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Nitrate leaching: comparing conventional, integrated and organic agricultural production systems

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Abstract: The impact of conventional, integrated and organic practices on groundwater quality were studied in northwestern Germany. Between 1993 and 1997 nitrogen budgets and the nitrate content of the unsaturated zone (soil sampling and porous suction cups) were measured in two field trials located on a clayey loam and a loamy sand, respectively. In each year of investigation three main crops per farming system were compared according to the defined site(soil)-adapted crop rotation. There was little decrease in the NO_3-concentration of the percolate and the amount of leached N (15% less) by shifting from conventional practice to integrated farming. Converting to organic farming reduced leaching losses of nitrogen by more than 50 %. Yields of the organic field plots were lower, but comparing the cash crop yields in relation to the amount of leached nitrate, the production efficiency (nitrate-N leached related to yield of crops) of the organic farming system was still clearly higher.

INTRODUCTION

In the Lower Rhine valley in northwestern Germany intensive agricultural land use based on cereals, maize, sugar beets, potatoes, vegetables on field scale and ornamental plants causes high nitrate concentrations in groundwater supplies. Since 1950 groundwater nitrate has been increasing, which in the project region reached 80 mg NO_3 l^{-1}. Several pumping stations have been closed. To reduce nitrate leaching significantly the local water supply company intended to convert the arable land around two pumping stations into extensive grassland or forestry, as other waterworks in the region already did or planned to do.

To avoid this set-a-side of productive land, organic and integrated farming were suggested as alternatives by regional authorities. Consequently, the impact on groundwater quality were studied by comparing organic with integrated farming and conventional practices in field trials from 1993 to 1997 (Berg, 2001). Results are shown in this paper.

The field trials were complemented by surveys in the water catchment area, where investigations on soil-nitrate-concentration and nitrogen-field-budgets under woodland, cut grassland and arable land in regional groundwater catchment areas were undertaken (Haas *et al.,* 1998). Pesticide leaching and modelling were investigated in a subproject. The project was performed together with the local water supply company, the regional water management, forestry and land survey authorities, local conventional farmers, the regional extension service and a consulting office advising the integrated farming system under study.

MATERIAL & METHODS

The three production systems were compared in two field trials (3 replications, single plot size 10 x 4.5 m) located on a clayey loam and a loamy sand, respectively. The areas for the field trials were chosen to represent the local soil condition and were farmed conventional until July 1993. The sites were at an altitude of about 31 m with an average annual rainfall of 767 mm yr^{-1} and temperature of 10.1°C. In each year of investigation three main crops per farming system were compared. The systems were defined as follows:

- Conventional: Local farmer's practice, which was monitored during the vegetation periods in addition to farmer's recommendations given during field trial visits. A fixed amount of mineral N-fertiliser was given each year.
- Integrated: Weekly inspection of field trials by a specialised consulting agency, which immediately communicated measures to be carried out. The integrated concept itself was periodically arranged by the regional extension service. Mineral-N-fertilising was mainly based on soil-nitrate-concentration at the beginning of crop growth in spring, resulting in lower or higher amounts of N given compared with conventional farming. The use of pesticides was more intensive than in the conventional plots.
- Organic: Performed according national and European standards and laws based on the experiences gained at the experimental farm for organic agriculture Wiesengut of the University of Bonn (Köpke, 1995). No synthetic N-fertiliser was allowed, instead legumes (grass/clover and pulse crops) were cropped.

The crop rotations represented the locally grown crops, and were typical for the production systems, soil-specific adapted and allowed comparisons of the main crops in each year of investigation (Table 1). Each system was defined to feed and manure according to one virtual livestock unit (LUE) per ha (1 LUE corresponds to 500 kg animal live weight), according the mean livestock density of the local farms.

Table 1. Crop rotation of field trials comparing organic, integrated (Int.) and conventional (Con.) farming (W – Winter, sown in autumn)

	Loamy sand
Int./Con.	Potatoes – W-Rye –W-Barley - starting again
Organic	Potatoes – W-Rye - Peas – Spring wheat – W-Rye – Grass/red clover
	Clayey loam
Int./Con.	Sugar beets – W-Wheat –W-Barley - starting again
Organic	Sugar beets – W-Wheat – Faba beans – Spring wheat – W-Rye – Grass/red clover

Soil nitrate concentration of the unsaturated zone was measured periodically by performing soil sampling (1.5 m depth) and soil water sampling using porous suction cups (3 cups per layer in 75, 105 and 135 cm depth per plot, respectively). Balancing the soil water status, an automatic weather station, tensiometer and time-domain-reflection-measuring devices were used to collect input data for a model to quantify the amount of leached water.

RESULTS & DISCUSSION

On both sites, integrated farming slightly increased cereal yield due to a more intensive pesticide use compared to conventional practice (Table 2). Average yield of organic cereal was clearly lower than conventional and integrated, but root crop yield level was comparatively high.

