# Nitrogen Turnover on Organic and Conventional Mixed Farms

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**Abstract** *Separate focus on crop fertilization or feeding practices inadequately describes nitrogen (N) loss from mixed dairy farms because of (1) interaction between animal and crop production and between the production system and the manager, and (2) uncertainties of herd N production and crop N utilization. Therefore a systems approach was used to study N turnover and N efficiency on 16 conventional and 14 organic private Danish farms with mixed animal (dairy) and crop production. There were significant differences in N surplus at the farm level (242 kg. N/ha. vs. 124 kg. N/ha. on conventional and organic dairy farms respectively) with a correlation between stocking rate and N surplus. N efficiency was calculated as the output of N in animal products divided by the net N import in fodder, manure and fertilizer. N turnover in herd and individual crops calculated on selected farms showed differences in organic and conventional crop N utilization. This is explained via a discussion of the rationality behind the current way of planning the "optimum fertilizer application" in conventional agriculture. The concept of marginal N efficiency is insufficient for correcting problems of N loss from dairy farms. Substantial reductions in N loss from conventional mixed dairy farms is probably unlikely without lower production intensity. The concept of mean farm unit N efficiency might be a way to describe the relation between production and N loss to facilitate regulation. This concept is linked to differing goals of agricultural development – i.e. intensification and separation vs. extensification and integration. It is discussed how studies in private farms – using organic farms as selected critical cases – can demonstrate possibilities for balancing production and environmental concern.*

**Keywords:** nitrogen balance, nitrogen loss, efficiency, fertilization, environment, dairy farms, intensity, system modelling.

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## Introduction

The environmental consequences of agricultural Nitrogen (N) loss have been intensively studied in both Europe and North America. Some countries have made legislative attempts to limit farm N loss by regulation of manure storage capacity and use in crop rotations. It has been thought that N leaching could be limited sufficiently by educating farmers about the use of fertilizer and manure in crop production (Smith and Chambers, 1993; Michelsen, 1994). This and similar approaches focusing on feeding practice have had little success in reducing fertilizer use and N loss sufficiently (Korevaar, 1992; Michelsen, 1994).

Problems with N loss from mixed farms having both animal and crop production may not be solved if only focusing separately on single activities like fertilization or feeding practice. The interactions between the farmer, the herd and crop production must all be considered to understand agricultural N loss (Conway 1987; Bacon, Lanyon and Schlauder, 1990; Sørensen and Kristensen, 1992; Edwards et al., 1993).

The purpose of this paper is to:

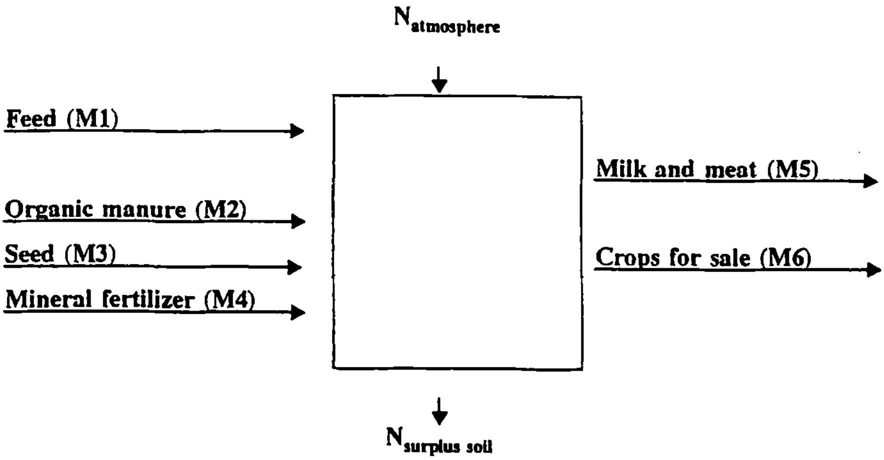
- explain variation in N surplus and N use efficiency on organic and conventional private mixed farms;
- demonstrate the importance of interactions between management, production and pollution;
- discuss the link between production intensity and N loss; and
- suggest different concepts of N efficiency to facilitate regulation of mixed dairy farming N losses.

## Materials and Methods

### Study Farms

The data were obtained from 30 private dairy farms affiliated with the National Institute of Animal Science. The registration period occurred during the two-year period May 1, 1989 to April 30, 1991 but data from some farms represent only one working year. While the farms had dairy production as the main enterprise, all had grain production. Fourteen of the farms met the Danish organic regulation prohibiting the use of chemically-produced fertilizers and pesticides. Non-organic fodder, only of Danish production, was limited to 15% and organic animal manure was applied only from 1.4 livestock units (LU) per hectare (ha.)/year.

There were some differences as regarding the type of land, crops and cattle within the two main groups (i.e. organic and conventional farming systems) in Table 1. While the average number of cows/year was nearly identical, the organic farms had slightly more land, more Jersey cows, and little fattening calf production, thus the number of livestock units per hectare was 40% greater on the conventional compared to organic farms. The acreage of permanent pasture and grass-clover in rotation was nearly identical for the two farming systems (11–12%). The acreage of alfalfa was 9% on organic farms compared to none on the conventional farms. Acreage with fodder beets and whole crop silage from small grains was twice as much on con-



$$N_{net\ feed} = M1 + M3 - M6 \qquad (1)$$

$$N_{surplus} = N_{net\ fed} + M2 + M4 + N_{atmosphere} - M5 \qquad (2)$$

$$N_{efficiency} = M5/(N_{net\ feed} + M2 + M4 + N_{atmosphere}) \qquad (3)$$

**Figure 1** Farm nitrogen turnover

ventional farms. The crops on the remaining area (approx. 35%) were different types of cereals including about 10% winter cereals. The total acreage of crops with a long growing season was 80-85% in both groups.

A detailed description of each farm's production system and yield during the two working years was presented in yearly publications (Østergaard, 1990; Østergaard, 1991). The average yield level per hectare of grain crops, beets or grass fodder was 15–30% lower on organic farms (Halberg et al., 1994a).

## *Data Collection and Calculation Methods*

The goal of data collection was to describe the farms' flow of energy, nutrients and money. Information was collected at farm level and on herd and field level as illustrated in Figures 1 and 2. Data collection includes characteristics of production potential (the framework of the production) and nitrogen input and output per unit of time, typically one year. Data were collected during biweekly visits on fodder consumption over a 24 hour period, stocks assessments and farm purchases and sales and the input in the crops.

