Variation of runoff and nitrogen leaching in a small agricultural catchment in southern Finland*

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Abstract Long term monitoring data from 1981–2000 was used to study nitrogen (N) losses from a small (15.4 km^2) agricultural catchment in southern Finland. The annual loads of total N, NO_3-N and NH_4-N varied considerably during the study period. The mean total N load was 820 kg km^{-2} yr^{-1}. More than half of the annual N load was in the form of NO_3-N, while the relative contribution of NH_4-N was low, which is common in Finnish agricultural fine-textured soils. The measured annual N loads were highly dependent on runoff. The highest annual N load (1310 kg km^{-2}) was observed in 1984, in accordance with the highest annual runoff (616 mm). Due to mild weather conditions during the winters since 1989, the relative proportion of winter runoff was higher than earlier. So far, no decrease could be seen in annual N loads, even though most of the farmers are participating in the Finnish Agri-Environmental Programme established in 1995. However, the amount of NH_4-N load seems to have remained very low (less than 50 kg km^{-2} yr^{-1}) in Savijoki since 1995, which may reflect changes in agricultural practices and a decrease in N deposition.

Keywords Agriculture; hydrological pattern; management practice; nitrogen load; winter runoff

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Introduction

Agricultural production is known to be the major source of diffuse nitrogen (N) load to surface waters in Finland. Total N load from catchments is highly dependent on the proportion of agricultural land (Rekolainen 1989). Today, water protection policy aims at a significant reduction of this load, due to increasing concern about water quality in inland waters and the Baltic Sea (Ministry of the Environment 1998). Recent studies in agricultural catchments and river basins indicate no reduction of N load, even though efforts have been made to ensure the development of agricultural practices towards higher sustainability (Vuorenmaa *et al.* 2002; Vuoristo *et al.* 2002; Räike *et al.* 2003).

Leaching of N and annual riverine N load is highly dependent on hydrometeorological conditions, such as variation of annual precipitation and discharge (Hogland 1994; Arheimer *et al.* 1996; Eltun and Fugleberg 1996; Vagstad *et al.* 1997; Ulen 1998; Mander *et al.* 1998; Vuorenmaa *et al.* 2002). While most of the annual N load in Finland originates during the high flow period, caused by melting of snow and soil frost, the autumn period is also of interest due to potential leaching of mineral N left in soil after ceasing of the vegetation N uptake. Detailed information is needed about the impacts of hydrological processes on the N cycle in order to control N losses on catchment scale and to develop models for estimating nutrient leaching.

The objective of this study was to analyse the annual hydrological pattern and its effect on N leaching in Savijoki catchment, a small (15.4 km^2) agricultural head water catchment, which represents intensively cultivated areas in south-western Finland. Savijoki catchment is one of the four core catchments for estimating agricultural nutrient loading in Finland. Long-term monitoring data on water flow and water quality was available, together with

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information on local agricultural management practices. Some measurements were also available for snow water equivalent and soil frost. Twenty years of data (years 1981–2000) were used to analyse the annual hydrological pattern and variation of annual load of total and inorganic N.

Material and methods

Description of the study area

The Savijoki catchment is located in south-western Finland, about 30 km northeast from the city of Turku (60°36′, 22°40′). It is a sub-catchment of the River Aurajoki that discharges to the Archipelago Sea of the Baltic at the city of Turku (Figure 1). Savijoki belongs to the Finnish network of small representative catchments, originally established for hydrological research in 1957 (Mustonen 1965; Seuna 1983). There are no lakes in the catchments and the