Table 2. Yield (FM t ha^{-1}) of cash crops in three farming systems at two locations in 1995 and 1996

	Winter wheat		**Sugar beets**		**Winter rye**		**Potatoes**	
	1995	1996	1995	1996	1995	1996	1995	1996
Conventional	7.8a	8.5a	57.7b	70.6	5.6a	4.6a	43.4a	63.1a
Integrated	8.3a	8.5a	59.1a	69.3	6.2a	5.1a	42.7a	53.0b
Organic	3.5b	6.7b	48.4b	72.6	2.1b	3.6b	35.0b	46.9c
$MSD_{Tukey\ 5\%}$	1.31	1.23	10.27	n.s.	0.95	0.87	4.98	5.77

Differences between the means (MSD) were tested using the Tukey test at the alpha 5% level indicated by different letters or as not significant (n.s.).

The N-budget of the crop rotation at the clayey loam site was reduced to a surplus of 10 kg N ha^{-1} in integrated compared to 34 kg N ha^{-1} in conventional farming. At the loamy sand site N-budgets were similar in both systems (conventional and integrated 54 and 46 kg N ha^{-1}, respectively). Organic farming gave N-budgets of the three parallel grown crops of -7 and +1 kg N ha^{-1} at the clayey loam and loamy sand site, respectively.

In Figure 1 results of crop rotation sequence 1 at the loamy sand site are shown. The starting crops were grass-red-clover ley in organic and pure grass (*Lolium multiflorum*) ploughed in autumn followed by white mustard in the integrated and conventional farming system. In spring 1995, all fields were ploughed and potatoes followed by winter rye in autumn 1995 were cropped. Soil-nitrate content of the organic plots were lower at all sampling dates whereas in the integrated plots only sometimes slightly lower soil nitrate contents compared with conventional were measured.

At the loamy sand site the nitrate concentration in the soil water always exceeded the limit of 50 mg l-1 (maximum level for drinking water) in integrated and conventional farming, whereas lower nitrate concentrations were always measured in organic farming.

Comparing the nitrate concentration in soil water after winter wheat at the clayey loam site over winter 1996/1997, the same ranking of systems was found (Fig. 2). The results of the soil nitrate measurements in the other crop sequences were similar (Berg, 2001).

Taking the water budget into account, up to 120 kg Nitrate-N ha^{-1} was leached during winter (Fig. 3). To minimise nitrate leaching after potatoes, which can be a problematic crop even in organic farming, new strategies have been developed (Haas & Köpke, 2000) using the results of this comparison study for weak-point analysis. At the clayey loam site the amount of leached nitrate was clearly lower (up to 50 kg Nitrate-N ha^{-1}), but still lowest in organic farming.

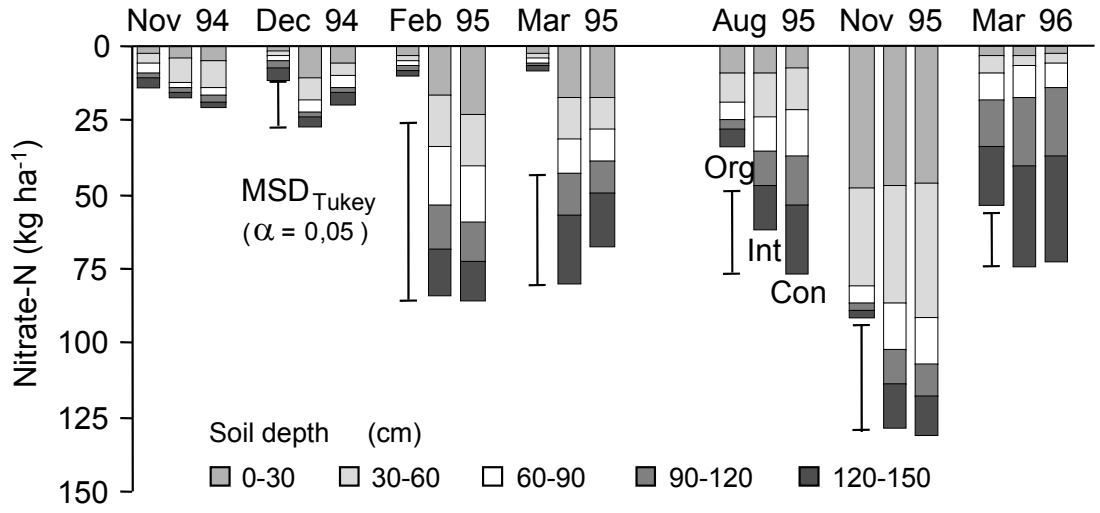


Fig. 1. Nitrate-N-content in the soil at the loamy sand site under of grass-clover ley (organic) and white mustard catch crop (integr./convent.) in 1994/95, respectively, followed by potatoes (Aug. '95) and winter rye (Nov. '95/March '96)

