Commission of the European Communities

INFORMATION ON AGRICULTURE

The spreading of animal excrement on utilized agricultural areas of the Community

I. SCIENTIFIC BASES FOR THE LIMITATION OF QUANTITIES AND CRITERIA FOR RULES THEREON

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FOREWORD

This study has been made under the study programme of the Directorate-General for Agriculture and the Environment and Consumer Protection Service of the Commission of the European Communities. It is the first part of a survey regarding land spreading of animal excrements1) and has been carried out by

> the Instituut voor Bodemvruchtbaarheid te Haren (Groningen) under the direction of Mr. C.M.J. Sluijsmans, assisted by Mr. T.A. Van Dijk, Mr. C.J. Kolenbrander, Mr. L.C.N. de la Lande Cremer, Mr. K.W. Smilde and Mr. C.H.E. Werkhoven.

The divisions "Statistics, balance sheets and general studies", "Production structures and environment" and "Coordination of agricultural research" in the Directorate-General for Agriculture and the "General planning and environmental improvement" Division in the Environment and Consumer Protection Service took part in the work.

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1) The other parts will be published in the same series

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I. Potential nuisances from manuring

Stocking intensities per hectare of cultivated land have increased sharply or are still increasing in various regions of the EEC and elsewhere. Social, economic and technological developments in the last few decades are responsible for this. For instance, better management of grassland has made it possible to increase cattle stocking rates. At the same time, technological developments have increased productivity per farm worker. On small mixed holdings where also pigs, fattening calves and poultry had traditionally been kept, this gave rise to a labour surplus, resulting in a loss of manpower and a considerable reduction in the number of farms. The farmers who remained on the land endeavoured to increase the scale of their farms in order to obtain an income equivalent to what could be earned in other occupations. Where this could not be achieved, or could be achieved only to an insufficient extent, by increasing the area farmed, the choice fell upon intensification.

From the point of view of feeding, the availability of mixed feeds competitive in price and quality with feedstuffs produced on the farm means that the number of livestock in a holding is no longer limited by its area of fodder crops. The preventive control of disease has also reduced the force of veterinary objections to the keeping of large numbers of animals. With regard to manuring, however, stocking intensities, and hence also manure production, ceased to be related to the area of cultivated land available for utilization of the manure. There is no cause for anxiety where this occurs only sporadically, as adequate channels for disposal of the excess manure can still readily be found in the immediate vicinity.

However, in consequence of historical trends and the requirements of supplying and processing industries, centres of concentration of intensive livestock enterprises with non-land-dependent (i.e. housed stock) production (e.g. pigs and poultry) arose, which are responsible for a variety of nuisances.

Apart from the problem of odours, the nuisance of manure surpluses calls for particular attention. This report is confined to the problems caused by these surpluses. Manure surpluses can lead to overdosage on the available land area, with possible consequences for soil, crops, animals, groundwater and surface water. This danger is exacerbated by the abandonment, for technical reasons, of separate storage of solid and liquid manure in favour of mixed storage. Since storage capacity is limited, the resulting liquid mixture can be stored only for a short time. In addition, the manurial value of this slurry is inferior to that of solid manure, so that transport over long distances quickly becomes uneconomic.

The problems of substantial and excessive applications of animal manure will not arise on livestock farms which grow their needed fodder themselves. A considerable proportion of the minerals taken up by the crops is recycled with the manure. Only losses arising from the sale of products, volatilization of nitrogen, and leaching and runoff must be made up with purchased organic or inorganic fertilizers. Possible overmanuring problems on these farms are attributable to imprudent manure management and can be avoided by spreading the manure over the farm's entire area of cultivated land.

However, where stocking rates are increased largely or even totally on the basis of purchased roughage and concentrated feeds, a substantial surplus of plant nutrients arises in the minerals balance sheet of the farm. If the excess manure can be removed to other farms with a deficit, there is no need for worry about soil and water pollution, as in the case of an intensive livestock farm situated among holdings with large areas of arable farming, horticulture or viticulture. A use can then easily be found for the surplus manure. On the other hand, modern grassland farms using large quantities of concentrates are now virtually unable to utilize manure from animals additional to their own cattle herds. For this reason, grassland areas are less suitable for the establishment of non-land-dependent livestock holdings.

