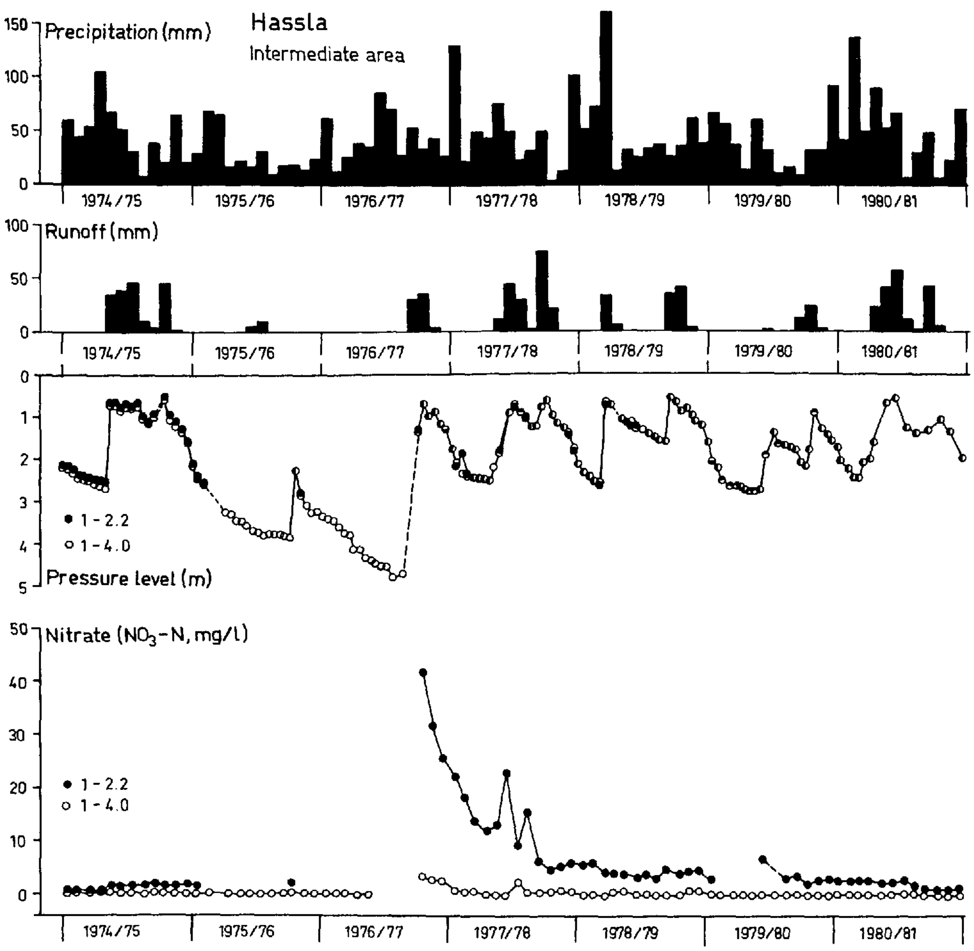

Figure 4. Precipitation, runoff, ground-water pressure, and content of nitrate in an intermediate area.

deterioration of the water quality. In intermediate areas the groundwater pressure shows considerable variation during the year. A substantial lowering of the groundwater table is common for years with low precipitation, as happened during the agrihydrological years 1975-76 and 1976-77 (Fig. 4). When the groundwater reservoirs were filled up again, after the precipitation reverted to normal, the water percolating the soil profile had a very high nitrate content. This was presumably an effect of a nitrate accumulation during the preceding dry period. The nitrate content of the shallow groundwater increased considerably. When normal conditions were established, the nitrate contents decreased and after four years the content was restored to the same level as before the groundwater depression.

Type of Soil

A factor of great importance for the nitrogen balance in the ground is the type of soil. The possibility of substantial differences as regards the nitrogen losses through leaching is illustrated in Figure 5. Mean values from fields with three different types of soil in the southern area are compared.

The sandy soils lost more than twice as much nitrogen compared with the clay soil. The root depth in the sandy soil rarely exceeds 40-60 cm, which is one explanation why the losses are so great. Nitrogen below this level is naturally not available for the crop and is exposed to leaching. For a clay soil with good structure, the situation is different. The root penetration can easily reach one meter and more, which results in more stable uptake of nitrogen by the crop.

