NITROGEN CYCLING IN A LEY-DOMINATED PRODUCTION SYSTEM

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ABSTRACT
N balance in a full-scale experiment with conventional and ecological farming systems at Öjebyn in northern Sweden was calculated with a nutrient flow model. Due to increased milk production there was a yearly increase in both N-input and output. N-fixation was on average twice as large in the ecological system. The *farm* N balance was increasingly positive in the conventional system and negative in the ecological. The *soil* N balance was more negative in the ecological system and less positive in the conventional system. Conclusions are: (1) ecological farming is possible without immediate DM yield reductions, but with negative effects on N balances, (2) sustainability is measured more stringently by soil balance than by farm balance, (3) estimates of N-losses need to be adjusted for north Swedish conditions.

KEYWORDS
Farming systems, yield, leys, barley, farm manure, urine, nitrogen balance

INTRODUCTION
"Low input farming" is now seen as one possibility to improve the sustainability and economy of agriculture. To study such relations and to utilize plant nutrients in a sustainable way, realistic, full farm-scale systems need to be investigated using simulation models for interpretation of the results (Kerner and Kristensen, 1993; Sörensen et al., 1993; Hallberg, 1993).
In a study of six ecological model farms in Denmark Olesen & Vester (1995) found positive N balances on four farms (3 to 36 kg N/ha) and negative on two farms (- 2 to -24 kg N/ha). In southern Sweden, Björklund and Salomon (1995) found for a three-year period in ecological farming positive N balances on the farm level but negative N balances on the soil level. Relevant comparisons with conventional farming were not made in either case. A more attractive, but scarce experimental approach is therefore to compare conventional and ecological farming at the same site. The aim of this paper is therefore to report five years of results on yield and N balance in an experimental farm, divided into an ecological and a conventional system. The work is a continuation of studies previously reported by Fagerberg et al. (1992), Fagerberg (1993) and Fagerberg et al. (1996).

MATERIALS AND METHODS
Project description. The experiment is located on the coastal plains of northern Sweden (Piteå, 130 km south of the Arctic circle, 65° N). The yearly average mean temperature is +2.1 °C and the total average precipitation is 500 mm (Hårsmar, 1991). The soils are drained, limed and in good condition with a pH about 5.8. (6% fine sand, 59% silt, 16% clay and 7% organic matter). Two milk production systems based on ecological and conventional principles are compared in a full-scale study. The feeding plans are based on feeds produced in the two systems. To compensate for differences between the systems in production, 40 ha and 40-47 dairy cows were used for the conventional and 50 ha and 50-53 dairy cows for ecological system. The 6-year crop rotation includes barley with undersown ley, three years of ley, barley and potatoes. Plant nutrient applications are standard manure and urine rates in both systems, and also standard fertilizer rates in the conventional system. (Fagerberg et al. 1996). In the ecological system, another 16 % of the area produces green fodder (peas and barley) for indoor feeding. The dairy herd in each farming system was divided into two groups:
(1) free access to forage, complemented with a low ration of concentrates
(2) free access to forage, complemented with a high ration of concentrates
Model description. With a nutrient balance model (Claesson and Steineck,1991; Fagerberg et al., 1993) the farm and soil N balance in the two farming systems was calculated for an indoor period of 11 months. N influxes are through fertilisers, seed, symbiotic N-fixation, N-deposition, purchased fodder and livestock. The calculation of the N-fixation of red clover is based on forage yields, clover content and N fertilisation (Kirchman et al., 1987; Torsell & Fagerberg, 1990). The estimation of N-fixation of peas in green fodder considers measured N-yields assuming that 50 % originated from biological fixation. The outfluxes from the farm are through sold plant and animal products and N-losses by ventilation, storage, manure spreading, decomposition of litter, denitrification and leaching from the soil. On the soil level, the influxes are in addition the farm manure as observed (or calculated by the model). The soil outfluxes are through harvested plant material and again decomposition of litter, denitrification and leaching. The model calculates the amounts of N produced in fresh organic manure and urine depending on type of animal, number of animals, time in the cowshed and milk production per animal and year. Losses of N through ammmonia volatilization is calculated depending on handling and storage alternatives for the manure and urine. Ammonia volatilization at spreading is calculated, accounting for spreading time and spreading technique.
Observations Every load of manure and urine were weighed before spreading and sampled for dry matter (DM) and N according to Swedish standard methods. Yields of DM and N were determined by weighing and sampling every load of harvested material and analysed according to conventional methods (Spörndly, 1989). The clover content in the leys was determined in each field by a ranking method (Fagerberg and Sundquist, 1994). The fodder was sampled daily and compiled into fortnightly samples, which were analysed for contents of dry matter, crude protein and metabolizable energy. The silage was also analysed for NH_4-N and pH. The milk yield of each cow was determined every fortnight and samples for fat, protein and lactose were analysed. From these data the yearly milk production per cow was calculated.