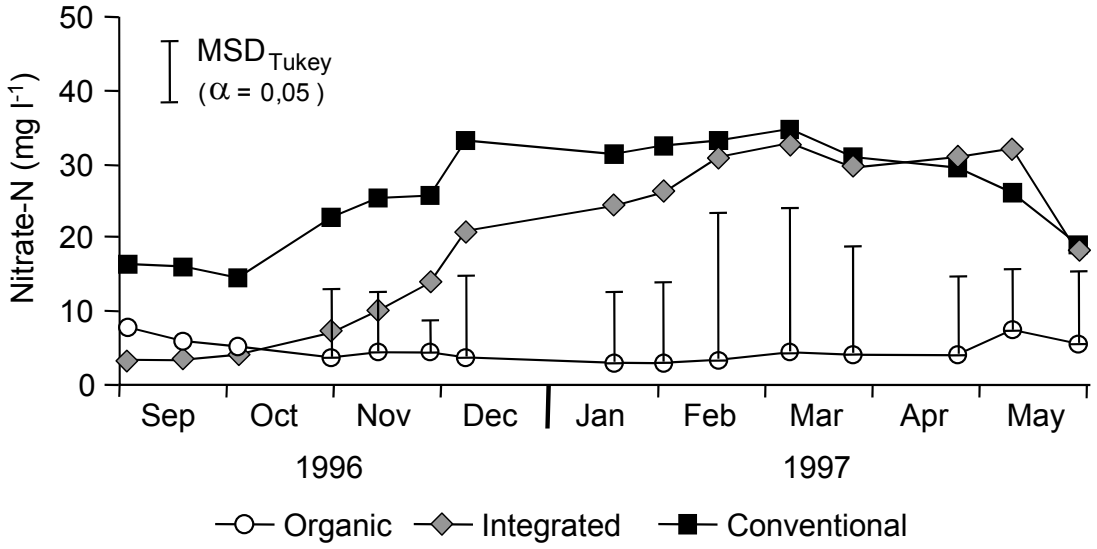
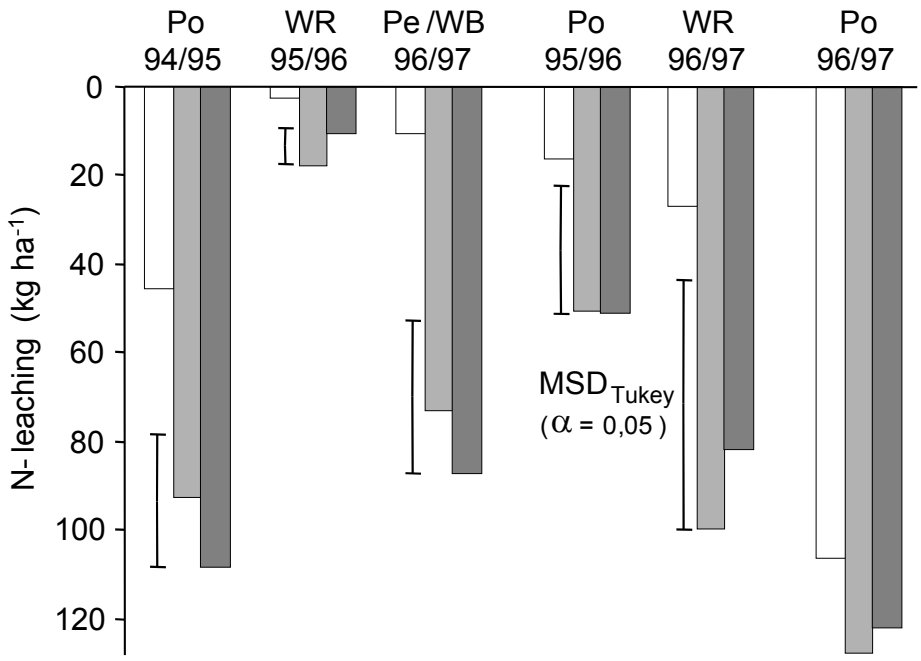


Fig. 2. Nitrate-N-concentration in the soil water in 135 cm depth after winter wheat followed by grass/clover (*Lolium multiflorum & Trifolium resupinatum*) sown as green manure in summer (organic) and winter barley sown in autumn (integr./convent.) in 1996 at the clayey loam site



Nitrate-concentration of the percolate (mg l^{-1})						
Organic	55 a	24 a	17 a	83 a	44 a	152
Integrated	113 b	148 b	100 b	260 b	152 b	199
Conventional	132 b	96 b	119 b	262 b	122 ab	186