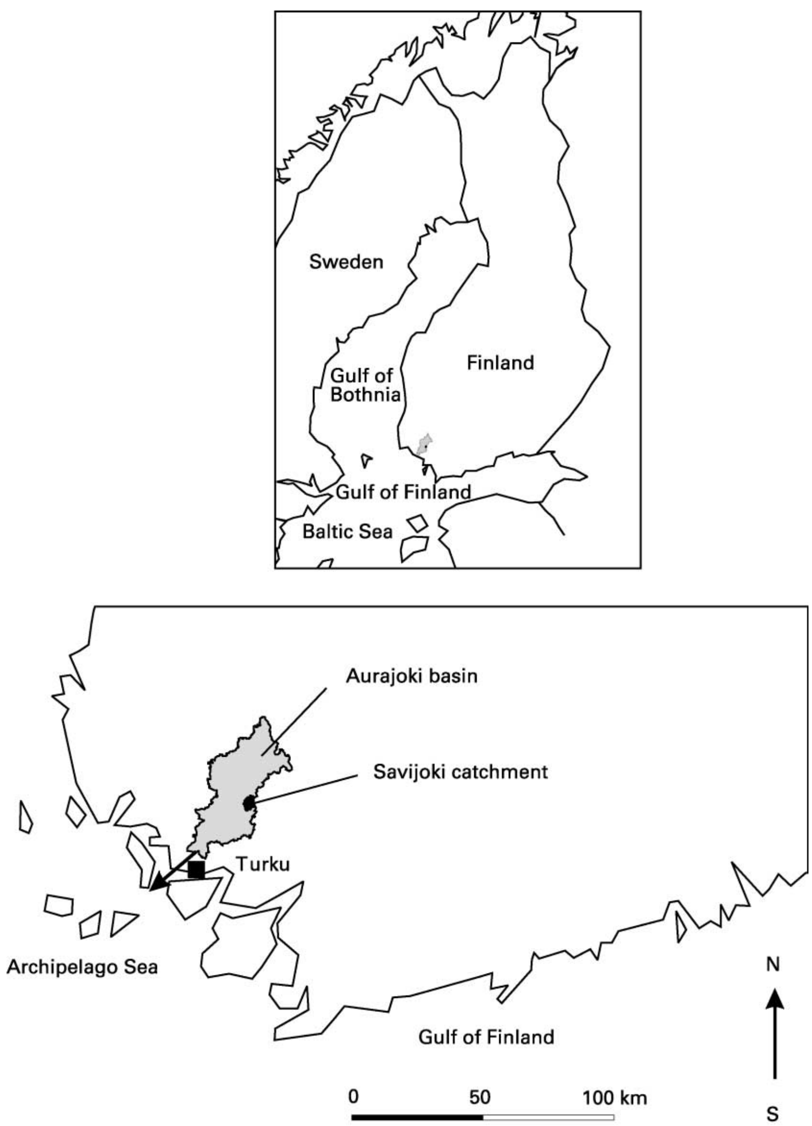

Figure 1 Location of the Savijoki catchment

network aims at collecting representative information in different climatic and soil conditions of the country.

Continuous monthly water quality monitoring was started in 1962 in order to estimate, for example, diffuse nutrient loading from the catchments. The data has been widely used to study the complex interactions related to nutrient leaching, and especially the impact of agriculture and forestry on water flow and quality (e.g. Lepistö 1996; Rekolainen 1989; Vuorenmaa *et al.* 2002). In Savijoki, the discharge and water quality measurements started in 1971. Before 1981, the water quality was sampled regularly at monthly intervals. This monitoring strategy was changed in 1981 by concentrating the sampling on high flow periods (Rekolainen 1989; Rekolainen *et al.* 1991; Vuorenmaa *et al.* 2002). Due to this change in sampling strategy, only data since 1981 was used in this study. Properties of the Savijoki catchment are presented in Table 1.

Detailed long term climatic data was available from Turku airport locating less than 30 km southwest from the Savijoki catchment. Precipitation and snow water equivalent were measured also within the catchment. The annual mean values for temperature and precipitation in 1971–2000 were 5.2°C and 698 mm (Drebs *et al.* 2002), respectively (Table 1). The highest precipitation occurs during the late summer and autumn. During the winter months (December–March) precipitation usually falls as snow.

More than half of the catchment is covered by coniferous forests growing on shallow glacial moraine soils (usually less than one meter deep). During the melting of the continental icecap most of the area was covered either by freshwater or saltwater, and thus the cultivated river valleys consist of thick clay layers of different ages. Artificial drainage is needed on fields to provide good conditions for management practices, especially after snowmelt in spring. Due to geological conditions, the groundwater resources are very low in the area, being usually sufficient only for single households (Haavisto-Hyvärinen *et al.* 1983).