RESULTS AND DISCUSSION
Nutrient fluxes to and from the farm. The large N-input into the conventional system is due to the N-fertiliser and the higher purchase of concentrates (Fig 1 right). There is a clear tendency for yearly increase in N-input through concentrates. This tendency is weaker in the ecological system (Fig 1 left). These changes reflect increased milk production (increase in both production per cow and in the number of dairy cows in the ecological system). The higher N-input in terms of symbiotic fixation into the ecological system is due to the high clover content in the leys in the ecological system, which is almost twice as high as in the conventional system (Fagerberg and Sundquist, 1994). The outflows of N (Fig.1) are similar in the two systems with small amounts of N through sold plant products, considerably larger through animal products and even larger through N-losses. These consist of an assumed amount of 25 kg/ha denitrification (Claesson and Steineck,1991; Hansen, 1993), 5kg/ha through leakage (Gustafson and Torstensson, 1983; Haak and Lindén, 1994; Hoffmann and Wall Ellström, 1994) and 4 kg/ha ammonium volatilisation from litter. The remaining losses, i.e. approximately half, are model calculated amounts for ventilation in the cow sheds, manure storage and spreading.
Nutrients fluxes to and from the soil. The calculated N influxes to the soil with solid manure and urine indicate a small increase over the years in both systems as a consequence of increased milk production. The amounts are somewhat larger in the conventional than in the ecological, due to the larger nutrient input through fertiliser and fodder (Fig.1. left). The N outfluxes from the soil are through harvested plant products (Fig. 2). The dry matter production (kg/ha) was, on average, only 5% lower in the ecological system during the first five years. The N yield was equal in the two systems during the first four years, but in the fifth year it was higher in the conventional system. There was no difference in N content (kg/ton) in solid manure between the systems. In urine there was 18% lower content of N in the ecological system. The observed amounts of N from both solid manure and urine applied in the field (kg/ha) are on average over the years 18 % lower in the ecological system than in the conventional. The difference between the systems in N was larger for urine than for solid manure.
Nutrient balances. Farm level. The N balances are consistently positive in the conventional, and negative in the ecological system (Fig.1). In the N- balance, the magnitude of the losses through denitrification and leaching (30 kg N/ha) are considerable compared with the other N flows and will consequently affect the balances significantly. An overestimate of denitrification and leaching would mean a better N balance in the ecological system, and also a larger surplus in the conventional system. An underestimate, on the other hand, would imply a more negative N balance in the ecological system and a less positive balance in the conventional system. This question cannot be solved without measurements, a statement that probably applies to most studies of this kind. **Nutrient balances. Soil level.** In the N balance with observed manure nutrients as input (Fig. 2) there is a trend of increased N surplus in the conventional system, but a clear and increasing negative balance in the ecological system. These trends are more evident in the soil balance than in the farm balance. There is only a slight indication of lower DM yields in the ecological system, but in the last year a reduction is more evident there for N and protein.

GENERAL DISCUSSION
Since only a 5% yield reduction was observed in the *ecological system* during the first five years the dairy herd was gradually increased from originally 43 to 53 cows to utilize the surplus of forage and grain. This means that the intensity increased in the ecological system from 0.8 to 1.1 dairy cow/ha and became the same as in the conventional system in the end of the five year period. With increased intensity in the ecological system the N balance on both farm and soil level has become more negative over time. These results are the opposite to those of Eriksen et al., (1995) for Danish ecological dairy farms. They found positive N farm balances for an intensity of 1.4 animal units per ha, but negative balances for a low intensity, 0.8 animal units per ha. The contradictory results may to some extent be explained by our different approaches to balance calculations. The assumed 20 % reduction in total dry matter yield in the

ecological system has not yet occurred, but in the last experimental years there is an indication of reduced N and protein yields in the ecological system. This implies that the DM yield in the ecological system is maintained at the expense of the soil nutrient store. The strength in these balance calculations is that they are based on accurate measurements and documentation of many flows to and from the farm/soil over the years. The weakness, on the other hand, is the difficulty to carry out some of the measurements (e.g. the amount of plant nutrients in manure) and the lack of measurements of N losses.

CONCLUSIONS

Ecological farming can be carried out in northern Sweden without immediate detrimental effects on dry matter yields, but with negative effect on the N balance. A nutrient balance on the soil level gives a more direct indication of sustainability than the balance on the farm level. The fertilisation recommendations for northern Sweden regarding N should be reconsidered for conventional farming. N losses in north Swedish soils need to be measured. N fixation by the legumes in the green fodder pea crop requires further research.

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Figure 1

Influxes (positive) and outfluxes (negative) of N to the farm during 1990-1995 in the ecological (left) and in the conventional system (right).
Influxes: Fertiliser and seed, purchased fodder and symbiotic N-fixation
Outfluxes: Sold plant and animal products, total N-losses.

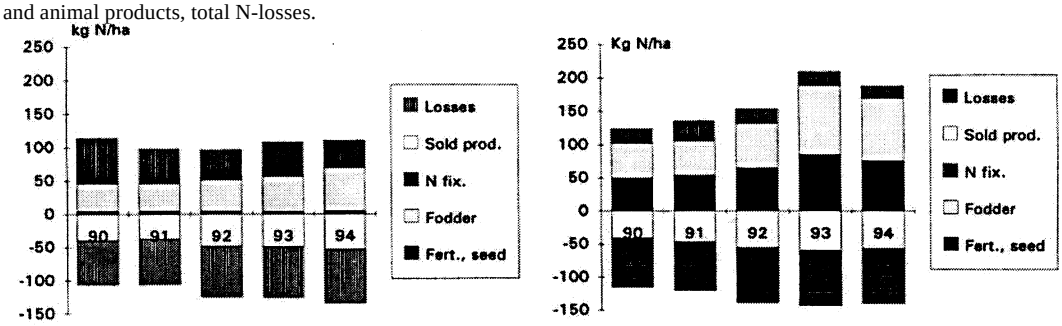

Figure 2

Yields of DM, N, digestible crude protein and soil N balance during 1990-1995 in the two systems.