Fig. 3. Leached nitrate-N and mean nitrate concentration of soil water in 135 cm soil depth at the loamy sand site (Po - Potatoes; Wb/Wr – Winter barley/rye)

CONCLUSION

Shifting from conventional to an integrated practice only 15% less nitrate leached and lower nitrate concentration was found. By converting to organic farming a reduction in N leaching losses of more than 50 %, resulting in nitrate concentrations lower than 50 mg NO_3 l^{-1}, was measured. These results of lower nitrate concentrations in the soil and therefore lower leaching rates in organic compared to integrated-conventional farming systems are supported by results of other authors (Brandhuber & Hege, 1991; Drinkwater *et al*., 1998; Eltun, 1995; Haas *et al.*, 2001; Philipps *et al.,* 1998; Smilde, 1989; Smolik *et al.,* 1993; Vereijken, 1990).

Yields of the organic field plots were lower. Comparing the dry matter yield of the cash crops sugar beets, potatoes, winter wheat and rye in relation to the amount of leached nitrate on average of both sites, the production efficiency (kg nitrate-N ha^{-1} yr^{-1} leached related to dm yield ha^{-1} yr^{-1}) of the organic farming system was clearly higher (relatively 100% conventional compared to 80% integrated and 57% organic) (Berg *et al.,* 2000).

According to the results achieved, the integrated farming system was not effectively adapted to clearly minimise nitrate leaching compared to conventional farming, rather than aiming for higher yields and therefore lower N-surplus, indicating a lack of effective instruments in integrated farming. Differences gained in these investigations besides the productions system itself were mainly based on different crop rotation, timing of soil cultivation together with catch crops (e.g. white mustard), the N-fertilising level and N-turnover.

Afforestation or extensive grassland farming, as aimed by the waterwork, can be avoided by converting to organic agriculture. Because arable land use covers 92% of the total farmed area in the district, the farms then may remain viable.

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REFERENCES

Berg, M. (2001) *Comparing conventional, integrated and organic arable farming* (in German). Ph.D. Thesis, in prep.

Berg, M., Haas, G. & Köpke, U. (2000) Organic farming and groundwater quality – a comparison with integrated and conventional practice. In: Alföldi, T., W. Lockeretz & U. Niggli (ed.): 13th Intern. IFOAM Scientific Conf. Proceedings, 28.-31.8.2000, VDF Hochschulverlag ETH Zürich, 164.

Brandhuber, R. & Hege, H. (1991) Nitrate contamination of the unsaturated zone of arable and grassland livestock farms (in German), Proc. (ed. by VDLUFA, Darmstadt, Germany) Vol. **44**, 203-208.

Drinkwater, L.E., Wagoner, P., & Sarrantonio, M. (1998) Legume-based cropping systems have reduced carbon and nitrogen losses. *Nature* 396, 262-265.

Eltun, R. (1995) Comparisions of nitrogen leaching in ecological and conventional cropping systems. *Biological Agriculture and Horticulture (BAH)* **11**, 103-114.

Haas, G., Berg, M. & Köpke, U. (1998) *Impact of land use on groundwater quality: Comparing conventional, integrated and organic farming, comparing arable farming, grassland and afforestation* (in German). Verlag Dr. Köster, Berlin, Germany.

Haas, G. & Köpke, U. (2000) Underseedings in potatoes to minimize environmental burdens. In: *Proc. **13th** Intern. Scientific Conf. - Intern. Federation of Organic Agriculture Movement (IFOAM),* 28.-31. Aug. 2000, Basel, Switzerland, 391.

Haas, G., Wetterich, F. & Köpke, U. (2001) Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. *Agriculture, Ecosystems & Environment* **83**/1-2, 43-53.

Köpke, U. (1995) Nutrient management in organic farming systems: The case of nitrogen. *Biological Agriculture & Horticulture (BAH)* **11**, 15-29.

Philipps, L., Stockdale, E.A. & Watson C.A. (1998) Nitrogen leaching losses from mixed organic farming systems in the UK. In: *Mixed farming systems in Europe* (ed. by Van Keulen, H., Lantinga, E.A. & Van Laar, H.H.), Proc. 25.-28.05.98, Wageningen, Netherlands.

Smilde, K.W. (1989) Nutrient supply and soil fertility. In: *Development of farming systems* (ed. by J.C. Zadoks), Pudoc, Wageningen, Netherlands.

Smolik, J.D., T.L. Dobbs, D.H. Rickerl, L.J. Wrage, G.W. Buchenau & T.A. Machacek (1993) *Agronomic, economic, and ecological relationships in alternative (organic), conventional and reduced-till farming systems*. Research report B 718, South Dakota State University, USA, p. 57.

Vereijken, P. (1990) Integrated nutrient management (INM) for arable farms. *Schweizerische Landwirtschaftliche Forschung* **29**/4, Switzerland, 359-365.

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