The input, output, surplus and efficiency of farm N utilization was measured and calculated according to Figure 1. Atmospheric nitrogen ($N_{atmosphere}$) includes nitrogen transported with precipitation ($N_{rainfall}$), and N fixed by legumes ($N_{fixation}$). $N_{Rainfall}$ was fixed at 21 kilograms N/ha. (Anonymous, 1990). $N_{fixation}$ was calculated

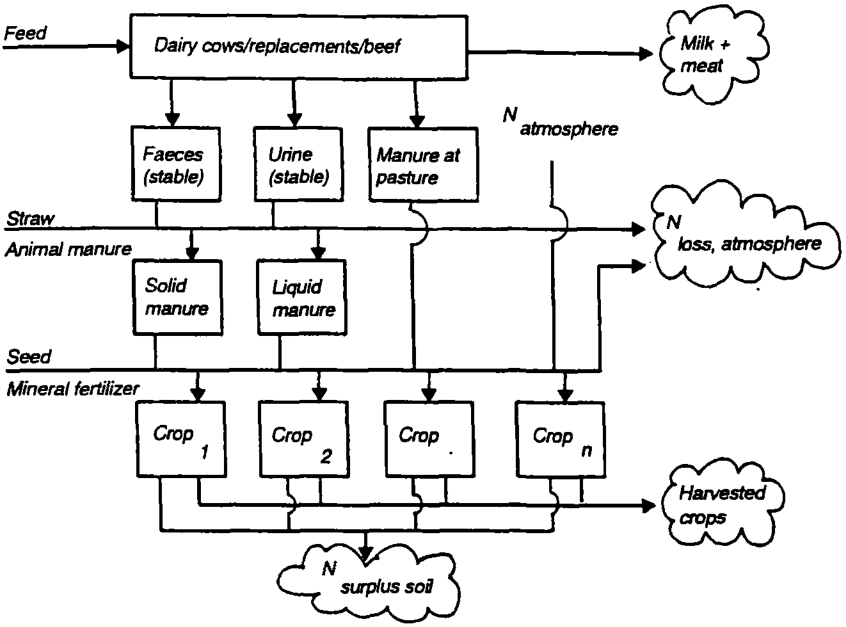


**Figure 2** Herd and crop nitrogen turnover

from the acreage in legume crops, taking into consideration the type and number of legumes (Halberg et al., 1994b). Surplus and efficiency are calculated by equations 2 and 3 in Figure 1, where the efficiency expresses the utilization of applied nitrogen (net purchase + atmosphere) to nitrogen in milk and meat.

To gain a greater understanding of the nitrogen turnover at farm level, a description of the nitrogen flow, according to the model shown in Figure 2, has been carried out on selected farms. The farms were selected to represent conventional and organic farming using both large and small numbers of animals per ha. The calculations apply to the growing season 1990 but include information from November 1, 1989 to April 30, 1991, fertilizer production in the winter of 1989/90 and feeding in the winter of 1990/91.

Nitrogen turnover on a farm can be divided into the two categories, herd and crops, as shown in Figure 2. Animal feed is converted to milk, meat and manure. Animal manure can be subdivided into three types: (1) faeces excreted in the stable, (2) urine excreted in the stable and (3) faeces + urine excreted during grazing. To this is added any purchased animal manure and bedding to form the total amount of manure.

The three types of animal manure can be divided separately among the individual fields and crops. As shown in Figure 2, part of the nitrogen in animal manure may be lost to the atmosphere ($N_{\text{loss, atmosphere}}$), mainly as ammonia during manure transfer in stables, storage, field application and grazing (Hansen et al., 1990; Jarvis and Pain, 1990). There is uncertainty about the proportion that is lost to the atmosphere, which depends on management as well as climatic conditions (Sommer, 1992). As

**Table 1**
Some characteristics for the analysed project farms

| System | Organic | | Conventional | |
|---|---|---|---|---|
| Number of farms: | 14 | | 16 | |
| Soil type: sandy + clay | 4+10 | | 12+4 | |
| Cattle type: heavy + light[a] | 7+7 | | 11+5 | |
| | Average | (min-max.) | Average | (min.-max.) |
| Area, ha. | 67 | (21–114) | 53 | (27–80) |
| – % permanent pasture | 11 | (0–32) | 12 | (0–57) |
| – % rotation grass/grass-clover | 28 | (0–65) | 26 | (0–60) |
| – % alfalfa | 9 | (0–38) | 0 | |
| – % fodder beets | 4 | (0–11) | 10 | (0–25) |
| Cows per farm | 56 | (24–100) | 58 | (35–88) |
| Livestock units[b] per ha. | 1.06 | (0.8–1.5) | 1.50 | (1.27–2.26) |

[a] Heavy types: Danish Frisian, Danish Red or Red and White. Light types: Jersey.
[b] 1 livestock unit is equal to 1 dairy cow of approx. 550 kg.

adequate details regarding these conditions on the participating farms were not known, it was assumed that $N_{loss,\ atmosphere}$ was from 20–40% of total N in stable manure, and from 10–20% of manure excreted during grazing. Jarvis and Pain (1990) calculated that ammonia loss (in percent of N excreted) during grazing is less than stable manure loss, therefore the percentage lost during grazing was assumed to be half of the percentage lost from N excreted in stable manure. Urinary N ex animals comprise about 60% of total N excreted by a herd (Hansen et al., 1990). Assuming that $N_{loss,\ atmosphere}$ is linked to urinary N, the above mentioned loss of total N is equivalent to 30–60% of urinary N if grazing is 25%.

Seeds, purchased mineral fertilizer, nitrogen from the atmosphere, and the animal manure comprise the input of nitrogen to individual crops. The difference between input and yield of nitrogen from the individual crops can be described as $N_{surplus,\ soil}$. This quantity describes the net supply to the soil for an individual year, but conveys nothing about the nitrogen's further turnover in the soil. Further details on data collection methods and a quantitative description of the nitrogen's route through the herd and crops can be found in Halberg et al. (1994b).