Agriculture is the main source of diffuse nutrient losses in the Savijoki catchment (Rekolainen 1989). Information about forestry practices was sparse, but the water quality impacts are probably low in this area. In the southern part of the country the annual total N (Tot-N) load from forestry land catchments is estimated to be in the range of 130–300 kg km^{-2} (Kortelainen *et al.* 1997) compared with 1500 kg km^{-2}, an average value for agricultural land (Vuorenmaa *et al.* 2002).

Detailed information on agricultural practices was collected by farmer interviews in the years 1987, 2001 and 2002, covering the years 1987 and 1999–2002. Data from the years 1987 (Pajala 1989) and 1999–2002 was used in this study. According to farmer interviews, the present crop distribution on agricultural fields is rather similar to that in 1987 (Figure 2). The latter interviews were carried out in order to evaluate the effects of the Finnish

Table 1 Main characteristics of the Savijoki catchment

Area (km^2)	15.4
Agricultural land (% of total area)	39
Soil types (% of total area):	
fine sand	1
Silt	1
Clay	34
Peat	7
moraine soils	57
Mean annual precipitation (mm)	698
Mean annual temperature (°C)	5.2
Mean annual runoff (mm)	369

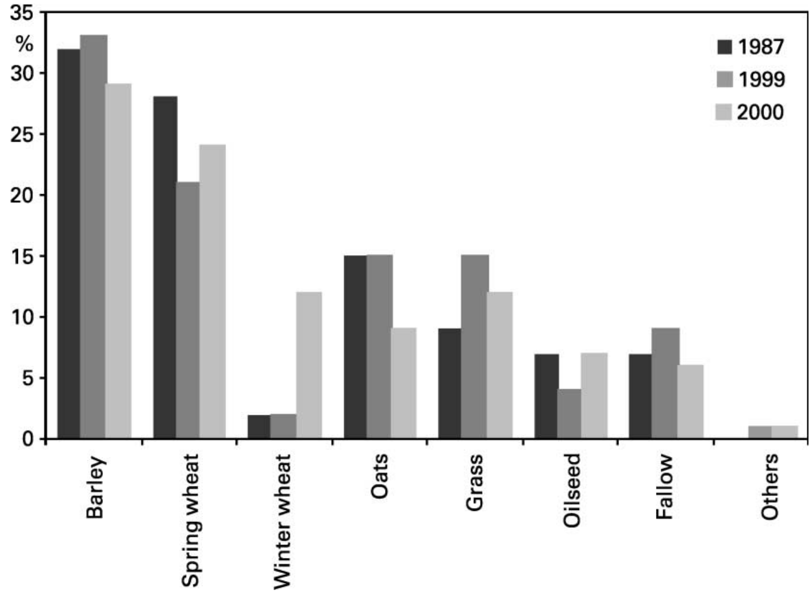

Figure 2 Crop distribution on fields in Savijoki catchment in years 1987, 1999 and 2000

Agri-Environmental Program (FAEP; Valpasvuo-Jaatinen *et al.* 1997), which was established in 1995, when Finland joined the European Union. Today, the FAEP forms the most important policy measure for controlling agricultural nutrient loading. Through the programme, farmers are paid for adopting environmentally sound management practices. For instance, farmers must establish buffer strips on the main ditches and water courses, and targeted levels of fertilization and manure application must not be exceeded. In Savijoki, most of the farmers are participating in the FAEP.

Hydrometeorological measurements and water sampling

The flow at the catchment outlet was measured continuously by a V-notch overflow weir and a water stage recorder described in detail by Mustonen (1965). Today, the water quality monitoring strategy is a combination of manual (ca. 15 samples per year) and high-frequency automatic flow-weighed sampling. The loads were calculated for Tot-N, NO_3-N and NH_4-N. The amount of organic N load was calculated by subtracting the sum of inorganic fractions (NO_3-N and NH_4-N) from the Tot-N load. A detailed description of the sampling technique and chemical analysis is given by Vuorenmaa *et al.* (2002).