Some of the nitrogen in a well-aggregated clay soil, i.e. the nitrogen found inside aggregates and micropores, is effectively protected against leaching. Most of the percolating water occurs in root canals and macropores. This physical state does not exist in a sandy soil, in which the water percolates all pores.

An interesting finding is that the runoff from the Skottorp field did not cause a higher leakage of nitrogen than at

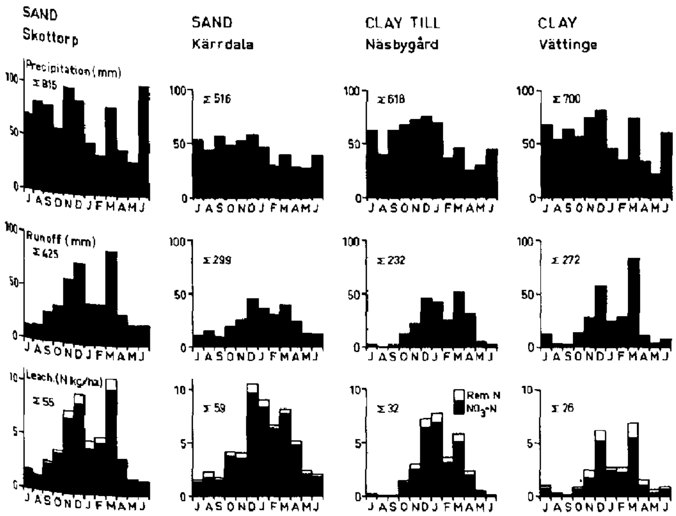

Figure 5. Precipitation, runoff, and leaching of nitrogen from four experimental fields in the southern area.

