# Ecological Measures Decrease Nitrate Leaching to Groundwater in Switzerland

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**Abstract**

In 1993 direct payments bound to ecological measures were introduced into Swiss agriculture. In order to assess the effectiveness of these ecological measures, temporal trends of nitrate contents in groundwater and the reasons for declining contents were investigated in a case study. In the four geographic regions of the canton of Berne, calculations with the nutrient flow model MODIFFUS were carried out. Between 1990 and 1999, nitrate contents in the groundwater decreased by 12% on average. In the Central Plains and in the Prealps of the canton of Berne, nitrate contents declined considerably due to decreasing areas grown with cereals and potatoes and larger areas under temporary grassland and sugar beets. Apart from varying crop areas, a lower nitrogen fertiliser use and more extended cover cropping contributed most to decreasing nitrate contents in groundwater. Half of the reduction can be assigned to the ecological measures.

**Keywords:** Agri-environment scheme, cover crop, fertilisation, nitrate content, nitrogen.

## Background and objectives

In the second half of the last century, nitrate ($NO_3^-$) contents in the groundwater of Switzerland increased strongly due to intensification in agriculture (BUWAL, 1993). In the 1980s nitrate contents of many drinking water wells exceeded 25 mg $L^{-1}$ $NO_3^-$, the quality target set by Swiss legislation. In some water catchments, nitrate contents were even higher than the Swiss tolerance value for drinking water of 40 mg $L^{-1}$ $NO_3^-$.

In 1993 Swiss agricultural policy was reframed by the introduction of direct payments. Part of these was bound to ecological programmes such as integrated production, organic agriculture, ecological compensation areas or extensively managed cereals. Following a public vote, a cross compliance system was enacted in the Swiss constitution in 1999. Farmers now have to meet the requirements of the 'Proof of ecological performance', a standard similar to integrated production, in order to qualify for any direct payments. With regard to nitrogen (N) management, these requirements comprise the following measures: (i) the whole-farm N balance has to be equilibrated, i.e. N input may not exceed crop demand by more than 10%; (ii) an appropriate soil protection by cover crops has to be established in autumn; (iii) maximum percentages for individual crops are set in the rotation; (iv) ecological compensation areas such as extensively used grassland or hedges must occupy at least 7% of the area used for arable and grassland.

In 1996 the Swiss government launched a programme for evaluating the impact and efficiency of the ecological measures (Herzog and Richner, 2005). Within the framework of this evaluation, temporal trends of nitrate contents in groundwater and the reasons for declining contents were investigated. One of the targets set by the government was to reduce nitrate contents of groundwater by 5 mg $L^{-1}$ between the reference period of 1990/92 and the year 2005. The aim of the present study was to analyse the effects of management and land use changes (including ecological measures) on nitrate leaching.

## Materials and methods

In a case study in the four geographic regions of the canton of Berne (Table 1), average nitrate contents of groundwater were calculated with the nutrient flow model MODIFFUS for the years 1990 and 1999 and then compared with measured values of wells (Spiess, 2004).

MODIFFUS is an empirical statistical **mo**del for estimating **diff**use N and phosphorus inputs into ground and surface water (Prasuhn and Mohni, 2003; Prasuhn and Sieber, 2005). For the present study, we only applied the submodels 'Water flows' and 'Nitrate leaching'. In MODIFFUS, the amount of nitrate leached under grid cells of 1 ha in size was estimated by coupling of spatial data, statistical data and standard loss coefficients for nitrate leaching. Spatial data comprised land use statistics of Switzerland 1992/97 (15 categories of land use, but no differentiation between arable and grassland; grids of 1 ha), a digital elevation model, a soil map 1:200,000, a climate map 1:200,000, long-term precipitations (grids of 4 $km^2$) and the borders of Swiss municipalities. In addition, statistical data per farm from the annual agricultural census were used (area of all categories of grassland and arable crops; animal numbers) and information on fields with tile drainage. Manure N production was calculated from animal numbers using a specific excretion coefficient for each animal category. Standard loss coefficients for nitrate leaching were derived from lysimeter trials, literature and expert knowledge (multi-annual mean values). These coefficients were corrected with factors for the amount of percolating water, altitude (as an indicator for mean temperature), soil type, N fertilisation level, intensity of grassland management, denitrification potential and tile drainage. Percolating water was calculated as the difference between precipitations and losses by evapotranspiration, overland flow and water from tile drainage. Long-term precipitation was extracted from the Hydrological Atlas of Switzerland; evapotranspiration was calculated from land use, long-term precipitation and data on slope and exposition. For the two years 1990 and 1999, input data only varied for the agricultural census, national mineral fertiliser use and the intensity of grassland management, but there was no land use statistics in Switzerland more recent than 1992/97.