In winter time the snow water equivalent, and the depth of snow cover and soil frost, was measured once or twice a month along a two kilometer route covering different vegetation types of the catchment. The location of some of the soil frost tubes has changed over time and, as a result, the measured values represent typical soil frost conditions rather than values of single profiles. Information on groundwater level or quality was not available.

In order to study the hydrological effects of the detected increase in winter temperatures since 1989–1990 (Drebs *et al.* 2002), the measured annual runoff values were compared to total runoff during the dormant season. Moreover, the total number of heat units (HU), here defined as the sum of positive daily temperature values, was calculated for the dormant season. Annual data on the length of the growing season for the Turku station was provided by the Finnish Meteorological Institute. The growing season usually started in April and ended in October.

Results and discussion

Agricultural features in south-western Finland and in the Savijoki catchment

Agricultural crop production is intensive in south-western Finland, due to favourable climatic conditions and fertile soils. While the overall percentage of agricultural land of the total land area in Finland is 8%, it is 26% in the drainage area of the Archipelago Sea. In this area agricultural production is dominated by cereal cultivation. Structural development within the agricultural sector caused an increase in farm sizes during the 1990s. At the same time the number of different crop and livestock species has decreased (Pakkanen and Jaakkola 2003).

In Finland, the use of inorganic fertilizers was highest at the end of the 1980s and the beginning of the 1990s. In the 1990s, reduction of agricultural nutrient loading was strongly emphasized, especially after FAEP was implemented in 1995. Commitment to the FAEP is high in the drainage area of the Archipelago Sea: according to data by Pakkanen and Jaakkola (2003) 93% of the farms are participating in it. The environmental support has increased the area of buffer zones. For instance, in the Aurajoki river basin, 14% of buffer zones included in the general buffer zone plan were established by the end of 2002. According to the data by Lemola *et al.* (2004) and Ministry of Agriculture and Forestry (2004), the average nitrogen soil surface balance on agricultural land decreased 30 kg from 93 kg N ha^{-1} in 1990 by 2000 in south-western Finland. Since 1996/1997, the quantity of N sold in fertilizers decreased by more than 5% by 1999/2000 (for the fertilization period) (Pakkanen and Jaakkola 2003). The average annual yields of spring cereals varied from less than 2000 kg ha^{-1} to 4000 kg ha^{-1} during 1981–2000. The yields were low in 1987, 1992 and 1999 (Figure 3) (Yearbook of Farm Statistics, 1981–2000).

In Savijoki catchment, detailed information on agricultural land use was not available for the entire study period. Farmer interview data was available only for the years 1987 and 1999–2002. Spring cereals were the most common crops in agricultural land (Figure 2). According to Pyykkönen *et al.* (2004), 10 of the 30 farms included in the interview study were engaged in livestock production. In 2002, the number of livestock units was 94 for cattle, 296 for pigs and 228 for poultry. During 2000–2002, the amount of N fertilization for barley varied from 85 to 105 kg ha^{-1} yr^{-1} and for oats from 93 to 98 kg ha^{-1} yr^{-1}.

Variation of annual hydrological pattern

The specific runoff in the Savijoki catchment was highly variable during the years 1981–2000. The mean, minimum and maximun values were 11.7, 0 and 303.5 $l\,s^{-1}\,km^{-2}$,