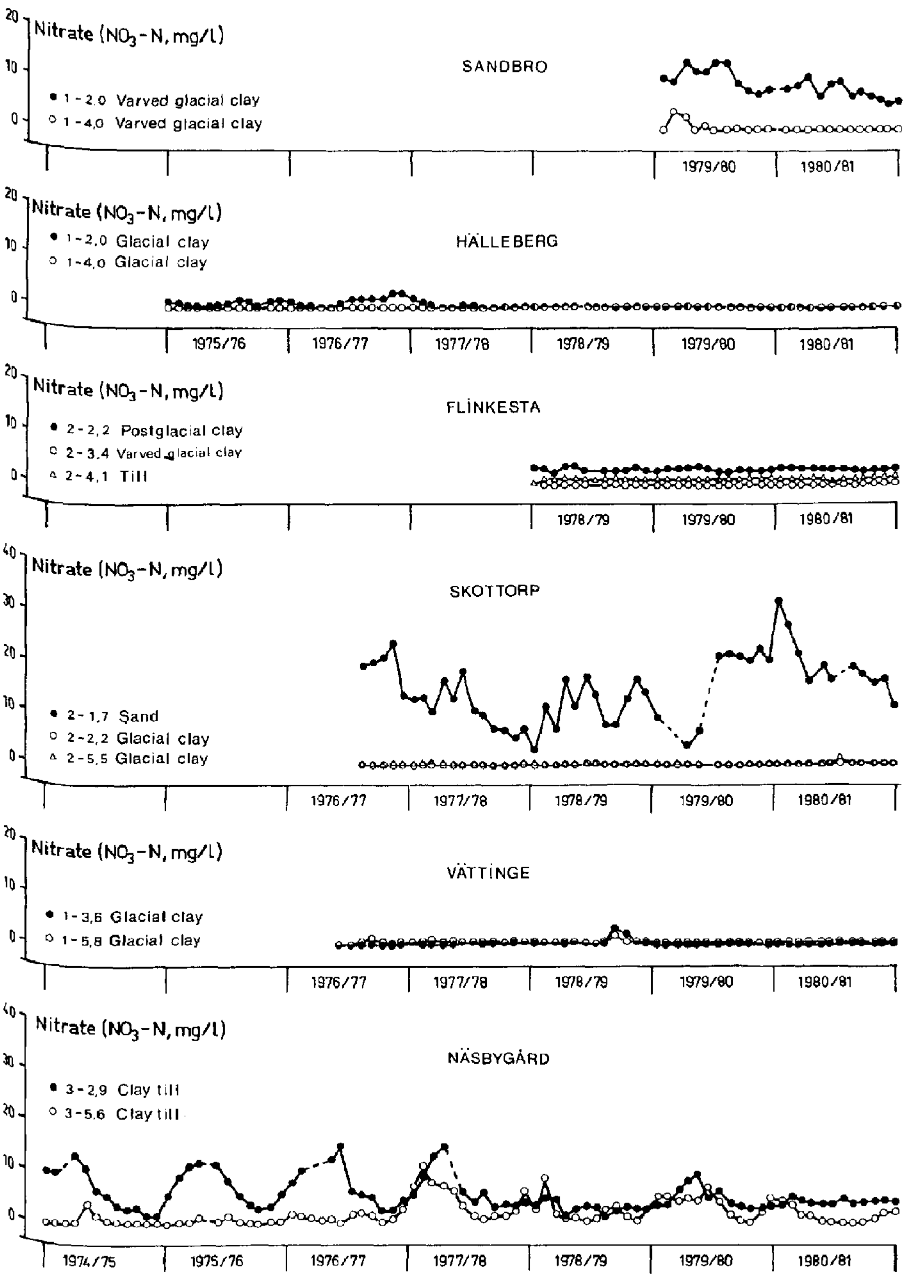

Figure 6. Nitrate in groundwater at some of the experimental fields.

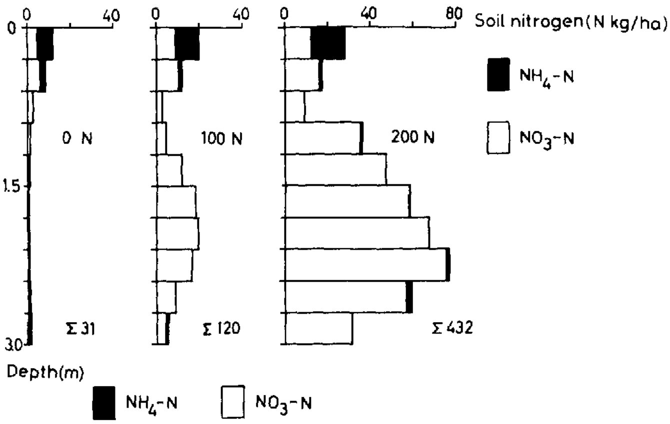

Figure 7. Nitrogen in the soil to a depth of 3 *m* in a cropping system with three different fertilization levels.

Table 2. Mean contents of nitrate found at 1.7 m in relation to crops sown

Crop	Potatoes	Grass ley	Ploughing up and oats
Nitrate (N mg/l)	24	11	20
Time of observation (months)	5	28	19

Kärrdala. The leaching of a sandy soil is apparently very effective, even when the runoff is moderate. In the event of a high runoff the supply of easily mobilized nitrate determines the leaching magnitude. At Kärrdala large amounts of nitrate were released through mineralization, primarily because of frequent use of manure. This is the main explanation why the leaching was highest from this field.

This indicates that raised nitrate contents in groundwater are to be expected for sandy and silty soils situated in intake areas. The results from the Skottorp experimental field seem to confirm this theory (Fig. 6). More unexpected are the raised nitrate contents in the deep groundwater (4–6 m) at Karstorp and Näsbygård with clay as dominant soil type (Figs. 3 and 6). One explanation would seem to be the occurrence of vertical deep crack planes, as observed at Näsbygård. These cracks can be either open or filled with a fine sand. The fertilizing intensity and cropping methods, which are discussed below, are naturally of great importance. In most cases the contents were fairly low in the deep groundwater. It must be remembered that there is no deep groundwater in a sandy soil represented in the material.

Fertilizing Intensity

The fertilizing intensity is obviously of great significance for the magnitude of nitrogen leakage. An intensive fertilizer dressing results in high amounts of crop residues, which are