Table 1 Altitude and land use in the four regions of the canton of Berne.

| Region | Altitude m a.s.l. | Land use Forest | Arable land | Grassland | Other[1] |
|---|---|---|---|---|---|
| Alps | 550 - 4200 | 27% | 0% | 33% | 39% |
| Prealps | 500 - 1500 | 36% | 24% | 33% | 7% |
| Central Plains | 400 - 900 | 25% | 41% | 12% | 21% |
| Jura | 450 - 1600 | 53% | 11% | 30% | 6% |

[1] Settlements and urban areas, unproductive vegetation, lakes, rocks and glaciers

**Results and discussion**

More than half of the percolating water in the canton of Berne originates from the Alps due to the large areal fraction and the high precipitations (Table 2). Most percolating water per surface unit, however, was recorded in the Jura. Precipitation in this region was lower than in the Alps, but there was far less overland flow because of the smaller share of areas without any vegetation.

In 1999 the modelled amount of nitrate leached and the average nitrate content in the percolating water were highest in the Central Plains as a consequence of the large share of arable land (Table 1). The average nitrate content of 21.5 mg $L^{-1}$ was more than double that of the Prealps. In the Alps, nitrate content was very low with 2.5 mg $L^{-1}$ due to the small share of arable land and the dilution of nitrate leached by large amounts of percolating water.

Table 2 Area, precipitation and modelled percolating water, amount of nitrate leached and average nitrate content in the four regions of the canton of Berne in 1999.

| Region | Area ha | Precipitation mm | Percolating water mm | Percolating water $10^6$ $m^3$ | Nitrate leaching t N | Average nitrate content mg $L^{-1}$ $NO_3^-$ |
|---|---|---|---|---|---|---|
| Alps | 272,753 | 1,823 | 820 | 2,238 | 1,259 | 2.5 |
| Prealps | 120,085 | 1,376 | 749 | 900 | 1,691 | 8.3 |
| Central Plains | 127,955 | 1,127 | 457 | 584 | 2,832 | 21.5 |
| Jura | 52,755 | 1,504 | 924 | 487 | 590 | 5.4 |
| Total / Average | 573,548 | 1,545 | 734 | 4,209 | 6,372 | 6.7 |

Model calculations show decreasing nitrate contents in all four regions between 1990 and 1999 (Table 3). Reductions were lowest in the Alps and highest in the Central Plains with 3.2 mg $L^{-1}$. This reflects the fact that the amount of nitrate leached decreased most under arable land and that reductions under grassland and forest were much smaller (Figure 1). These findings are in line with national evidence by BUWAL and BWG (2004) indicating that average nitrate content of groundwater decreased by 3.7 mg $L^{-1}$ in Switzerland between 1989/91 and 2002/03.

Table 3 Comparison of calculated (MODIFFUS, percolating water) and measured average nitrate contents (wells) in the four region of the canton of Berne (values in mg $L^{-1}$ $NO_3^-$).

| | MODIFFUS | | | Wells | | | |
|---|---|---|---|---|---|---|---|
| Region | 1990 | 1999 | Difference | 1990-92 | 1999-01 | Difference | Number |
| Alps | 2.6 | 2.5 | -0.1 | 2.5 | 2.6 | +0.1 | 64 |
| Prealps | 9.8 | 8.3 | -1.5 | 19.6 | 16.9 | -2.7 | 76 |
| Central Plains | 24.7 | 21.5 | -3.2 | 25.8 | 24.1 | -1.7 | 109 |
| Jura | 5.9 | 5.4 | -0.5 | 7.5 | 7.4 | -0.1 | 14 |