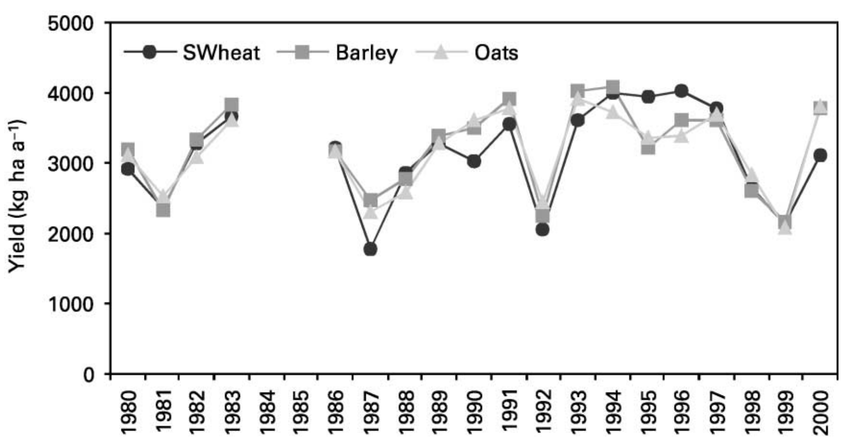

Figure 3 Average annual yields of spring cereals in south-western Finland in 1981–2000

respectively. Accordingly, the measured annual runoff showed a high variation and was correlated to annual precipitation. Figure 4 shows the measured annual precipitation, runoff and maximum measured areal snow water equivalent. The mean annual runoff was 369 mm. The highest runoff (616 mm) occurred in 1984, corresponding to the highest precipitation (874 mm, local station) and snow water equivalent (119 mm).

The mean monthly runoff also showed considerable variation (Figure 5). The highest runoff usually occurred in April during the snow melt period. A smaller peak was detected at the end of the year, as a result of autumn rains. During the low flow period in summer time (June–August) the runoff was usually very low (practically zero mm), due to evapotranspiration. However, local summer storms can occasionally cause a flow peak even in summer. The catchment typically has rapid response to snow melt and precipitation events. This is mostly due to low groundwater storage in the forested area and intensive sub-surface drainage on fields.

The mean annual temperature was higher in the period 1991–2000 than in 1981–1990 (4.7°C vs. 4.1°C, respectively). The latter decade was also drier than the earlier one (mean annual runoff 351 mm and 389 mm, respectively). The winters since 1989–1990 were warmer than earlier: the total number of heat units during the dormant season remained

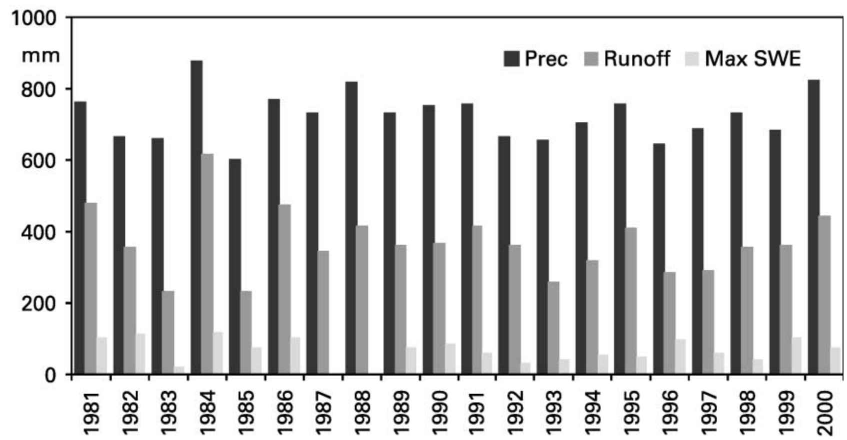

Figure 4 Annual variation of precipitation, runoff and maximun measured areal snow water equivalent (SWE) in Savijoki catchment. Data is missing for SWE in years 1987 and 1988

