16th IFOAM Organic World Congress, Modena, Italy, June 16-20, 2008
Archived at http://orgprints.org/view/projects/conference.html

Comparative analysis of conventional and organic farming systems: Nitrogen surpluses and nitrogen losses

Kelm, M.[1], Loges, R.[1] & Taube, F.[1]

Key words: Nitrogen, nitrate, leaching, farming systems, nitrogen fixation

Abstract

Nutrient management is a key factor for both economic viability and environmental performance of farming systems. On 32 representative conventional and organic farms in Northern Germany, nutrient management was analyzed in the interdisciplinary monitoring project "COMPASS". Organic farms had significantly lower nitrogen (N) surpluses compared with conventional farms. The majority of organic farms had very low or even negative N surpluses, indicating insufficient N supply in the cropping system. Nitrogen leaching, however, was too high in many cases on both conventional and organic farms. Strategies for a more targeted nutrient supply in organic farming need to be developed and implemented.

Introduction

Nutrient-efficient farming is characterized by the minimization of nutrient losses to the environment while ensuring the necessary nutrient supply to crops and livestock. Organic farming is generally associated with sustainable nutrient management. Representative data from typical farms is scarce, however. Symbiotic N_2 fixation of legumes represents the most significant N input in organic farming. Even though both own and purchased organic fertilizers are applied on most organic farms, a sufficient N supply to crops cannot always be realized. On the other hand, N losses to the environment, e.g. through leaching, should be minimized.

In the present study, N fluxes and N leaching on 32 commercial farms in Northern Germany were analyzed in a 3-year monitoring project that allowed for a direct comparison of conventional and organic faming systems.

Materials and methods

The project "COMPASS" was carried out over the period 2004-2006 on commercial farms in Northern Germany. 16 pairs of farms were selected by two main criteria:
a. Farm type: Specialized arable farms, specialized dairy farms.
b. Intensity: Conventional farms, organic farms.

Within a pair of farms, a conventional farm and a comparable organic farm were located at the same site. This project set-up allowed for a direct comparison of conventional and organic farms under similar soil and environmental conditions. We analyzed 8 pairs of arable farms and 8 pairs of dairy farms. The comparability of farms within a pair was assured by comparable farm size, and similar specialization under the prevailing soil conditions. In dairy farming, the stocking rate was generally lower on organic farms (mean: 0.86 LSU ha^{-1} vs. 1.46 LSU ha^{-1} on conventional dairy farms).
Farm management was documented accurately, covering all aspects of crop and animal production. Additionally, we sampled forage yields, forage quality, botanical diversity of grassland, and symbiotic N_2 fixation of legumes on representative fields.

Symbiotic N_2 fixation was determined according to Høgh-Jensen et al. (2004). N balances were calculated for all 32 farms. N input included purchased fertilizers, feedstuffs and livestock, and N_2 fixation. N output was the sum of sold crops, animals, milk, and manure. From the difference between N input and N output at the farm scale, NH_3 emissions during manure storage and application were subtracted.
N leaching was determined on 8 selected farms. We used suction cups during the leaching periods (November-April) of 2004-2005 and 2005-2006 in representative fields of selected crops (see Table 1).
18 (arable crops) or 24 (permanent grassland) suction cups were installed per field. N concentrations (NO_3-N + NH_4-N + $N_{organic}$) in the leaching water (sampled at weekly intervals) were measured photometrically with an autoanalyzer. Total N leaching per winter [kg N/ha] was calculated as the sum-product of N concentrations and amounts of leaching water over the sampling period.
In a separate experiment (split-plot with four replicates, large plots of >600 m²), N turnover and N leaching were measured after the renewal of an organically managed permanent grassland sward on a sandy soil (ploughed in spring or autumn).