## Results

### *Nitrogen Turnover at Farm Level*

Tables 1 and 2 show the nitrogen turnover on conventional and organic farms expressed in kg. N per ha. per year on the individual farms. Results are arranged by LU per ha. in recognition of the impact of animal husbandry on the purchase and yield of nitrogen. Nitrogen purchased as fodder expresses the net purchase of crops (the purchase of fodder, straw and seeds less any sold crops, see equation 1, Figure 1).

Tables 2 and 3 document yearly differences in the nitrogen turnover for a given

## Table 2

Nitrogen flow on conventional farms during 2 working years in kg N/ha/year, and utilization efficiency

| | | | | Net purchase | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. | Soil type | Year[a] | Live-stock unit per ha. | "Fodder"[b] | Animal manure | Mineral fertilizer | Atmos-phere | Net sales Milk + Meat | Sur-plus | Effici-ency(%)[c] |
| 1 | Sandy | 1 | 1.08 | 19 | 0 | 190 | 53 | 36 | 226 | 14 |
| | | 2 | 1.07 | 20 | 0 | 160 | 30 | 37 | 173 | 18 |
| 2 | Sandy | 2 | 1.11 | 66 | 20 | 190 | 29 | 36 | 269 | 12 |
| 3 | Sandy | 1 | 1.11 | 19 | 0 | 133 | 84 | 34 | 202 | 14 |
| | | 2 | 1.14 | 40 | 0 | 144 | 65 | 37 | 212 | 15 |
| 4 | Clayey | 1 | 1.25 | 26 | 0 | 150 | 37 | 39 | 174 | 18 |
| | | 2 | 1.24 | 50 | 0 | 151 | 38 | 38 | 201 | 16 |
| 5 | Clayey | 2 | 1.27 | 90 | -31 | 111 | 24 | 38 | 156 | 20 |
| 6 | Sandy | 1 | 1.32 | 67 | 0 | 128 | 39 | 47 | 187 | 20 |
| | | 2 | 1.49 | 80 | 0 | 127 | 77 | 51 | 233 | 18 |
| 7 | Sandy | 1 | 1.55 | 73 | 0 | 177 | 45 | 48 | 247 | 16 |
| | | 2 | 1.26 | 40 | 0 | 168 | 56 | 43 | 221 | 16 |
| 8 | Sandy | 1 | 1.43 | 80 | 0 | 168 | 52 | 50 | 250 | 17 |
| | | 2 | 1.44 | 61 | 0 | 133 | 76 | 48 | 222 | 18 |
| 9 | Sandy | 1 | 1.51 | 81 | 0 | 136 | 35 | 36 | 216 | 14 |
| | | 2 | 1.58 | 78 | 0 | 122 | 35 | 46 | 189 | 20 |
| 10 | Clayey | 1 | 1.53 | 94 | 0 | 204 | 69 | 46 | 321 | 13 |
| | | 2 | 1.60 | 93 | 0 | 172 | 70 | 45 | 290 | 13 |
| 11 | Sandy | 1 | 1.61 | 71 | 0 | 181 | 36 | 50 | 238 | 17 |
| | | 2 | 1.60 | 98 | 0 | 179 | 43 | 53 | 267 | 17 |
| 12 | Sandy | 2 | 1.62 | 75 | 0 | 192 | 21 | 47 | 241 | 16 |
| 13 | Sandy | 1 | 1.74 | 173 | 0 | 120 | 62 | 62 | 293 | 17 |
| | | 2 | 1.69 | 107 | 0 | 114 | 132 | 59 | 294 | 17 |
| 14 | Sandy | 2 | 1.72 | 83 | 0 | 156 | 24 | 48 | 215 | 18 |
| 15 | Sandy | 1 | 2.15 | 94 | 0 | 198 | 40 | 57 | 275 | 17 |
| | | 2 | 2.16 | 101 | 0 | 200 | 49 | 60 | 290 | 17 |
| 16 | Clayey | 2 | 2.26 | 205 | 0 | 232 | 21 | 71 | 387 | 16 |

## Table 2 contd.

| | | | Live-stock | | Net purchase | | | Net sales | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. | Soil type | Year[a] | unit per ha. | "Fod-der"[b] | Animal manure | Mineral fertilizer | Atmos-phere | Milk + Meat | Sur-plus | Effici-ency(%)[c] |
| Mean | | | 1.50 | 77 | 0 | 161 | 50 | 47 | 240 | 16.4 |
| S.D. | | | 0.32 | 42 | 7 | 32 | 24 | 9 | 52 | 2.1 |
| Mean per livestock unit | | | - | 51 | 0 | 107 | 33 | 31 | 160 | - |

[a] 1 = 1989–90. 2 = 1990–91.
[b] See Figure 1, eq. (1).
[c] See Figure 1, eq. (3)

## Table 3
Nitrogen flow on organic farms during 2 working years in kg. N/ha./year, and utilization efficiency

| | | | | Net purchase | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Soil type | Year[a] | Livestock unit per ha. | "Fodder"[b] | Animal manure | Atmosphere | Net sales Milk + Meat | Surplus | Efficiency(%)[c] |
| 1 | Clayey | 1 | 0.79 | 11 | 0 | 125 | 24 | 112 | 18 |
| | | 2 | 0.80 | 28 | 0 | 98 | 25 | 101 | 20 |
| 2 | Clayey | 1 | 0.86 | 12 | 0 | 128 | 24 | 116 | 17 |
| | | 2 | 0.86 | 11 | 0 | 113 | 25 | 99 | 20 |
| 3 | Sandy | 1 | 0.87 | 34 | 15 | 116 | 24 | 141 | 15 |
| 4 | Sandy | 1 | 0.85 | 16 | 55 | 81 | 21 | 131 | 14 |
| | | 2 | 0.90 | 34 | 31 | 83 | 23 | 125 | 16 |
| 5 | Clayey | 1 | 0.88 | 29 | 4 | 82 | 27 | 88 | 23 |
| | | 2 | 0.90 | 7 | 10 | 161 | 28 | 150 | 16 |
| 6 | Clayey | 1 | 0.90 | 29 | 29 | 77 | 26 | 109 | 19 |
| | | 2 | 0.90 | 1 | 29 | 95 | 29 | 96 | 23 |
| 7 | Clayey | 1 | 0.97 | 46 | 0 | 112 | 28 | 130 | 18 |
| | | 2 | 1.01 | 64 | 2 | 94 | 26 | 134 | 16 |
| 8 | Clayey | 1 | 1.05 | 61 | 0 | 83 | 36 | 108 | 25 |
| | | 2 | 0.94 | 49 | 24 | 112 | 32 | 153 | 17 |
| 9 | Clayey | 2 | 1.01 | 34 | 21 | 102 | 30 | 127 | 19 |
| 10 | Clayey | 1 | 1.14 | 38 | 0 | 112 | 38 | 112 | 25 |
| | | 2 | 1.10 | 39 | 0 | 123 | 39 | 123 | 24 |
| 11 | Clayey | 1 | 1.17 | 46 | 0 | 118 | 35 | 129 | 21 |
| | | 2 | 1.11 | 26 | 0 | 107 | 34 | 99 | 26 |
| 12 | Sandy | 1 | 1.45 | 50 | 0 | 133 | 39 | 144 | 21 |
| | | 2 | 1.29 | 39 | 0 | 137 | 42 | 134 | 24 |
| 13 | Clayey | 1 | 1.37 | 66 | 0 | 116 | 41 | 141 | 23 |
| | | 2 | 1.42 | 62 | 0 | 117 | 41 | 138 | 23 |
| 14 | Sandy | 1 | 1.56 | 97 | 20 | 94 | 53 | 158 | 25 |
| | | 2 | 1.44 | 83 | 0 | 82 | 49 | 116 | 30 |
| Mean | | | 1.06 | 39 | 9 | 108 | 32 | 124 | 20.7 |
| S.D. | | | 0.23 | 24 | 14 | 21 | 8 | 19 | 4.1 |
| Mean per livestock unit | | | - | 37 | 8 | 102 | 30 | 117 | - |

