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NITROGEN AS A POTENTIAL SOURCE OF POLLUTION

door

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1. DEVELOPMENT OF N-USAGE IN AGRICULTURE

In the middle ages, cereal production did not exceed 800 kg$\cdot$ha^{-1}. In 1800, wheat production had increased to appr. 1000 kg$\cdot$ha^{-1}. After 1850, however, an accelerated growth occurred, leading to current yield levels of appr. 5700 kg winter wheat per ha (De Wit, 1971). This accelerated growth, also occurring with other crops, became possible because, over the years, soil fertility could be increased by the introduction of fertilizers. Another reason was that crops and varieties with a higher yield potential, and consequently a higher N-demand, were developed, whereas at the same time, weed control and crop protection measures were strongly intensified.

From 1950-1975 the average rate of potassium application on cultivated land was appr. 60 kg $K_2O\cdot ha^{-1}$ (range 54-72 kg$\cdot$ha^{-1}) and of phosphate appr. 48 kg $P_2O_5\cdot ha^{-1}$ (44-53 kg$\cdot$ha^{-1}).

In this period, however, nitrogen consumption, in the form of fertilizers, increased sharply, viz. from 67 kg N$\cdot$ha^{-1} in 1950 to 208 kg N$\cdot$ha^{-1} cultivated land in 1975.

The actual intensification of agriculture in this period, however, has been much greater yet. The reason for this is that through feed concentrates for animal production also important quantities of plant nutrients are imported from other countries. In 1951/52 only 0,75 mln. tonnes of concentrates were imported; in 1975/76 imports had increased to appr. 9,5 mln. tonnes, a twelve-fold increase (Landbouwcijfers 1974 en 1975)

Assuming an average nitrogen content of concentrates of 3% N on a dry matter basis, in 1975/76 these concentrates contained appr. 285 mln. kg N. Of this nitrogen appr. 84% is excreted in faeces and urine (Rijtema, 1978). Of the excreted nitrogen appr. 20% is lost through ammonia volatilization following application as manure or during grazing. On our area of cultivated land of appr. 2,1 mln. ha, through concentrates, imported from other countries, appr. 90 kg N$\cdot$ha^{-1}. y^{-1} will be applied.

Soil, before the introduction of fertilizers, only supplied 30 kg N$\cdot$ha^{-1}.y^{-1} (De Wit, 1971); in 1978 this quantity is negligible compared with the annual supply of nitrogen in fertilizers (210 kg N$\cdot$ ha^{-1}) and in concentrates (90 kg N$\cdot$ ha^{-1}).

2. THE N-BALANCE SHEET OF ARABLE- AND GRASSLAND

The total annual nitrogen input on our cultivated land, including sources not mentioned yet, amounts to appr. 1.10^9 kg N, of which appr. 23% is used on arable land and 77% on grassland. The question arises: What is the fate of all this nitrogen?

Table I shows the average input-output balance per ha arable- and grassland in 1970. Appr. 48% of the input on grassland is traced back in the grass produced for grazing or silage making. The horticultural and agricultural crops contain appr. 34% of the input into this sector.

Appr. 20% of the input is recirculated in the form of roots, stubble, seed and plant material and green manures (arable land 23%, grassland 18%). If the cutting and grazing losses on grassland are taken into consideration as well, appr. 25% of the input on grassland is recirculated.

Table I. Nitrogen balance sheet of arable- and grassland in the Netherlands in 1970.

Input	kg $N.ha^{-1}$	
	arable land	grassland
rainfall	15	15
fertilizers	134	200
manure + excrements	103	287
compost	4	-
biologically bound N	4	15
recirculation:		
a. cutting and grazing losses	-	43
b. roots, stubble, seed- and plant material	89	125
total input	349	685

Output		kg N.ha^{-1} arable land	kg N.ha^{-1} grassland
grazing	excl. stubble	-	240
hay and silage	and roots	-	88
horticultural production		8	-
agricultural production		112	-
roots, stubble		80	125
total output		200	453
	deficit	149	232
total input		349	685
output in % input		57	66

	arable land	grassland
Losses in % of input:		
leaching	18	6
denitrification	20	15
NH_3-volatilization	5	13

Table I shows that the total output varies from 57% on arable land to 66% on grassland. Assuming an equilibrium condition, i.e. a constant store of nitrogen in the soil, this means that 43% and 34%, respectively, of the nitrogen input has disappeared.

This deficit is caused by three processes:

a. denitrification

b. leaching

c. ammonia volatilization.

If there is no equilibrium in the soil, apart from the three mentioned processes, biological N-adsorption in microorganisms or crop residues may contribute to the deficit.

3. LOSSES OF NITROGEN BY LEACHING AND DENITRIFICATION

3.1. Soil heaviness

Analysis of lysimeter trials shows that on arable land losses through leaching decrease as the soil becomes heavier (Kolenbrander, 1969).
Analysis of ground-water under grassland gives a similar picture (Steenvoorden en Kolenbrander, 1978).
The effectiveness of fertilizer nitrogen on heavier soils, however, is not much better than on light, sandy soils (Kolenbrander, 1973).
The smaller leaching losses, found in lysimeter trials on heavier soils imply larger denitrification losses, because in lysimeter trials biological adsorption or adsorption by soil particles are excluded from the "balance-deficit".
These greater denitrification losses in heavier soils can possibly be explained by the fact that, with increasing soil heaviness, more moisture is present in small pores.
This strongly enhances the chance of anaerobic conditions to occur in a greater part of the profile, and thus the chance of stronger denitrification losses. The quantitative aspects are dealt with in paragraph 3.3.