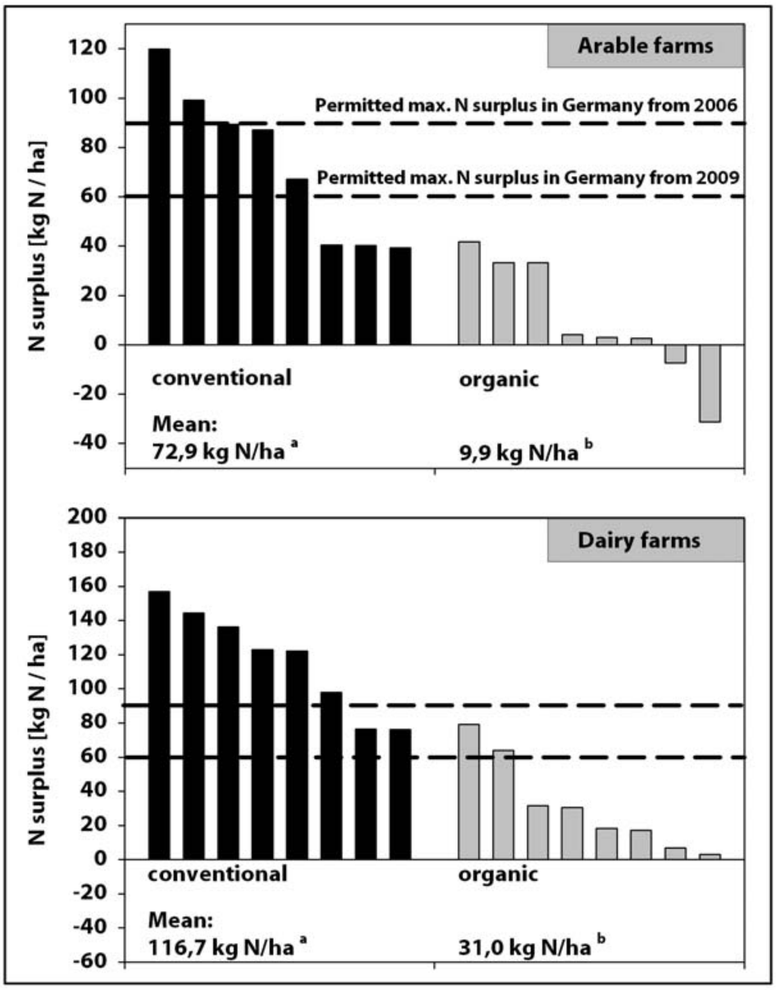
Results and discussion

Farm-gate N surpluses (indicating the total potential N loss to the environment) were significantly higher in conventional farming compared with organic farming, with generally higher N surpluses on dairy farms compared wiith arable farms (Figure 1). This is in line with some former studies (e.g., Dalgaard et al., 1998). Other investigations, however, did not find systematic differences in N surpluses between conventional and organic farms (e.g., Hansen et al., 2000).

The majority of analyzed conventional farms – both arable and dairy farms – need to improve their N management in order to fulfil future requirements. The large variation among individual farms clearly shows the potential for improvement. Some conventional farms already show that efficient nutrient management is possible without yield losses. Amongst conventional farms, there was no significant correlation between N surpluses and crop yields or milk yields, respectively. Weak points in conventional agriculture were mainly associated with N fertilization. In many cases, mineral N application to crops was far too high, or nutrients in slurry were not accounted for. Replacement rates frequently exceeded 35%, and the feeding ration was not always well adjusted.

In contrast, the majority of organic farms suffered from low or even negative N surpluses at the farm scale, which indicates a lack of nitrogen (Figure 1). The main reasons for variation in N surpluses were the proportion of legumes in the crop rotation and N_2 fixation rates of legume crops. For instance, the proportion of grass/clover in the crop rotation of organic arable farms varied from 0% to 53% (mean: 19%). N_2 fixation rates ranged between 45 kg N/ha (Persian clover *[Trifolium resupinatum],* mulched) and 339 kg N/ha (red clover *[Trifolium pratense]*, mixed cutting/mulching). N_2 fixation rates of red clover/perennial ryegrass (*Lolium perenne*) swards were in the range 150-250 kg N/ha, depending on the proportion of red clover, soil type, and cutting, mulching or grazing treatment. Some organic arable farms tried to maximize cash crop production by eliminating grass/clover from the crop rotation. N input was realized only through N_2-fixing cover crops, undersown clover in cereals, or purchased organic fertilizers. Even though this strategy could be opportune from an economic point of view, declining soil fertility and increasing weed levels might limit cash crop yields of these systems in the long run. Another weak point on organic farms was the adjustment of feeding rations to lactating cows. Both milk yields and animal health could be improved significantly by constantly providing a well-adjusted ration.

Figure 1: Net N surplus of conventional and organic farms, mean of 2004-2006.



[a, b] significantly different for P<0.05

Significant N leaching losses were observed in both conventional and organic farming (Table 1). In organic farming, the 'critical N load', which corresponds to a mean concentration of 50 mg/l nitrate in leaching water, was exceeded if grass/clover was ploughed in autumn (followed by winter wheat), a finding supported by a number of other authors (e.g., Dreymann, 2005). The same occurred after silage maize harvest on sandy soils. Organic silage maize was grown after grass/clover ploughed in spring. Additionally, high amounts of slurry and manure were applied, which is not necessary, since the N supply to silage maize is already ensured by the mineralization of grass/clover residues. Neither conventional nor organic maize fields had a winter cover crop. On grassland and in cash crop production, N leaching losses were significantly affected by N input (mainly N fertilizer, slurry, and excrements) and N surpluses at the field scale. In silage maize production, however, this relationship was absent. Mineralization of soil organic matter seemed to have a much stronger effect on N leaching since these fields have been fertilized with manure and slurry for many years, which accumulated a large pool of soil nitrogen.

Extremely high N leaching losses of 115-125 kg N/ha were observed in the first winter after the renewal of organically managed permanent grassland (data not shown). It made no significant difference if the grass sward was ploughed in spring or autumn. Mineralization of organic matter from the grass sward released very high amounts of N that could hardly be utilized until the following leaching period. As a consequence, grassland should be maintained in good condition as long as possible in order to postpone the renewal of grassland swards.

Tab. 1: N leaching (kg N ha^{-1} yr^{-1}; sum of NO_3-N + NH_4-N + organic N) in representative crops on conventional and organic farms. Mean of 18-24 suction cups per field, averaged over leaching periods 2004-2005 and 2005-2006.

Farm	**Winter wheat** *after oilseed rape (c) or grass/clover (o)*		**Oilseed rape (c) or grass/ clover (o)** *after cereals*		*After* **silage maize**		**Permanent grassland** *(1 cutting + grazing)*	
	Arable farms		**Arable farms**		**Dairy farms**		**Dairy farms**	
conventional	32.1	L	28.7	L	22.1	L	40.1	L
organic	45.4	L	13.2	L	27.8	L	26.2	L
conventional	45.5	L	42.2	L	52.4	S	38.2	S
organic	37.5	L	15.2	L	65.5	S	19.5	S

L: loamy soils, S: sandy soils

Conclusions

Organic farms were characterized by lower N surpluses and – in most cases – lower N leaching losses compared with conventional farms. N leaching on organic farms, however, still exceeded a ‘critical N load’ in most crops. Options for improved N management in organic farming include the layout of crop rotations, grass/clover management, more efficient utilization of manure, and better adjustment of feeding rations (Taube et al., 2007).

Acknowledgments

The project “COMPASS” was supported by the Ministry of Agriculture, Environment and Rural Areas (MLUR) of Schleswig-Holstein, the Rentenbank Frankfurt/Main, and the foundation Schleswig-Holsteinische Landschaft.

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