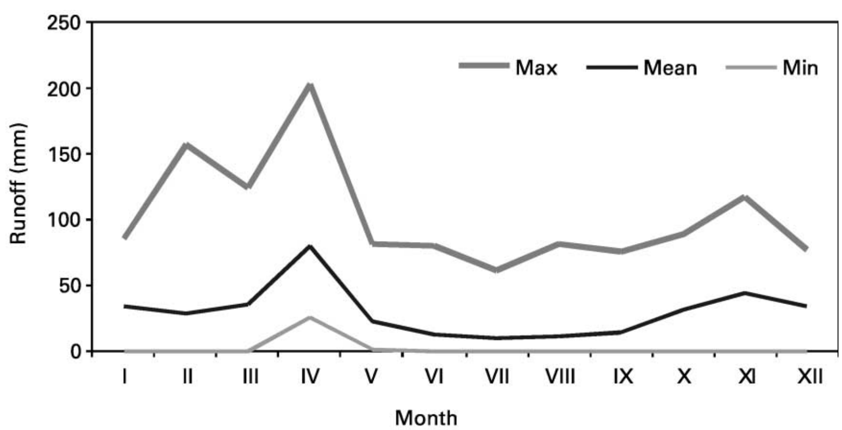

Figure 5 Maximum, mean and minimum monthly runoff in Savijoki catchment

higher than 200°C since 1989 (Figure 6). As a result, the wintertime runoff was typically somewhat higher than earlier (Figure 6), constituting more than 60% of the annual runoff. According to a time series analysis by Hyvärinen (2003), the annual maximum of the areal water equivalent of snow has generally been decreasing in southern and western Finland during 1947–2001. Moreover, the winter runoff has generally been increasing strongly in southern Finland. Annual discharge in the south and west also increased to some extent.

Due to the low number of snow water equivalent measurements (once or twice a month) the annual duration of the snow cover could not be analyzed in detail with this data. The soil frost measurements proved to be insufficient, because the sites of the measuring tubes have changed during the study period. Measured soil frost showed considerable variation between years and in different tubes (not shown). The maximum measured soil frost was approximately 90 cm.

Variation of annual nitrogen load

The annual loads of Tot-N, NO_3-N and NH_4-N varied considerably during the study period (Figure 7). The mean Tot-N load was 820 kg km^{-2} yr^{-1}. Usually, more than half of the annual N load was in the form of NO_3-N, while the relative contribution of NH_4-N was low (Figure 8). This is common in Finnish agricultural mineral soils (Jaakkola 1984; Lemola *et al.* 2000). However, surface application of slurry can occasionally cause leaching of NH_4-N in surface runoff (Turtola and Kemppainen 1998). In Savijoki, the NO_3-N load (as well as the Tot-N load) was correlated to annual runoff, reflecting the high mobility of this anion (Figure 9). The highest annual Tot-N load (1310 kg km^{-2}) was measured in 1984, in accordance with the highest annual runoff.

Vagstad *et al.* (2001) analyzed observed nutrient losses from 35 small Nordic and Baltic catchments, including the Savijoki catchment. The average annual losses of Tot-N ranged from 500 to 7500 kg km^{-2} in 1994–1997. There was also large interannual variability in nutrient losses within each catchment. According to Vagstad *et al.* (2001), the interactions between agricultural practices and basic catchment characteristics, including hydrological processes, determine the final losses of nutrients to surface waters. Hence, it is necessary to understand these interactions in order to efficiently manage diffuse losses of agricultural nutrients. According to a review by Grimvall *et al.* (2000), most of the interannual variation in the export of nutrients to the North Sea and the Baltic Sea appears to be related to natural fluctuations in runoff, and the export of nitrogen has been particularly difficult to reduce.

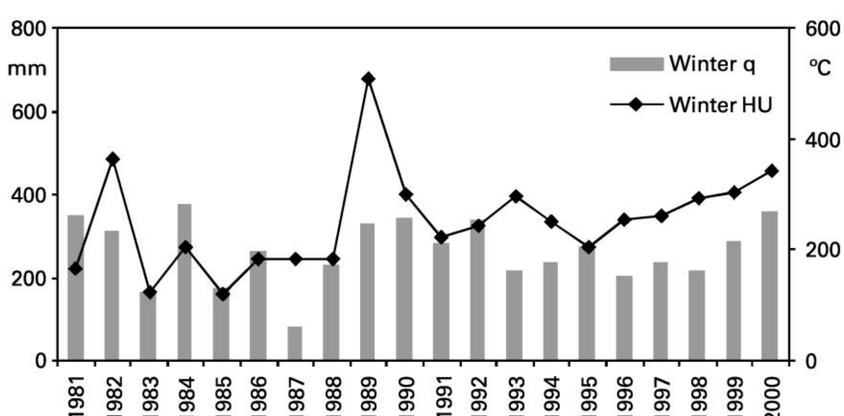

Figure 6 Measured runoff (Winter q) and total number of heat units (Winter HU) during the dormant season in Savijoki catchment