3.2. Ground-water level

Ground-water level plays an important part with regards to N-losses by leaching. Rijtema (1978) has drawn up a model, in which livestock density, fertilizer application, drainage situation and leaching are included.
Assuming certain conditions, he arrives at the conclusion that leaching in a situation with moderate drainage, a livestock density of one cattle unit (CU) per ha and a fertilizer application rate of appr. 100 kg $N \cdot ha^{-1}$ for a sandy, a clay and a peat soil is similar to the situation with good drainage and a livestock density of 3.5 $CU.ha^{-1}$ (table II).

TABLE II. Influence of drainage on N-leaching on grassland

	drainage			
	moderate			good
livestock density, CU, ha^{-1}	1,0	2,5	3,5	3,5
N-fertilizer, kg N.ha^{-1}	100	230	230	280
leaching, kg N.ha^{-1}:				
sandy soil	30	83	107	30
clay	20	50	67	13
peat soil	9	25	32	3

Table II also shows the increase in leaching losses, calculated by Rijtema (1978), with higher stocking rates on soil having moderate drainage, as well as the positive effect of drainage on leaching under conditions of intensive stocking (3.5 CU ha^{-1}).

The cause of this effect is twofold. With lower ground-water levels, the water capacity of the entire profile increases. As a result of this, on average, a smaller part of the precipitation surplus will reach the ground-water, thus decreasing leaching from the rooted profile.

On the other hand, residence time of nitrogen in the rooted profile will be much longer in a good drainage situation, which may increase denitrification losses. According to Rijtema (1978) it may be assumed as a rule of thumb, that in comparison with poor drainage, the nitrogen content of soil moisture with good drainage will be appr. 50% lower before deep ground-water is reached. In a poor drainage situation nitrogen will through a short residence time in the rooted profile still reach the surface water in the same winter. An increasing residence time in the rooted profile, by a deeper movement of the shallow ground-water, may also lead to larger denitrification losses.

Such a deeper movement of shallow ground-water was created in lysimeters with various ground-water levels above the drainage water outlet. Table III shows that, although Cl-leaching for all treatments is of a similar order (221 ± 20 kg Cl. ha^{-1}.y^{-1}), N-leaching decreases as the water table above outlet rises.

TABLE III. Course of N/Cl ratio in drainage water in lysimeters with different ground-water levels

ground-water level		leached: $kg.ha^{-1}.y^{-1}$		N/Cl
below soil surface	above outlet	N	Cl	
35 cm	85 cm	4	192	0.021
60 cm	60 cm	7	227	0.031
85 cm	35 cm	22	240	0.092
110 cm	10 cm	28	224	0.125

Assuming that this is not the result of differences in N-adsorption in the soil, it must be caused by greater denitrification.
The large differences in N/Cl ratio therefore are indicative of very significant denitrification losses when nitrogen residence time in the ground-water increases strongly for an extended period, stimulated by deeper channels of movement in the shallow ground-water.

3.3. *Influence of level of fertilization*

Considering the fact that soil heaviness and ground-water level may strongly influence nitrogen losses by leaching, it is necessary to take these factors into consideration, when analyzing the effect of level of fertilization.
Figure 1 shows the nitrogen losses by leaching, as found by a number of research workers (Dowdell and Webster, 1974; Foerster, 1973; Garwood and Tyson, 1973; Van Geneijgen, 1973; Hood, 1976; Jung und Jürgens-Gschwind, 1973; Kolenbrander, 1969, 1973; Low, 1973; Pfaff, 1950; Vetter und Klasink, 1972).
The results concern arable- and grassland on sand and clay soils and were obtained under widely varying conditions (lysimeters, catchment areas, and profile- and ground-water research in field trials).
Noteworthy in figure 1 is the variation in fertilization level, from very low (fertilizer) rates to very high (animal manure) rates ("dumping").

There is, however, the difficulty that in animal manure, apart from mineral nitrogen, also a large amount of organically bound nitrogen is present, which becomes available slowly. To improve the comparability of lysimeter trials, and trials including animal manure, only the mineral-N fraction was taken into consideration, in addition to a possible fertilizer application. Data from Sluijsmans en Kolenbrander (1977) served as a basis, viz. 50% mineral N in cattle- and pig slurry and 70% in poultry slurry.

By this method the quantity of mineral nitrogen from animal manure that becomes available in the long term may be underestimated. On the other hand, however, there is also an over-estimation, because volatilization losses of ammonia nitrogen from animal manure are not taken into consideration.