[a] 1 = 1989–90. 2 = 1990–91. [b] See Figure 1, eq. (1). [c] See Figure 1, eq. (3)

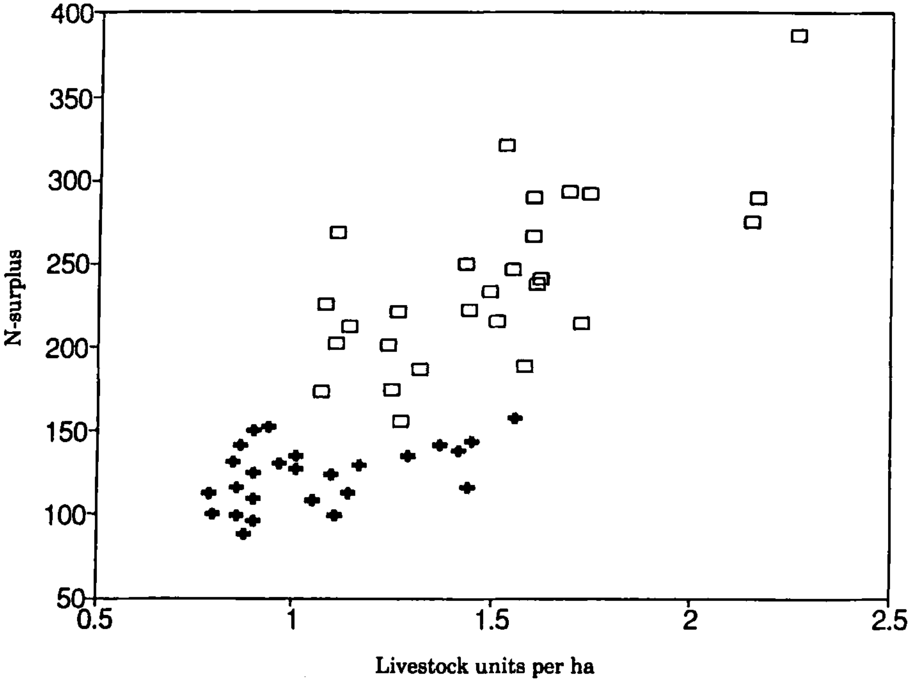


**Figure 3** $N$-surplus as a function of stocking rate at conventional (□) and organic farming (+)

farm. This could be caused by changed proportion of livestock to crop acreage, growth of different crops or varied levels of fertilization and N fixation. However, there was no overall significant effect by farming year ($P > 0.5$).

Any simple connection between the level of individual input factors and output across the farms can hardly be expected because different input factors may substitute for each other. The total input, yield and surplus is a consequence of complex relations between animal husbandry, choice of crops, type of soil, climatic conditions, prices etc.

Tables 2 and 3 show systematic differences in the forms of applied nitrogen. On conventional farms (Table 2) a large amount of mineral fertilizer was purchased (56% of the input). On organic farms (Table 3), where mineral fertilizer was not purchased, $N_{\text{atmosphere}}$ supplied a large part (69%) of the input. N surplus was larger and the N efficiency was less on the conventional compared to the organic farms. There were, however, large variations within the two groups. Since such factors as soil type and stocking rate differed, it is not possible to directly compare the two groups.

Variations in $N_{\text{surplus}}$ and $N_{\text{efficiency}}$ were analysed for the effects of the stocking rate, soil type and farming system (conventional vs. organic) using a statistical model. Since two observations (2 working years) on the same farm are not assumed to be independent, the analysis was performed using average data for each farm. While the effect of soil type was of no significance ($P > 0.2$) on either N surplus or

**Table 4**
Nitrogen surplus and efficiency by farming systems (Least squares estimate ± S.D. – one observation per farm)

| | Organic | Conventional | P-value |
|---|---|---|---|
| N-surplus in kg. N/ha./year | | | |
| 1) Uncorrected | 124 ± 11 | 242 ± 11 | 0.0001 |
| 2) Corrected for stocking rate[a] | 132 ± 13 | 217 ± 9 | 0.0001 |
| 3) Corrected for stocking rate[a] + 50% N-fixation[b] | 177 ± 14 | 230 ± 10 | 0.01 |
| N-efficiency | | | |
| 1) Uncorrected | 20.4 ± 0.8 | 16.4 ± 0.7 | 0.0008 |
| 2) Corrected for stocking rate[a] | 23.5 ± 0.9 | 16.2 ± 0.7 | 0.0001 |
| 3) Corrected for stocking rate[a] + 50% N-fixation[b] | 18.8 ± 0.8 | 15.5 ± 0.6 | 0.01 |

[a] Corrected to 1.28 livestock units per ha. (= average of all obs.).
[b] N-fixation in legumes is assumed to be increased by 50% at each farm.