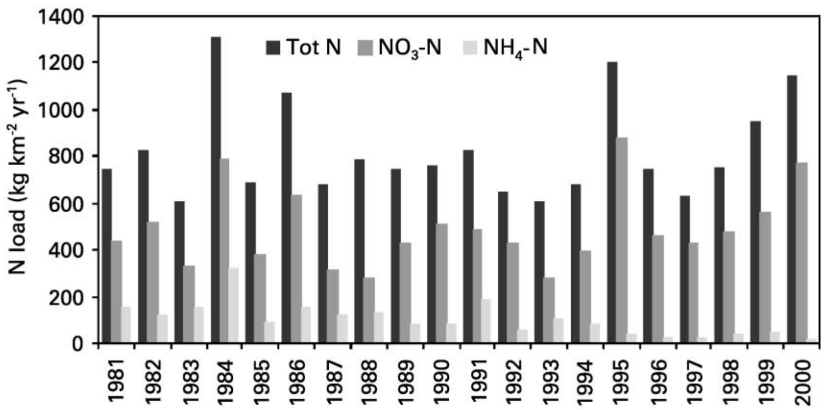

Figure 7 Annual variation of nitrogen load in Savijoki catchment

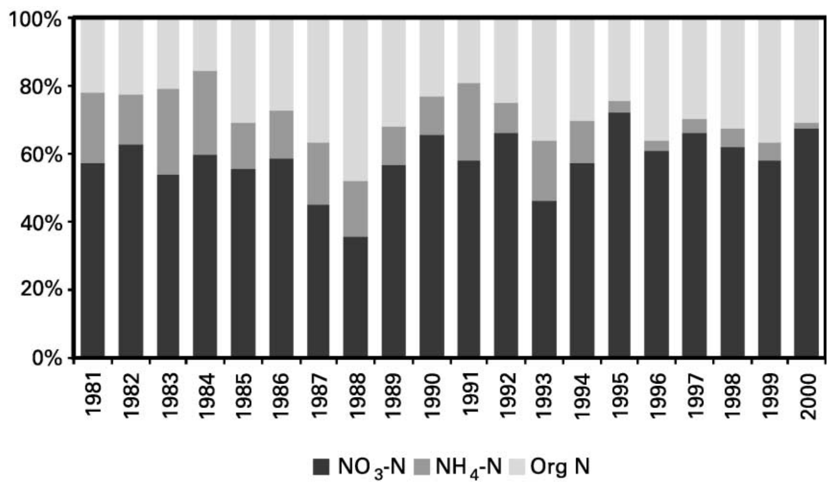

Figure 8 Relative proportion of different N fractions in annual nitrogen load

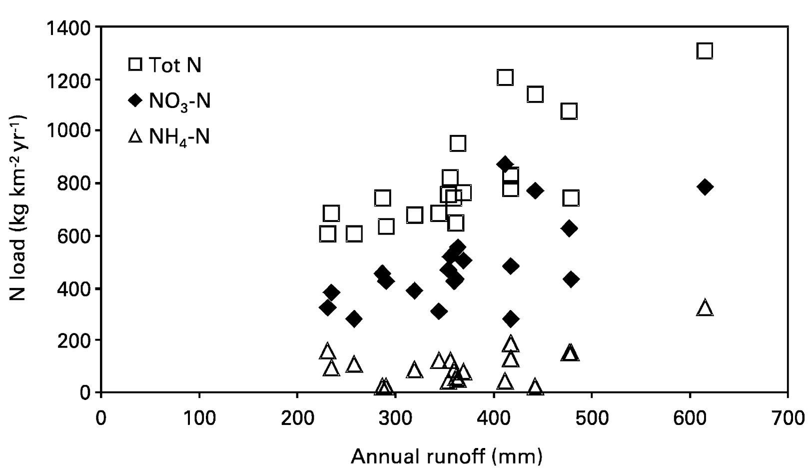

Figure 9 Relationship of annual N load and runoff in Savijoki catchment

So far, the annual N loads in the Savijoki catchment show no decrease even though most of the farmers are participating in the FAEP. According to Palva *et al.* (2001), the average use of N and P in fertilizers during the first period of FAEP (1995–1999) decreased close to the target levels defined in the FAEP in the studied catchments. The same trend would be expected in Savijoki also, due to high participation in the FAEP. A decrease of N deposition, observed in southern Finland during 1981–2000 (Figure 10), also lowered the external input of N to the catchment. According to Antikainen *et al.* (2004), the continuous nutrient surplus to the fields (29 kg N $ha^{-1} yr^{-1}$, a calculatory average for the period 1995–1999) is one apparent contribution to leaching.

The mean annual Tot-N load in 1991–2000 did not differ from that in 1981–1990 (819 vs. 821 kg $km^{-2} yr^{-1}$), even though the climatic conditions were warmer. It is possible that the potential effects of new agricultural measures are masked to some extent by the effects of climatic conditions.The Tot-N load has not decreased, but the amount of NH_4-N load seems to have remained very low (less than 50 kg $km^{-2} yr^{-1}$) in Savijoki since 1995 (Figures 7 and 8). The higher NH_4-N load in 1980s was usually due to high concentrations during the spring flow peak. The relative decrease in the NH_4-N load may be due to changes in agricultural practices required by the FAEP (e.g. restrictions related to manure