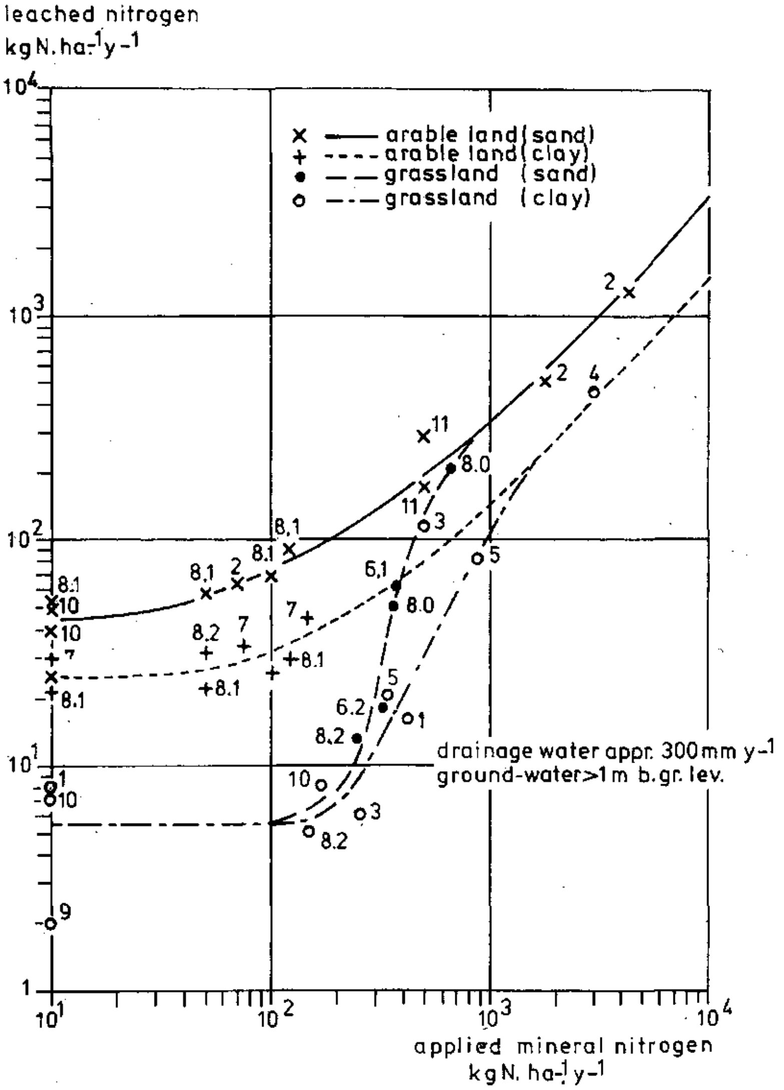
Figure 1 shows that, at very low rates of application, the leaching levels on arable land are significantly higher than on grassland. This is caused by the difference in the nature of the N-uptake pattern of the crop.

On grassland, however, a strong increase in N-leaching occurs at rates higher than 200 kg of mineral nitrogen (N-min) per ha per annum. At very high rates (higher than 800 kg N-min.$ha^{-1}.y^{-1}$), losses on grassland approach those on arable land. In that case one can no longer speak of fertilization, but of "dumping", and the nature of the crop will no longer play an important role in determining the rate of leaching.

On both arable land and grassland, N-leaching in heavier soils is lower than in light soils. On arable land, this is already apparent in treatments without fertilization; on grassland it only shows when the nitrogen application exceeds 100 kg N-min.$ha^{-1}.y^{-1}$. Upon dumping at a rate of 1000 kg N-min. $ha^{-1}.y^{-1}$, the loss on light soil amounts to appr. 35%, on heavier soils to appr. 15% of the mineral nitrogen applied.

4. THE N-REQUIREMENT IN AGRICULTURE

It is the task of agriculture to economically bind as much solar energy as possible, so as to meet the "energy"-requirement of the population in the form of food.



1	Dowdell c.s.	(1974)	lys.
2	Foerster	(1973)	field
3	Garwood	(1972)	lys.
4	v. Geneygen	(1973)	field)
5	Hood	(1976)	field
6.1	Hupselsebeek	(1972)	catchm.
6.2	De Leyen	(1974)	catchm.
7	Jung c.s.	(1973)	lys.
8.0	Kolenbrander	–	lys.
8.1		(1973)	lys.
8.2		(1969)	lys.
9	Low	(1973)	lys.
10	Pfaff	(1950)	lys
11	Vetter c.s.	(1972)	field

Fig. 1. Leaching of nitrogen from arable- and grassland

On a world scale, this is no mean task, which imposes the duty to utilize nitrogen in such a way that maximum dry-matter production is coupled with minimum stress on the environment.

4.1. The N-requirement of arable land

The optimum N-rate on arable land depends on soil type (organic matter, structure, depth of rooted layer), cropping plan, and climatological conditions.
On average, the optimum N-rate will vary from 110 kg $N.ha^{-1}$ for cereals to appr. 200 kg $N.ha^{-1}$ for root crops (and maize). Based on the average cropping plan in the Netherlands, a weighted average of 170 kg $N.ha^{-1}$ as the optimum amount of nitrogen can be computed.

4.2. The N-requirement of grassland

If crude protein production of grass is taken into consideration, results of Van Steenbergen (1977) show that rates of more than 500 kg $N.ha^{-1}.y^{-1}$ on grassland still show an increase in crude protein production. Dry-matter production, however, is already strongly limited at rates exceeding 300 kg $N.ha^{-1}.y^{-1}$. Thomas (1974) gives as maximum applications 400-500 kg $N.ha^{-1}.y^{-1}$ for grassland on sandy soils, 350-400 kg $N.ha^{-1}.y^{-1}$ for grassland on clay soils, and 200-250 kg $N.ha^{-1}.y^{-1}$ for grassland on peat soils.
The average fertilizer rate on grassland in the Netherlands in 1975 was estimated at appr. 250 kg $N.ha^{-1}.y^{-1}$ by Den Boer (1978). On the intensively managed "nitrogen pilot farms", which can be considered as "forerunners", the average N-rate during 1973-1977 amounted to appr. 380 kg $N.ha^{-1}$ grassland.
In principle no relationship necessarily exists between N-fertilizer rate and livestock density, because by purchasing roughage or concentrates, any livestock density can be maintained.
Figure 2, however, shows that in agriculture on e.g. dairy farms such a relationship clearly exists. Increased fertilizer applications lead to increased dry-matter production on grassland. This, in combination with purchased roughage and/or concentrates, will create the possibility of an increased livestock density.
In Figure 2, a cattle unit (CU) is defined as a dairy cow with a live weight of