**Table 5**
Variation (min.-max.) in herd N turnover by farming systems in kg. N per livestock unit and year

| Farming system | Total input | Yield of milk + meat | Atmosphere | Manure to crops |
|---|---|---|---|---|
| Conventional | 170–183 | 28–34 | 21–52 | 87–125 |
| Organic | 164–200 | 26–34 | 22–52 | 92–139 |

efficiency, the stocking rate was ($P < 0.0001$ in both cases). In Figure 3 the surplus is illustrated against the stocking rate. Only conventional farms had more than 1.6 LU/ha. and the variation in stocking rate was relatively small on organic farms. There was significant interaction between stocking rate and system (N surplus: $P < .08$, N efficiency: $P < 0.003$). The regression coefficient thus showed an increased N surplus of 117 kg./ha. per LU on conventional farms compared to 33 kg./ha. per LU on organic farms.

Table 4 shows the estimated effect of the farming system on N surplus and efficiency. Whether the two farming systems are compared uncorrected (1), or corrected for the stocking rate within the farming system (2), the organic farms had significantly less surplus and larger efficiency of nitrogen utilization than the conventional farms. The uncorrected difference was 118 kg. N/ha. surplus and 4%-units utilization. Corrected to 1.28 livestock units per ha. (the average of all farms), the difference was 85 kg. N/ha. surplus and 7.3%-units N efficiency.

Nitrogen input from fixation was calculated from the type and area of legumes and is therefore subject to some uncertainty. Therefore model 3 in Table 4 set N fixation to be 50% higher than in Tables 2 and 3, corresponding to 528 kg. N/ha. in alfalfa and 372 kg. N/ha. in a healthy clover grass field. While the differences between the two farming systems were decreased to 53 kg./ha. N surplus and 3.3%-units N efficiency, the differences were still significant. The effect of the stocking

## Table 6

Variation (min.-max.) in crop N turnover by farming system and stocking rate in kg. N per ha. and year

| | Mineral-N fertilizer | Animal manure | Atmos-phere | Total N input | Yield | Surplus |
|---|---|---|---|---|---|---|
| *6 Organic Farms* | (0.86-1.5 | LU/ha.) | | | | |
| Permanent pasture | | 37-107 | 39-56 | 88-163 | 83-120 | 3–59 |
| Grass/clover grass | | 158-283 | 120-408 | 278-464 | 222-323 | 18-231 |
| Fodder beets | | 170-267 | 21 | 191-288 | 146-258 | -61-142 |
| Grain crops | | 0-318 | 21-200 | 48-339 | 65-230 | -55-206 |
| All crops mean[a] | | 84-200 | 82-137 | 197-287 | 143-213 | 35-90 |
| *2 Conventional Farms* | (1.07-111 | LU/ha.) | | | | |
| Permanent pasture | 167-201 | 49-87 | 21 | 266-280 | 123-176 | 95-152 |
| Grass/clover grass | 245-266 | 111-200 | 51-54 | 410-517 | 225-280 | 185-237 |
| Fodder beets | 70-156 | 228-596 | 21 | 319-773 | 256-259 | 63-514 |
| Grain crops | 105-193 | 47-142 | 21 | 173-356 | 95-131 | 58-238 |
| All crops mean[a] | 160-190 | 108-145 | 29-30 | 298-364 | 164-181 | 117-200 |
| *2 Conventional Farms* | (2.16-2.26 | LU/ha.) | | | | |
| Permanent pasture | 130-251 | 142-250 | 21 | 293-522 | 149-193 | 100-373 |
| Grass/clover grass | 220-345 | 197-253 | 21-119 | 563-592 | 337-351 | 212-255 |
| Fodder beets | 154 | 392-546 | 21 | 567-721 | 137 | 430-584 |
| Grain crops | 152-231 | 156-279 | 21 | 391-452 | 157-277 | 114-285 |
| All crops mean[a] | 200-232 | 219-284 | 21-49 | 468-537 | 213-263 | 205-324 |

[a] Mean of all crops per farm, weighted for acreage of each crop.

rate remained unchanged.

## *Nitrogen Turnover in Herd and Crops*

To improve the understanding of farm nitrogen turnover, N input, yield and surplus for individual crops and herds were quantified on ten farms in the growing season 1990 according to the Figure 2 model. The conventional farms were selected to represent both the effect of stocking rate and the deviation from stocking rate influence on the nitrogen surplus (farms no. 1, 2, 15, and 16 in Table 2). The organic farms (no. 2, 4, 6, 12, 13 and 14 in Table 3) were selected to represent a high stocking rate, and varying types of soil and manure. The farms have been grouped according to farming system and stocking rate.

Table 5 shows the turnover of nitrogen in the herds. The total N input per LU and N yield in milk and meat varied within each group but there was little difference between the two systems. The average atmospheric loss from the ten farms was 24–47 kg. N per LU and 98–121 kg. N/LU was applied to the crops. Note that the "manure to crops" values include variation between high and low ammonia loss and between farms in the same group. This is also the case in Table 6 for "Animal manure," "Total N input" and "Surplus."

Table 6 shows the N turnover in the crops. For the purpose of comparing organic farms to conventional farms with low and high stocking rate respectively, these were grouped in two – with farms no. 1 and 2 separated from farms no. 15 and 16. The amount of animal manure applied (Table 6) was calculated for each farm from production per LU (from Table 5) multiplied by the stocking rate plus the amount of any purchased animal manure (Tables 2 and 3). Due to elapsed time, the total N surplus calculated from Tables 5 and 6 need not necessarily correspond to the N surplus shown in Tables 2 and 3 as the production of animal manure could have changed. The N loss during beet top preservation was not included and N input from seeds was omitted from Table 6. Seeds typically add an average of 2 kg. N/ha./year.

Of the total supply of 278–464 kg. N/ha. to the grass-clover and alfalfa on organic farms, 158–283 kg. N/ha. was supplied in manure; either during grazing or applied by the farmer. 120–408 kg. N/ha. came from atmospheric N, primarily via $N_{fixation}$. As the total amount of N removed with fresh and conserved grass was 222–323 kg./ha., the surplus varied between 18–231 kg. N/ha. on the organic farms. Because the largest yield in grass was not harvested at the farm with the highest total N input, the variation in surplus shown in Table 6 cannot be directly calculated from these figures. Likewise, the highest N fixation (408 kg./ha.) was estimated in alfalfa (farm no. 12) that did not receive any manure and yielded 322 kg. N/ha. Grain crops include winter and spring sown cereals as well as mixtures of cereals and annual legumes. Some barley crops for whole crop silage under sown with perennial ryegrass were supplied with slurry after the grain was cut (ultimo July). This was the explanation for a total supply of up to 452 kg. N/ha. in some conventional grain crops, where also the N harvested in aftermath was included in "Yield."