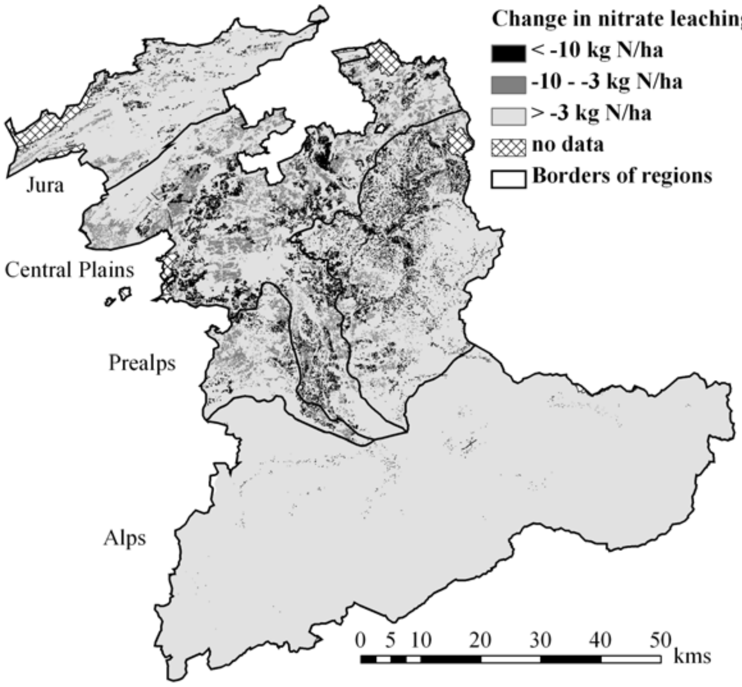


Figure 1 Change in the amount of nitrate leached in the canton of Berne between 1990 and 1999 (in kg N $ha^{-1}$).

Results of MODIFFUS are mostly in good agreement with values measured in wells (Table 3). Larger differences in the Prealps can be attributed to the great number of wells situated in the areas with intensive agriculture close to the Central Plains. On the other hand, only few wells were in higher areas with more forest and grassland. In the Central Plains, where reductions were overestimated by modelling results, the measuring network did not comprise several wells which had been abandoned due to excessive nitrate contents and where reductions were expected to be highest.

A validation of modelling results is difficult to achieve because (i) the network of wells does not entirely represent the four regions, (ii) the catchment area of many wells is unknown and (iii) the residence time of groundwater in the aquifer varies widely. Because of the latter, the impact of measures taken in agriculture on nitrate contents of groundwater can only be observed in the wells some years after their introduction (Bach *et al.*, 2002, Beaudoin *et al.*, 2006). Measured values in Switzerland still show decreasing nitrate contents between 1999/2001 and 2002/03 (BUWAL and BWG, 2004) even though the implementation of ecological measures on most farms was before the year 2000.

According to the model calculations, increasing proportions of crops less vulnerable to nitrate leaching, reducing N fertiliser use in arable farming and increasing cover cropping contributed most to decreasing nitrate contents in groundwater, whereas the influence of a decreasing atmospheric N deposition and the management of grassland with no or only low fertiliser application was small (Table 4). On the whole, a reduction of 12% in groundwater nitrate contents between 1990 and 2000 was calculated. Our calculations suggest that about half of the reduction from 1990 to 1999 could be due to ecological measures. Decrem *et al.* (2007) also conclude that a lower N fertilisation and cover cropping reduced nitrate leaching from arable land. The other part of the reduction is supposed to be a consequence of other policy measures (e.g. reduction of duties according to WTO agreements), altered nutritional habits (e.g. lower meat and potato consumption) and an increase in productivity (e.g. lower cow number due to increased milk yield per cow).

Table 4 Estimated reductions in nitrate leaching between 1990 and 1999 due to various influencing factors (in % of the amount of N leached from the whole surface of the canton of Berne in 1990).

| | Influencing factor | Reduction |
|---|---|---|
| (i) | Change in the shares of arable crops | 4% |
| (ii) | Lower N fertiliser use in arable farming | 4% |
| (iii) | More extended cover cropping | 3% |
| (iv) | Decreasing atmospheric N deposition | 1% |
| (v) | Grassland with no or low N fertilisation | < 1% |
| | Total | 12% |

The influence of the different factors can be explained as follows:

(i) Change in the shares of arable crops: Between 1990 and 1999 the area of arable land was nearly constant in the canton of Berne (Table 5). But areas with cereals (- 16%) and potatoes (- 27%) decreased while areas with temporary grassland (+ 18%) and sugar beets (+ 32%) increased. Nitrate losses after the harvest of cereals and potatoes are higher than under temporary grassland or after sugar beets (Goulding, 2000).