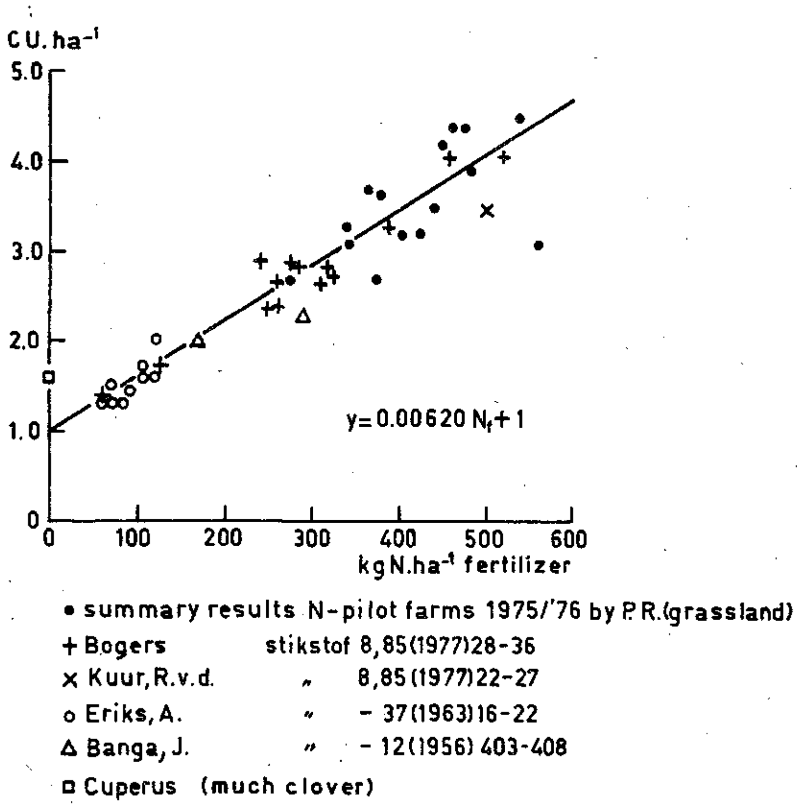


Fig. 2. Relationship between rate of fertilizer application and number of cattle units per ha of grassland

550 kg and an annual milk production of 4000 l with 4% fat and a starch equivalent requirement of 6300 g per day; feed consumption and manure production by other animals are converted to this basis. Extrapolation of figure 2 shows that, without fertilizers, only 1 $CU.ha^{-1}$ can be kept. This is in agreement with agricultural practice. On the farm of Cuperus in Friesland, on which no fertilizer is used, a livestock density of 1.5 $CU.ha^{-1}$ (Van der Molen, 1975) can be maintained. This, somewhat higher, livestock density is possible because the sward contains more clover which can maintain itself on this clay soil. This clover, on the basis of figure 2, supplies a quantity of nitrogen equivalent to appr. 125 kg $N.ha^{-1}.y^{-1}$ as fertilizer nitrogen.

4.3. Limiting factors

It has been shown that optimum fertilizer rates very often cannot be exceeded without risk of yield reductions. In particular on arable land, excess of nitrogen has a negative effect, such as lodging of cereals, decrease in contents of dry matter and starch of potatoes, reduction in sugar content and sap purity of sugar beet, and nitrate accumulation in vegetables.

On grassland, potassium rather than nitrogen is the major limiting factor. Because of the high potassium- and crude protein contents in grass, easily resulting from too high manure applications based on nitrogen requirement, hypomagnesemia may occur. This risk can be reduced by ample magnesium fertilization or feeding, but it would appear to be useful to set as a norm that on sandy soils a maximum of 340 kg $K_2O.ha^{-1}.y^{-1}$ may be applied, whether in the form of fertilizers or animal manure, or a mixture of both.

Henkens (1978) concludes that potassium balance sheet of grassland on sandy soils is slightly positive at 3 $CU.ha^{-1}$, whereas on clay soils, due to less leaching, this is already the case at 2 $CU.ha^{-1}$. This means that, for a potassium production in faeces and urine of 100 kg $K_2O.\ CU^{-1}.y^{-1}$, the maximum rate for sandy soil is 300 kg $K_2O.ha^{-1}.y^{-1}$ and for clay soil 200 kg $K_2O.ha^{-1}.y^{-1}$. This rate is somewhat lower than the 340 kg $K_2O.ha^{-1}.y^{-1}$ mentioned before, but the order of magnitude is similar to the rate for sandy soil.

5. ANIMAL MANURE AS A SOURCE OF N, P, AND K

Nitrogen in animal manure partly consists of a fraction which cannot easily be broken down by microorganisms, and consequently also only slowly becomes available to the plant (Sluijsmans en Kolenbrander, 1977).

"Efficiency indices" of nitrogen can therefore be distinguished for short- and long-term effects. The long-term effect expresses itself in supplying, over the years, an increasing part of soil nitrogen to the plant, thus decreasing fertilizer requirement.