On all organic farms but one, there were crops which removed more N than was supplied by manure etc. This was mostly found for beets and spring sown cereals for whole crop silage. No crops on the conventional farms removed more N than was supplied. Due to their long growing season, fodder beets can utilize large amounts of N mineralized during summer. This capacity has only been utilized at the organic farms. All fodder beet crops on the conventional farms were supplied considerably more total N (63–584 kg. N/ha.) in manure and fertilizer than was harvested. The weighted mean $N_{\text{surplus soil}}$ (total per ha.) varied within the three groups of farms but there was no overlap between the two systems: 35–90 vs. 117–324 kg. N/ha. on the organic and conventional farms, respectively.

## Discussion and Conclusions

### *N Surplus as an Indicator of Nitrogen Loss*

The calculated N surplus is an expression of the total potential loss of N from a farming system. The loss is a combination of ammonia volatilization, leaching and denitrification, the latter being considered low from most Danish sandy soils in rotation (Lind et al., 1990). Ammonia volatilization was assumed to be minimum 20% and maximum 40% of stable manure N and 10% and 20% of N excreted during grazing. Table 5 shows that N atmosphere was thus calculated to vary from 21 to 52 kg. per livestock unit on the 10 selected farms.

It can be argued that organic farmers may have a greater economic motivation to reduce atmospheric N loss because the marginal effect of N often will be large in organic crops. The practice of composting animal manure on several organic research farms might—other things being equal—increase the N loss to the atmosphere. Since there is no evidence of a systematic difference in atmospheric N loss between farming systems at an identical stocking rate, the difference in their N surplus can be assumed to equal the difference in N surplus of the soil.

Nitrogen surplus in the soil can be immobilized or lost, primarily as leached nitrate. It is likely that a large part of the soil's N surplus will be lost by leaching. Hassink and Neeteson (1991) found that the level of added mineral N to grass crops did not affect the size of the soil's total N pool since the surplus mineral N was lost to the surroundings. The mineralization from a given soil is assumed to be proportional to the soil's N pool and therefore rises accordingly to any rise in the size of the soil pool (Barraclough and Jarvis, 1989; Christensen, 1989). In the long run a balance will be established between immobilization and mineralization. Therefore leaching was probably significantly lower from the organic than from the conventional farms we studied.

The two types of farms differed with respect to the dominating soil type. More organic farms than conventional had clay soils (Table 1) which would theoretically reduce nutrient leaching compared to sandy soils. Statistical modelling of crop-yield differences on the same project farms showed a greater yield difference between organic and conventional grain crops on sandy soils compared to clay soils (Halberg et al., 1994a). This was probably due to the faster leaching of nutrients on sandy soils during periods of excessive precipitation. Conventional farmers can better compensate for these losses by applying fertilizers. Since no significant effect of soil type on N surplus was found, the results were not adjusted for the imbalance of soil types.

## *Fertilization Planning and Stocking Rate*

Fertilizer utilization at a conventional livestock farm is often planned according to the following procedure, which in principle is used also in the Danish extension service (Finck, 1982; Anonymous, 1991; Lindén et al., 1992): An economically optimum level of (total) N supply for each crop is calculated on the basis of local yield expectations, N response values from experiments and prices of the crop and mineral fertilizer. Three factors are subtracted from this optimum economic supply: (1) The expected or measured amount of mineral N in the soil in early spring ($N_{min}$). (2) The expected amount of mineralized N released from soil organic matter during the growth season—including mineralized N from manure applied in previous years ($N_{soil}$). (3) The amount of manure applied to the crop multiplied by a utilization factor (first year effect). The utilization factor expresses the percentage of the total N in manure that the crop is expected to utilize during the (first) growing season. This percentage equals the amount of fertilizer N that 100 kg. of total N from a given type of manure can replace under given conditions (time and method of application), which again have been established by experiments (Pedersen, 1992). Thus, the calculation for each crop is as follows:

Economically optimum fertilizer application =
Economically optimum N supply - $N_{min}$ - $N_{soil}$ - ($N_{manure}$ * utilization factor)

In a given situation several factors add great uncertainty to this calculation:

(1) The possibility of lower (or higher) yield than expected from drought, pests or weeds causing decreased crop N uptake. Variations in grain yield and total N content in grain were found to be the most important (retrospective) factor determining the optimum rates for fertilizer N application at eight experimental sites during a three year period (Lindén et al., 1992).

(2) For some crops—especially grass and grass—clover for grazing— the knowledge behind the assumed optimal N supply is insufficient.

(3) Variations in manure N content and the amount of manure available. The amount and concentration of N in slurry per LU is influenced by animal feeding levels, the type of N in the feed and animal utilization for production of milk and meat production, N loss in stable and during storage and the amount of water (rain + spill over from animals drinking water) in the slurry storage tank. While the standard Danish N production per LU for cows is 108 kg./year (5000 Scandinavian Feed units (SFU)/cow) (Lauersen, 1987) production on the 10 farms presented here varied between 136 and 166 kg. N/LU/year.

(4) Variations in the utilization factor (first year effect) of the applied manure from variations in ammonia loss during application (Sommer, 1992). The utilization factor for cattle slurry applied to winter-wheat crops in spring varied between 35 and 52% in three field trials at different locations in 1991 and between 21 and 65% in five trials in 1990 (Pedersen, 1991; 1992).

(5) Different N mineralization during the growth season than expected because of climatic conditions or lack of knowledge concerning the impacts from previous

crops (Lindén et al., 1992).

The relationship between crop sale price and price of fertilizer often makes it economically rational for risk-adverse farmers to safeguard the crop from N lack by underestimating the N supply from manure and soil (Young et al., 1985). Since the organic farmer has less access to N, the organically grown crops usually lack N during some periods of the growing season. These crops would therefore be capable of using extra N from increased mineralization. On the other hand, low yields caused by weeds and pests could theoretically increase N surplus in organic crops. However, the weighted mean $N_{\text{surplus soil}}$ was lower on all the organic farms than on the two conventional farms with stocking rate below 1.2 LU/ha. (Table 6). Since production per cow and stocking rates were nearly identical, this difference in N surplus reflects the fact that the same amount of milk and meat was produced with a lower supply of N in fodder and fertilizer/manure on the organic farms. The most important explanation for this appeared to be the lower level of fertilization of the organic crops.