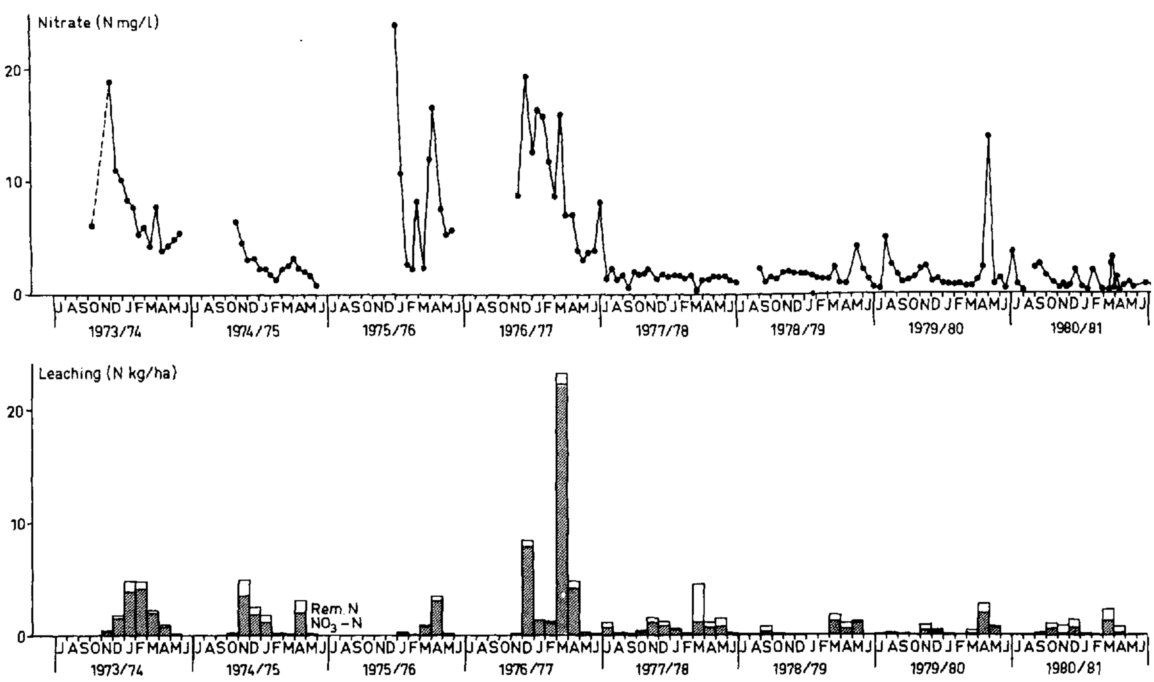

Figure 8. Nitrate in drainage water at Flinkesta.

exposed to mineralization after harvest. There is a clear risk of overdoses of nitrogen since the presence of other factors determining the yield is usually restricted. In other words the crop cannot make full use of applied fertilizer. This is very well documented in experiments using increasing amounts of nitrogen. A field experiment in progress since 1974 on a Swedish clay soil shows that repeated, excessive use of nitrogen fertilizer causes a considerable leakage within a few years (Brink and Lindén 1980).

Nitrogen profiles down to a depth of 3.0 m from three of the treatments included in this experiment (0, 100, and 200 *N* kg/ha per year) are discussed below. The soil samples were collected during December 1981. The highest amount of nitrogen used causes a substantial accumulation of nitrate in the soil profile. This accumulation is obvious throughout the profile (Fig. 7). There is a difference of 89 *N* kg/ha between the 100-N treatment and the treatment with no nitrogen at all. It is evident that crop production at normal fertilization level also causes a minor accumulation of nitrate in the soil profile.

Type of Crop

The crop has a considerable influence on the leakage, which lends significance to crop rotation. Crops harvested late cause less mineralization of crop residues, since the temperature normally drops steeply as winter approaches. Winter wheat and other crops sown during the autumn can absorb nitrogen late in the season. A grass ley of several years' standing would provide optimum conditions. Such a subdued nitrogen leakage caused by a ley is illustreated by a series of measurements from Flinkesta (Fig. 8). The following crop succession was started in 1973: winter wheat, spring rape, winter wheat, barley, oats with re-seed and finally three years of ley. The ley was ploughed in November 1980 with no effects on the nitrogen losses the following winter, presumably by reason of the late date of this ploughing. The influence of grass ley on the groundwater quality was also apparent on a sandy soil. Table 2 indicates the mean contents of nitrate found at a depth of 1.7 m. (see page 70).

A possible method of preventing losses of mineralized and unused nitrogen, accumulated after harvest, is to sow a "second crop" in connection with the harvest of the "main crop." This "second crop" stores the nitrogen in organic compounds. Late in the autumn or during the spring it is ploughed up. The organic matter will mineralize and be available for the next crop instead of being leached out.

Chemical Reduction of Nitrate

Danish investigations point to the ability of the soil to reduce nitrate (Lind and Pedersen 1980). This ability relates primarily to the purely chemical reactions, especially the ferrous iron-nitrate redox system. This process mainly occurs in clay soils due to slow water movements and anaerobic conditions. The results show that the contents of nitrate usually decrease with the depth of sampling, which indicates that the process is effective (Figs. 3, 4, and 6).

References Cited

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