The long term N-efficiency index (N_{ei}), averaged for spring and autumn application, for cattle slurry on arable land can be calculated at 60% of that of fertilizer nitrogen and for grassland (including the grazing period) at 74%. The N_{ei} for other kinds of manure on arable land is of the same order as for cattle slurry. On grassland N_{ei} is much lower as a result of larger ammonia losses, because the manure is not ploughed down, whereas precisely these other types of manure have a larger part of their total nitrogen in mineral form. The N_{ei} makes it possible to convert manure- nitrogen quantities into fertilizer rates.

The calculations can be simplified further by converting the quantities of plant nutrients, present the animal manure produced, into cattle equivalents (CE). The basis for this is the cattle unit (CU) (for definition, see 4.2.). Such an CU produces 90 kg nitrogen (with a long-term N_{ei} of 0.60 for arable land and 0.74 for grassland), 40 kg P_2O_5 and 100 kg K_2O per annum. P_2O_5 and K_2O have an efficiency index of 100%. This can summarized as follows:

1 CU = 6300 g starch equivalent per day
1 CE-N = 90 kg $N.y^{-1}$
1 CE-P = 40 kg $P_2O_5.y^{-1}$
1 CE-K = 100 kg $K_2O.y^{-1}$

Table 4 summarizes the factors for conversion of manure of various animal groups to CU and CE.

The average fertilizer requirement on arable land ranges, as mentioned before, from 110 kg $N.ha^{-1}$ for cereals to 200 kg $N.ha^{-1}$ for root crops, with a weighted average of 170 kg $N.ha^{-1}$.

These values can be converted into CE, taking the N_{ei} into consideration. A fertilizer requirement "a" for arable land amounts to:

$$\frac{1}{90} . \frac{10}{6} \times a \quad \text{CE-N}$$

The nitrogen requirement on arable land will therefore vary from 2.0 CE-N for cereals to 3.7 CE-N for root crops. Figure 3 makes estimation possible of the CE-N requirement on the basis of the proportion of cereals in the cropping plan.

The desired quantity of animal manure on grassland is determined on the basis of the potassium application, which should not exceed 340 kg $K_2O.ha^{-1}$. Because 1 CE-K is equivalent to 100 kg $K_2O.ha^{-1}$, the maximum application is 3.4 CE-K. This corresponds with an effective nitrogen amount of $3.4 \times 90 \times 0.74 = 226$ kg $N.ha^{-1}.y^{-1}$. This quantity, however, does not satisfy the nitrogen requirement of

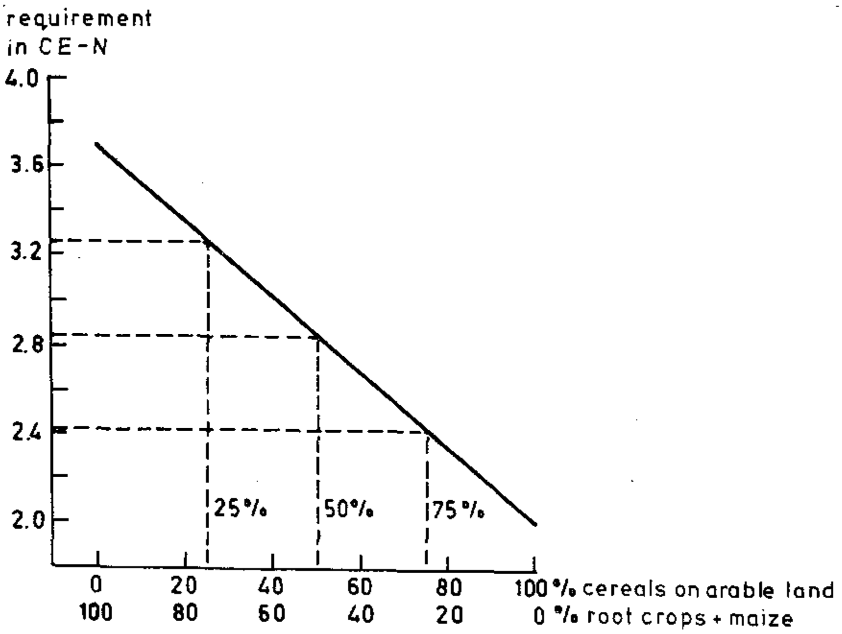


Fig. 3. Acceptable nitrogen fertilization in CE-N per ha of arable land as a function of the cropping plan

grassland, which varies from 300 kg N.ha^{-1} based on dry-matter production to more than 500 kg N.ha^{-1} based on crude protein. In fertilization of grassland, the CE-N / CE-K ratio in animal manure may play a role, because this value varies fairly widely for different types of animals. For cattle manure it is 1, but for chicken manure 2.3 and for pig manure 2.7. From the viewpoint of an efficient nitrogen utilization of manure produced on the farm, it would be useful to apply pig and chicken manure (despite its lower N_{ei}) to grassland and cattle manure to arable land, but this method of operation could give rise to serious stench problems.