The difference in N surplus was larger when the organic farms were compared to the two farms with higher stocking rates (2.2 LU/ha.). When planning fertilizer application, the part of the N content in manure that is expected to be utilized in total is the sum of the utilization factor (first year effect) and the percentage utilized in the second and following years by succeeding crops. Utilization of manure N in succeeding years is typically estimated to be 10–20% (Anonymous, 1991). Since the utilization factor for cattle slurry applied to cereal crops is estimated to be 35–45%, when using this calculation method the farmer will supply more total N than would be removed by the crops. One can expect this surplus to rise when increasing amounts of manure are applied per ha., as shown by the conventional farms in our investigation.

This is in agreement with Doluschitz, Welck and Zeddies (1992) who, however, also found great variation in N surplus among farms with equal stocking rates, suggesting some room for management.

Korevaar (1992) also found that the intensity of Dutch dairy farms – in terms of kg. of milk produced per ha. – had a great impact on the surplus of N in kg. per ha. Increasing milk yield from 8,700 kg. to 20,500 kg. per ha., raised $N_{\text{surplus}}$ from 376 kg. N to 650 kg. N per ha., from a combination of increased fertilizer application per ha. and a greater input of roughage and feed concentrates.

## *Possibilities for Traditional Optimization*

The size of the N surplus, averaged for all crops in a given rotation, may differ from farm to farm and is influenced by physical conditions and the farmers' choice of crops and level of fertilization. Farmers can be expected to differ in their responses to the described uncertainties and in their (or their advisors') skills for estimating crop yield, N content in manure and N mineralization (the conventional farms studied consulted their local agricultural advisory services). Therefore, it may be questioned if the N surplus of the conventional farmers could have been much lower, had they more thoroughly used all knowledge and methods to fertilize at the optimum level. Would the difference between systems then have been much lower?

Another way to examine this problem is to review mixed farms in which all existent methods to minimize the described uncertainties and increase utilization of manure have been applied in order to limit the N loss, without reducing crop yields. This has been done at three private dairy farms, which are comparable to our conventional farms, by the Farmers Advisory Service for demonstration purposes (Anonymous, 1993). Though a reduction in mineral fertilizer use was achieved on the farms during a three-year period, the N surplus was not reduced below 175 kg. N/ha. when stocking rates were not changed.

While limitations on the use of manure and purchased fodder reduce the stocking rate on Danish organic farms to 1.0–1.5 LU/ha., the official limit for conventional dairy farms is 2.3 LU/ha. The difference in stocking rate (intensity) between the two types of farms thus is not coincidental. Neither is the lower fertilization level, which is probably the primary reason for the lower N surplus on the organic farms.

Though dairy production in the Netherlands is more specialized than in Denmark, with higher stocking rates and a large proportion of land in permanent or long term grass leys, it is interesting to review Dutch farm studies on reduction of N loss. Korevaar (1992) reviewed several Dutch projects for reducing N input and surplus on dairy farms through better management. Although substantial reductions were achieved on some farms, in only one project was N surplus reduced to less than 300 kg. N per ha. and year. Aarts, Biewinga and van Keulen (1992) expected to reduce N loss on an experimental dairy farm producing 13,000 kg. milk per ha. (approx. 2 LU/ha.) to below 125 kg. N per ha. without a reduction in intensity. Their calculations assumed that increase in milk yield per cow from 5,700 kg. to 8,500 kg. would contribute to better animal N utilization. This assumption is questionable, but even if it was possible to increase animal N efficiency by increasing milk yield it would almost only reduce the amount of ammonia in the manure. The amount of organic N in faeces produced per cow – which is the difficult part to utilize in crop production – is proportional mainly to the amount of dry matter in the feed (Thomsen, 1979).

Our study illustrates that the problems of N surplus and N loss on a mixed farm cannot be attributed to separate activities like feeding or fertilization practice, because of the relationships between animal and crop production. The many options for crop rotations and responses to the uncertainties in fertilization planning and N turnover in cows combined with yield variation make it difficult to predict how much the N loss on a mixed farm could be reduced, from experiments studying single factors. It remains, therefore, to be seen how much N surplus can be reduced on private conventional farms without monetary compensation for loss of yield. The organic farms in our study were compensated for lower yield by charging a higher milk price and new initiatives under the Common Agricultural Policy (CAP) of the European Union (EU) allow for compensation to farmers for reducing their fertilizer use.

A study of N turnover on a Pennsylvania dairy farm by Bacon, Lanyon and Schlauder (1990) also stressed the importance of interactions between the livestock unit and nutrient recycling via fodder crops to assess the possibilities for reducing nutrient loss. They suggested combining farm level N flow with more detailed information on nutrient flows through the herd and individual fields, because these are the management units of the farm.

We conclude that N surplus from conventional farms can be reduced to, for example, the level produced on the organic farms only by reducing the production level, that is the crop yield per ha. and/or the stocking rate. This negative relationship between the production level and loss of N pits the farmer's personal economic interests against the societal goal of reducing N pollution. Since no production is possible without loss, our goal is to find the right balance between the two interests.

## *Nitrogen Efficiency*

N efficiency in this paper is defined as $N_{output}/N_{input}$ (Figure 1). The overall N efficiency on the conventional farms was 16% (Table 2), which is slightly higher than the 14% average found for Dutch dairy farms in the mid 1980s (Aarts et al., 1992). The organic farms averaged 25% higher N efficiency than the conventional farms when considering the whole farm unit.

In Tables 5 and 6 N efficiency can be calculated individually for animal and crop production respectively on the selected farms (yield/total input, not shown). Interestingly, there were few differences in N efficiency between herds of the two farming systems. In both groups between 16 and 19% of the total supply of fodder N was sold as milk and meat products. Therefore, the significant differences in overall N efficiency must result from differences in crop production assuming that there were no systematic differences in ammonia-volatilization. Crop production N efficiency calculated from Table 6 varied between 40–61% on the conventional farms and from 63–86% on the organic farms.