(ii) Lower N fertiliser use in arable farming: Farmers often had to reduce N fertilisation to achieve an equilibrated N balance according the regulations of the 'Proof of ecological performance'. Mineral N fertiliser use decreased by 23% on average in Switzerland, and N applied with animal manure by 9% in the canton of Berne. Reductions in manure application were higher in the Central Plains (-13%) and in the Prealps (-10%).

(iii) More extended cover cropping: Cover crops are mainly established between main crops harvested by early autumn and spring-sown crops. The area of crop sequences of this type with a potential for cover crops decreased in the 1990s whereas the area effectively grown with cover crops remained constant (Table 5). Therefore, the relative frequency of cover crops increased in this decade.

(iv) Decreasing atmospheric N deposition: Deposited nitrogen has been continuously decreasing since 1980. On the one hand, ammonia emissions have been declining due to lower animal numbers and manure production; on the other hand, nitrogen oxides from traffic and industry declined as well.

(v) Grassland with no or low N fertilisation: In Switzerland, nitrate leaching under permanent grassland is generally low (Furrer and Stauffer 1986). There is only a small proportion of sandy soils, and N fertiliser applications and stocking rates are mostly adequate. Therefore, the abatement potential per hectare is much lower than under arable land. As in 1999 only 13% of permanent grassland were extensively managed, the reduction is rather moderate.

Table 5 Area of arable crops in the canton of Berne in 1990 and 1999.

| Arable crop | 1990 ha | 1999 ha | Difference ha | Difference % |
|---|---|---|---|---|
| Temporary grassland | 30,416 | 35,971 | +5,555 | +18 |
| Winter cereals | 27,760 | 23,635 | -4,125 | -15 |
| Spring cereals | 6,385 | 5,090 | -1,294 | -20 |
| Sugar and fodder beets | 3,558 | 4,695 | +1,138 | +32 |
| Potatoes | 6,988 | 5,067 | -1,921 | -27 |
| Silage and grain maize | 9,356 | 10,127 | +771 | +8 |
| Other crops | 3,955 | 4,593 | +637 | +16 |
| Total | 88,417 | 89,179 | +761 | +1 |
| Cover crops | 12,636 | 12,864 | +228 | +2 |

Calculations with MODIFFUS indicate that lowering N fertilisation in arable farming and establishing more cover crops decreased nitrate losses by 4% each (or 7% relating to arable land only). Simulations of reduced N fertilisation in Scandinavia yielded reductions of nitrate leaching by 5 up to 11% (Deelstra *et al.*, 2002; Hoffmann and Johnsson, 2000; Müller-Wohlfeil *et al.*, 2002). Introducing of cover crops resulted in these countries in reductions of nitrate losses by 5 up to 38% (Askegaard *et al.*, 2005; Deelstra *et al.*, 2002; Hoffmann and Johnsson, 2000). Whereas cover crops were newly introduced in the crop rotations in these studies, cover cropping was already widely spread in the canton of Berne in 1990, but was intensified until 1999.

## Conclusions

Our results show an impact of ecological measures on nitrate contents of groundwater, but the effect was below the expectations of the Swiss government. The average reduction of 5 mg $L^{-1}$ could not be reached, but nitrate contents in wells decreased by 3-4 mg $L^{-1}$. Decrease in nitrate leaching was substantial in intensively farmed regions with a large proportion of arable land such as the Central Plains and the Prealps. The reduction was lower in the other two regions, dominated by forest and grassland. Apart from an increase in arable crops less vulnerable to nitrate leaching, reduced N fertilisation and more expanded cover cropping contributed most to the reduction in nitrate leaching.

More information on the spatial distribution of arable land and more crop-specific farm data on the application of fertiliser and manure would be required to improve the precision of model results. Validation of modelling results could be improved by better knowledge on the catchment areas of the wells and on the residence time of groundwater in the aquifer.

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