TABLE IV. Conversion factors for calculating cattle units (CU) and cattle equivalents (CE) from the number of animals of different animal groups

Animal group	cattle units (CU)	cattle-equivalents (CE)			Number of CE per CU		
	–	N	P_2O_5	K_2O	N	P_2O_5	K_2O
1	2	3	4	5	6	7	8
Horses	1,000	0,9173	0,7000	0,8850	0,9173	0,7000	0,8850
Dairy cattle	1,000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
Young stock, under 1 year	0,300	0,3000	0,3000	0,3000	1,0000	1,0000	1,0000
Other cattle	0,600	0,6000	0,6000	0,6000	1,0000	1,0000	1,0000
Breeding sows ≥ 50 kg	0,460	0,2447	0,3349	0,0920	0,5320	0,7280	0,2000
Pigs ≥ 20 kg, without breeding sows	0,250	0,1330	0,1820	0,0500	0,5320	0,7280	0,2000
Other pigs	0,100	0,0532	0,0728	0,0200	0,5320	0,7280	0,2000
Sheep	0,110	0,1500	0,1300	0,1300	1,3636	1,1818	1,1818
Goats	0,110	0,1500	0,1300	0,1300	1,3636	1,1818	1,1818
Laying hens, 100	1,420	0,9090	1,8363	0,4000	0,6401	1,2932	0,2817
Broilers, 100	0,710	0,4546	0,9183	0,2000	0,6401	1,2932	0,2817
other chickens, 100	0,300	0,1667	0,4000	0,1000	0,5557	1,3333	0,3333
Geese, independent of age, 100	1,500	0,7778	1,2500	0,4800	0,5185	0,8333	0,3200
Ducks, independent of age, 100	1,500	0,7778	1,2500	0,4800	0,5185	0,8333	0,3200
Turkeys, independent of age, 100	0,500	0,2000	0,4500	0,1600	0,4000	0,9000	0,3200

6. THE PROBLEM OF MANURE SURPLUSES

Taking the standards mentioned above as a starting point, it can be calculated to what extent animal manure, produced on a farm or in a region, can fulfil the nitrogen-, potassium-, and phosphate requirements. A prerequisite for such a calculation is that cropping plan, size and nature of the animal population are known, while it is assumed that the manure will be spread evenly over the farm or the region.

If in certain regions many farms occur with an intensive animal husbandry, which is characterized by being only slightly "land-dependent", and which import large amounts of roughage and/or concentrates, there is a good chance that more nitrogen, potassium and phosphate are produced in animal manure than is required for optimum crop production.

In that case one can speak of a manure surplus, whereas for grassland nitrogen fertilizer still has to be purchased, because too much potash would be given if only animal manure were applied.

From a recent EEC-study (1978) it appears that, generally speaking, the threshold lies at 3 $CU.ha^{-1}$ cultivated land. Below this limit, generally, no manure surpluses are to be expected, except for individual, extreme cases.

7. NITROGEN FERTILIZATION AND CRITERIA FOR WATER QUALITY

Three criteria for water can be mentioned, which should be considered as maximum values. These are:

eutrophication	0.3 mg $N_{no_3}.l^{-1}$
fishing water	0.5 mg $N_{no_3}.l^{-1}$
drinking water	11 mg $N_{no_3}.l^{-1}$

When evaluating measures that will help to achieve these standards, it should be realized that, depending on ground-water level and residence time, important denitrification losses occur in the shallow ground-water (par. 3.2.). Such losses also occur in the surface water. Vollenweider (1970), for instance, who drew up an N-balance sheet for six large lakes in Switzerland, found that appr. 60% of the nett nitrogen load was apparently lost by denitrification. This value agrees well with measurements of Van Kessel (1976), who found, already after a residence time of 1.7 days, an N-loss by denitrification of 56% in a canal over a distance of 800 m. Rijtema (1978) therefore assumes that, on average, appr. 50% of the leached nitrogen will disappear from ground- and surface water by denitrification.

Utilizing this margin means that leaching losses twice as high as those with the above mentioned standards as a basis, are permissible.

The standard for drinking water of 11 mg NO_3-$N.l^{-1}$ is generally accepted, and has also been advised by the EEC. The WHO, however, also gives an upper limit and recommends that it should not be exceeded. This limit is twice the value mentioned before, and amounts to 22 mg NO_3-$N.l^{-1}$. The range from 11-22 mg NO_3-$N.l^{-1}$ is considered "acceptable".

For drinking water consequently three leaching levels could be distinguished, viz. level A corresponding with the most desirable concentration (11 mg NO_3-$N.l^{-1}$) without any limiting condition. Level B (twice as high as A) assuming that, under the condition of denitrifation loss of 50% in ground- and surface water, the standard concentration A (11 mg NO_3-$N.l^{-1}$) is still achieved. In addition, a level C, being twice as high as the WHO-standard of 22 mg NO_3-$N.l^{-1}$, on the assumption that here also, through a denitrifation loss of 50%, the maximum acceptable concentration of 22 mg NO_3-$N.l^{-1}$ is reached. If the conditions for denitrification losses are not incorporated, level B automatically constitutes the maximum concentration (22 mg NO_3-$N.l^{-1}$).

Assuming a ground-water supply of 300 mm. y^{-1}, these concentrations can be converted to maximum acceptable leaching losses in kg $N.ha^{-1}.y^{-1}$ and as such introduced into figure 1. The standard concentrations and the calculated acceptable leaching losses are presented in table V.

On the basis of these acceptable leaching losses it can be determined to what extent Dutch agriculture can meet the requirements regarding water quality.