In crop science the traditional concept of nutrient efficiency is defined as unit of product produced per unit of nutrient supplied (de Wit, 1992; Huggins and Pan, 1993). In fertilization planning experimentally derived response curves help to establish the economically optimum fertilizer level. Such growth- response functions normally reveal decreasing returns (i.e. decreasing marginal efficiency, kg. product/kg. N) when the supply of one production factor is increased while all other growth conditions are kept constant (de Wit, 1992). This law of diminishing returns is used in basic production economics to derive the economically optimum supply of a production factor; the point at which the price ratio line (price per unit output/price per unit input) is tangent to the production function (Doll and Orazem 1984).

This concept of economic efficiency has usually been perceived as securing optimum efficiency also from the societal point of view. Using the Aristotelian terms krematistics and oikonomia modernized by Daly and Cobb (1989), one might say that the marginal efficiency pairs with krematistics as "manipulation of private capital in the aim of maximising the short sighted value of the owner . . . ." In opposition to this, oikonomia means the co-ordination of a household (or society with its land, resources and institutions) with the goal of increasing the wealth of all members in the long run. According to Daly and Cobb krematistics has been erroneously considered to equal oikonomia.

As discussed by Sørensen and Kristensen (1992), from the 1950s to the mid-1980s economic productivity was one of the main goals of agriculture and optimization of inputs became important. The CAP in the sixties and seventies, supporting prices of produced commodities, reflected these goals. The current discussion of N pollution suggests that traditional concepts of productivity and marginal N efficiency no longer insure the optimum allocation and use of resources from society's (oikonomia) point of view. In this time of overproduction and increasing environmental concern contradictions have become apparent and the discourse has changed (Harper, 1993; Michelsen, 1994).

If the problem could be solved simply by introducing a tax on commercial fertilizer, the marginal efficiency calculation would still be sufficient. This, however, appears not always to be the case (Rude, 1991). In addition to the difficulty of internalizing the effects of a global externality (Daly and Cobb, 1989) like N pollution, there are several problems with the tax method. Geographic differences in the acceptable levels of N loss, even within the small country of Denmark, would make it difficult to set one appropriate tax level. The tax burdens would be unevenly distributed between livestock and crop producers. If the fertilizer tax caused a shift toward N fixing crops potential loss could rise. Fertilizer tax gives farmers no incentives to reduce stocking rates because of possible substitution of N in fertilizer with higher feed input (Gaarn Hansen, 1991).

Besides this, the calculation of N use based on marginal N efficiency does not include the total amount of N in manure as demonstrated in this study. Therefore, it does not give a true picture of the total N loss from a farm. The traditional concept of marginal N efficiency with its close link to productivity, however suitable for optimizing on farm return (krematistics) is insufficient to secure optimum use of N from the broader social and environmental perspective (oikonomia).

Since mean N efficiency (kg. $N_{out}$/kg. $N_{in}$) decreases with increasing N supply and production intensity, using this concept will better illustrate the need to balance production against the values of other parties – for instance future generations' need for pure drinking water or the fishermen's opportunities to catch fish. Therefore, it is better in accordance with the ideas of oikonomia. This task of balancing different interests – and the question of who have legitimate interests to be taken care of – can be perceived as an ethical dilemma. The problems of N loss cannot be solved solely at the farm level, as the environmental impacts of N loss are diffuse and call for political solutions. But, because decisions concerning N use are made by farmers, it is necessary to develop a concept which is applicable at farm level. Doluschitz et al. (1992) have proposed including N balance in farm accounts. Gaarn Hansen (1991) suggested a system of taxation on all farm N inputs, with a tax refund for N output as products.

## *Intensification vs. Extensification*

The discussion of differing definitions of N efficiency links up with a discussion of two perspectives of agricultural development in a situation of over-production and great environmental concern: Separation and intensification vs. integration and extensification (Weinschenk 1986; de Wit, Huisman and Rabbinge, 1987). The ques-

tion discussed is whether the problems are best solved by *either*
- allowing further intensification of production in the most competitive areas and accepting the marginalization of large areas with the poorest conditions for agriculture and thereby giving place for ecological refuges and extensive use of land, *or*
- attempting to limit production by promoting less intensive farming systems in general, which could ease environmental concern and secure the survival of agriculture also in less endowed regions.

We believe that there is a great need to study ways of balancing production and economy against environmental concern and use of resources in livestock farming systems. The concepts of farm level N surplus and efficiency used in this study fit well into the extensification perspective. But, examining nitrogen pollution from this angle is only one aspect of the agricultural sustainability problem (Burkhardt, 1989). Possible solutions might be found among the vast variations that exist between farmers (van der Ploeg, 1993). This resource of existing knowledge could be utilized and systematized through research activities like farming systems research (Sørensen and Kristensen, 1992; Bonnemaire, 1993; Edwards et al., 1993).

Searching for more sustainable farming systems, this and other studies of nitrogen surplus (van der Werff, Baars and Oomen, 1994) and energy efficiency (Pimentel, 1993; Refsgaard and Halberg, 1994) show that organic farms might be feasible critical cases. Danish organic farming rules for controlling both N input and stocking rate have evolved from grass roots movements. These regulations are a compromise between sustainable agricultural ideals and the farmer's economic concern. The rules are based on goals of minimizing pollution from pesticides and fertilizers, increasing efficiency in using resources and securing animal and social welfare. There is, however, a lack of ways to express these values of farming in comparison with farm economics and production. The National Institute of Animal Science (NIAS) has started a research project to develop a tool for facilitating an aggregated description of such values attributed to a given production period and from that the dialogue between farmer and researcher. The idea behind this ethical accounts system is described in a letter to the editor of this journal (Sørensen, 1994).

Since the N surplus was very dependent on the farm manager's decisions, it is necessary to ask how the farmer's value orientation influences his choice of production methods. Van der Ploeg (1993) related differences in N surplus on Dutch dairy farms to variations in farming style (the strategic notion of farmers). We expect that sociological studies of the value orientation of the farmers in this study can contribute to explaining the large differences within the two systems. This is the subject of a Danish Ministry of Agriculture research project involving sociological and agricultural scientists. The hypothesis is that the farmer's value orientation could be included in a process of redirecting agricultural production to be more "oikonomic." For this purpose the farmer may use the ethical account as a strategic planning tool.

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