application), but may also be related to weather induced changes in the nitrification and retention processes in the catchment. The weather conditions during mild winters since 1989 (see Figure 6) have probably provided favourable conditions for enhanced mineralization in soil during the dormant season.

Runoff and mineral N content in soil are commonly known to affect leaching of N from agricultural land (Bergström and Brink 1986; Vagstad *et al.* 1997; Simmelsgaard 1998). A study by Vagstad *et al.* (1997) on Norwegian agricultural catchments indicated that a major part of the leached nitrogen originated from the mineralization of organic matter rather than that from applied fertilizers. Crop systems, crop management and soil organic matter management were considered as key factors influencing N losses from agricultural fields. The recent farmer interviews in Savijoki catchment will provide valuable information for further analysis of the actual management practices and crop rotation on field parcels.

Conclusions

Long term monitoring data on water flow and quality was used to calculate annual runoff and nitrogen leaching from a small agricultural catchment (Savijoki) in southern Finland.

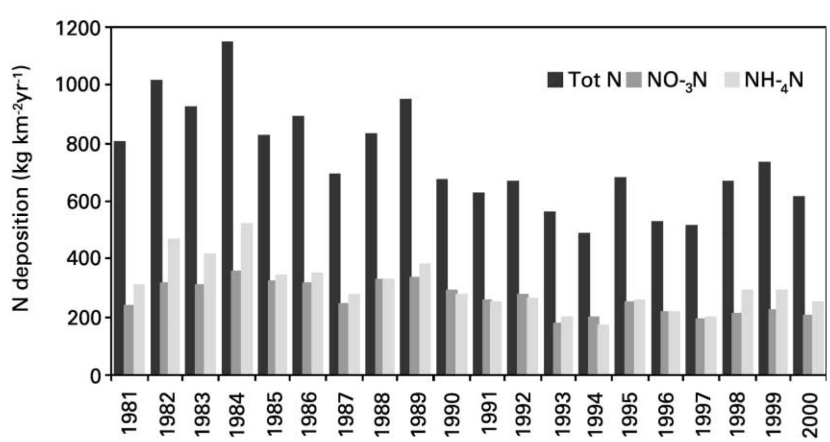

Figure 10 Annual N deposition in southern Finland

The results indicated that the measured nitrogen loads were strongly dependent on weather-induced variation in runoff. In Savijoki catchment most of the farmers participate in the Finnish Agri-Environmental Programme, aiming at a reduction of agricultural nutrient loading. In spite of this, no reduction of nitrogen load has been achieved so far. It is possible that the positive effects of the new agricultural measures are partly masked by the recent mild weather conditions.

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