TABLE V. Calculated acceptable leaching losses of nitrogen based upon criteria for water quality

nature	standard concentration mg NO_3-N.l^{-1}	acceptable leaching kg. N.ha^{-1}.y^{-1}
eutrophication	0.3	0.9
fishing water	0.5	1.5
drinking water: level A	11	33
" " " B	11	66
" " " C	22	132

7.1. Eutrophication and fishing water

Assuming an acceptable leaching loss for fishing water of 1.5 kg N.ha^{-1}.y^{-1} (table V), figure 1 clearly shows that agricultural land, even if no or little fertilizer is applied, can never meet the standards for fishing water and eutrophication. Only if this cultivated land by a definitive removal of plant nutrients has been disposed of the major part of its stock of nitrogen (impoverishment e.g. as a result of "exhaustive farming") and has regained the status of "natural land", will there be a chance that the standards for fishing water and eutrophication will be met.

Grazing does not fit well into this pattern of impoverishment, because considerable recirculation of nitrogen and other plant nutrients is taking place, caused by trampling and fouling of the grass with excrements, as a result of which a large part of the grass is not ingested by the cattle.

7.2. Drinking-water

7.2.1. Arable land

Table VI shows the acceptable fertilization levels for arable land on clay- and sandy soils, based upon the criteria for water quality and the leaching model in figure 1.

TABLE VI. Calculated acceptable fertilization level on arable land (sandy and clay soils)

acceptable leaching		expected concentration	acceptable fertilization level, kg $N.ha^{-1}.y^{-1}$	
level	kg $N.ha^{-1}.y^{-1}$	mg NO_3-$N.l^{-1}$	sand	clay
A	33	11	0	100
-	42	14	-	170 *
B	66	11	70	360
-	100	17	170 *	-
C	132	22	260	900

* optimum rate

Table VI shows that on arable land on sandy soils there are no possibilities to meet level A (11 mg $N_{no3}l^{-1}$, without denitrification). This might be possible on arable land on clay soils, up to a level of 100 kg $N.ha^{-1}.y^{-1}$, but this rate is still lower than the optimum for an average cropping plan. Level B (11 mg NO_3-$N.l^{-1}$, including 50% denitrification losses) can be achieved on arable land on clay, but on sand rates of only 70 kg $N.ha^{-1}.y^{-1}$ are possible, which is far below the optimum rate. Level C (max. WHO-standard + 50% denitrification) opens wide perspectives. Also at the optimum average rate of 170 kg $N.ha^{-1}.y^{-1}$, leaching remains below the maximum of 22 mg NO_3-$N.l^{-1}$. According to table VI on arable land on sand, on average, a content of 17 mg NO_3-$N.l^{-1}$ may be expected. It may be concluded that on arable land on clay soils, even at higher fertilizer rates than the current optimum, the drinking water standard of 11 mg $N_{no3}.l^{-1}$ can be met. On arable land on sandy soils this will not be the case. Concentrations will, however, remain below the maximum acceptable WHO-standard of 22 mg NO_3-$N.l^{-1}$ also when in the future fertilizer rates would have to be increased to optimize yields.

7.2.2. *Grassland*

Table VII shows, in a similar way as for arable land, the maximum acceptable quantities of N-min.$ha^{-1}.y^{-1}$ for grassland for the three leaching levels A, B and C (table V). In this case, however, N-min does not only include fertilizer-N, but also the mineral nitrogen fraction (α) in animal manure. This fraction for cattle-, pig-, and chicken slurry amounts to appr. 50%, for farmyard manure 10% and for liquid manure appr. 94% (Sluijsmans en Kolenbrander, 1977).

The relationship between N-min, nitrogen in mineral fertilizers (Nf) and the livestock density in CU.ha^{-1}(L) is as follows:

N-min = Nf + α. 90 p. L (1)
N-min = applied fertilizer + fraction of mineral N (α) in animal manure
Nf = fertilizer application in kg N.$ha^{-1}.y^{-1}$
p = number of CE-N (cattle equivalents nitrogen) per CU
L = livestock density in CU.ha^{-1} grassland.

For a dairy herd α = 0.50 and p = 1
For a stock of pigs α = 0.50 and p = 0.5
(for p see table VI, column 6).
For a dairy herd the formula (1) becomes:
N-min = Nf + 45.L. (2)

TABLE VII. Maximum acceptable quantities of mineral nitrogen in fertilizers and for animal manure based upon drinking water standards

drinking water	sand grassland	clay grassland
leaching level	N-min kg N.ha^{-1}	N-min kg N.ha^{-1}
A	320	500
B	380	725
C	500	1100

When in formula (2) the maximum value for N-min from table VII is substituted, for each of the three leaching levels on grassland on sandy- and clay soils, respectively, the relationship between the maximum acceptable fertilizer rate and the corresponding maximum acceptable livestock density can be calculated. These relationships have been plotted in figure 4, using the information in fig. 2 as a basis.

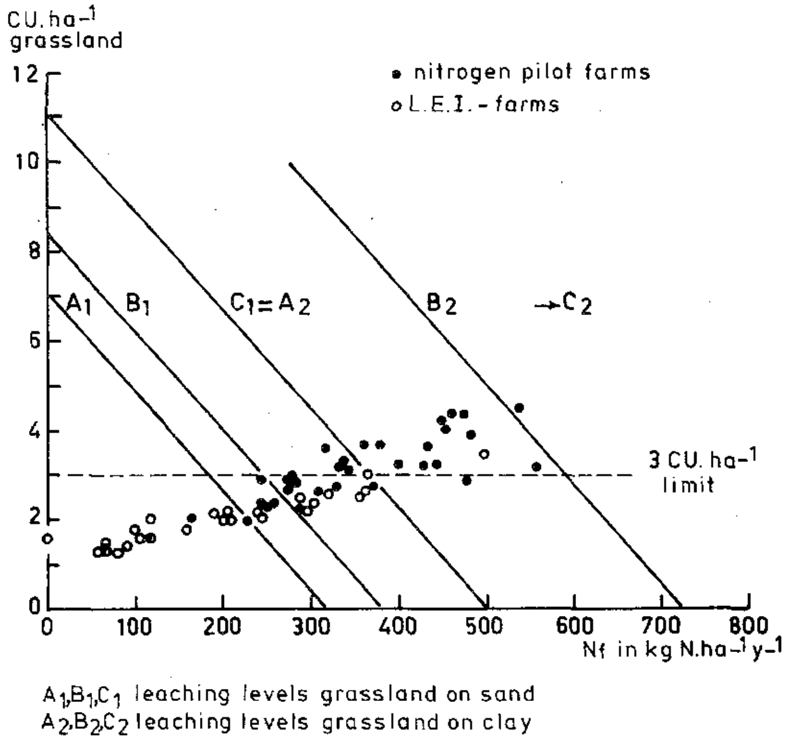


Fig. 4. Fertilizer-N application and livestock density at three maximum acceptable leaching levels on the basis of drinking water standards and the practical conditions of dairy farming.

This information was obtained from observations in actual agricultural practice, mainly concerning dairy farming on different soil types ("nitrogen pilot farms" and farms monitored by the Agricultural Economics Research Institute (L.E.I.). Figure 4 shows that, on grassland on sandy soils, with the current average fertilizer application of 250 kg $N.ha^{-1}$ and a livestock density of 2.5 $CU.ha^{-1}$, the standard of leaching level B (11 mg $N_{no_3}.1^{-1}$, with 50% denitrification losses) can just be satisfied. There are no difficulties on grassland on clay, because level A can still be met. Increasing the livestock population density to the levels of the "nitrogen pilot farms", on light soil will lead to overstepping level B and even the maximum level C. On grassland on clay, no difficulties are to be expected with regard to the NO_3-N content of the water. Livestock density, however, reaches too high a level with regard to potash supply, because on clay grassland at level B the standard of 3 $CU.ha^{-1}$ is clearly exceeded and consequently on grassland manure surpluses will occur. This danger is also present on the "nitrogen pilot farms" with a current livestock density of 3.3 $CU.ha^{-1}$.

It may be concluded that, considering the current fertilization level (250 kg fertilizer $N.ha^{-1}.y^{-1}$) on grassland, and the average livestock density (2.5 $CU.ha^{-1}$), the nitrate concentration in ground- and surface water on grassland on clay soils to be used as drinking water, will remain below 11 mg $NO_3.N.1^{-1}$. This will also be the case on grassland on sandy soils, when 50% of the leached nitrogen will still be denitrified in ground- and surface water. With further intensification of grassland farming on sandy soils, this standard will easily be exceeded. A level of 350 kg $N.ha^{-1}.y^{-1}$, however, can be applied before the maximum WHO-standard (22 mg $NO_3.N.1^{-1}$) is reached. When the livestock density rises above this level, the potassium supply of grassland will be the cause of a serious risk of manure surpluses to occur.

8. CONSIDERATION OF PREVENTIVE MEASURES

The preceding paragraphs show that, to reach the standard of 11 mg $NO_3.N.1^{-1}$ in ground- and surface water for drinking water purposes, it will be necessary to reduce the N-fertilization level on arable land on sandy soils by 60% from (on average) 170 kg $N.ha^{-1}$ to 70 kg $N.ha^{-1}$ (expressed as fertilizer nitrogen). In this case it is a prerequisite that 50% of the leached nitrogen is lost in the shallow ground-water or surface water by denitrification. The lesser the extent to which this last prerequisite is met, the closer the nitrate content will approach the maximum WHO-standard for drinking water.

In areas with manure surpluses (generally areas on sand- and clay soils with a livestock density higher than 3 $CU.ha^{-1}$) these surpluses should be transported to other farm enterprises or areas with a lower livestock density. The intensification of stock farming, often governed by economic reasons, might also be restricted. All these measures, however, demand detailed administration of livestock density per farm and a check on fertilizer purchases, and on import and export of animal manure from holdings within a certain region. This task could possibly be given to "manure banks".

Such interventions into fertilization management, however, will result in a reduced food production (reduced binding of solar energy) and increasing costs per kg of produce.

It will therefore be necessary to weigh the effects of the measures outlined above on the quality of ground- and surface water for drinking water purposes against the costs to be made to technologically process the small quantities of "drinking water" that are really needed per head (a few percent of total water consumption) so as to meet the standard of 11 mg $N_{no_3}.l^{-1}$. When considering these technological possibilities one should not think of a second water mains system, but of the possibility of using ion exchangers to treat the water of one or more points of delivery per connected unit, with or without chlorinating to avoid bacterial infections. This possibly presents an important future task for the Water Companies. Although it appears that fertilization, in particular on arable land on sandy soils, cannot without difficulty meet the standard of 11 mg $NO_3.N.l^{-1}$ for drinking water, it is even more difficult to bring agriculture into line with nitrate standards for fishing water and eutrophication (7.1). These standards can only be met by "natural lands" that have never been used for agricultural purposes.

To return to this level, agricultural land will have to be taken out of production completely and "impoverished" for many years, by remove all plant nutrients that are taken up by the crop, in particular nitrogen, from the relevant area. Grazing therefore does not very well fit in with this scheme, because only limited amounts of plant nutrients are exported in milk and meat.

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