The problem of manure surpluses becomes acute where concentrations of intensive livestock farms arise in regions with large areas of grassland (in the last few years much arable land has been turned into pasture for economic reasons). It then becomes difficult to dispose of surplus manure in the immediate vicinity. Instead of selling his manure, the stockfarmer must supply it to more distant farmers free of charge; as distances involved increase, he will even have to pay a share of the transportation costs himself or incur other expenses for disposal of the manure. In the last two cases mentioned, the question arises of how much manure the available land can accept without harmful consequences to plants and animals, if necessary by use of specific techniques of spreading and ploughing-in - as well as the extent to which these quantities are ecologically justified in the short and long term. At a certain stage, regulatory measures for the quantities of animal manure per hectare of cultivated land, or the corresponding stocking rates, may perhaps have to be considered.

This report considers the above problems from the point of view of agricultural research.

II. Elaboration and discussion of a scientific basis for limiting application of animal manure on agricultural land

Introduction

The yield of agricultural crops generally rises with increasing doses of animal manure. However, beyond a certain point, the effect of a further increase become smaller and smaller, eventually falling to nil, after which yields may even begin to decline. Other aspects, such as the quality and susceptibility of the crops to disease, may be adversely affected even earlier. There are also ecological disadvantages: soil pollution (undesirable accumulation and reactions with certain constituents of the manure) and pollution of groundwater and surface water.

The permissible charge of the soil with animal manure could be established on the basis of either the economic optimum or minimum pollution of soil and water. As long as the permissible quantity in accordance with the former criterion is lower than that given by the latter, there is little reason for concern, and no official regulation of rate of manure application need be contemplated. In this situation economic considerations will result in doses of manure that are acceptable from the viewpoint of pollution of the environment.

This is no longer the case if the economic optimum exceeds the threshold above which soil and/or water pollution can occur. For convenience, this threshold will be called the ecological optimum. The problem becomes the more serious the lower the market value of the manure, particularly if this value becomes negative (i. e. if the farmer has to pay for the disposal of the manure). The basic question discussed in this Chapter is whether the economic optimum exceeds the ecological optimum, and, if so, to what extent.

The economic optimum corresponds to the quantity of manure at which the difference between the financial yield from the crops and the price obtainable from the sale of the manure is greatest. This is indicated in figure 1 by the points P1, P2 and P3 for a price of >0, 0 and <0 monetary units respectively. If the market value of the manure is positive, doses in excess of P1 lead to a fall in profit owing to reduction of the additional yield. The closer the price obtainable for the manure approaches to 0, the nearer the economic optimum comes to the physiological optimum (P2). As soon as the manure producer has to contribute to the cost of disposal of his manure, the optimum dose shifts further in the direction of P3.

A stockfarmer who has more animal manure than he can dispose of on his own land thus has the following possibilities :

The economically optimum dose of manure depends for him on the monetary value of the manure, measured by the selling price. If he receives nothing for the manure or even has to pay for its removal or disposal, then the amount which he can use on his farm is P2 or P3 respectively, shifting even further to the right as disposal costs increase. If the livestock farmer receives nothing for the manure, but it is removed free of charge, he will have to dispose of all manure exceeding the quantity P2 (physiological optimum), otherwise his yield will fall and he will sustain a financial loss. Finally, if there is some return on the manure, the farmer - from the purely economic point of view - must limit the amount of manure used to P1 and sell the surplus. If he were to apply more, his profit from crop production would fall.

An arable farmer who buys chemical fertilizer or animal manure acts in the same way. As the cost of fertilizer or manure falls, the economic optimum dose shifts towards the right, in the direction of P2. In the imaginary case of the farmer's being paid to take manure, the dose could even increase to, for example, P3.

With regard to the possibility of official regulation of manuring, particular attention must be devoted to the position of the physiological optimum compared with the ecological optimum. On the one hand, the former seems to be more constant in time and place than the economic optimum, thus facilitating its use, and, on the other, the economic and physiological optima are frequently identical where there are manure surpluses. For instance, in a province of the Netherlands severely affected by manure surpluses, it was found that, of farms disposing of manure in 1971, over 63% of those producing solid manure and over 80% of those producing slurry already had to supply manure free of charge[1] (situation P2 in the diagram).

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[1] Report, manure survey of pig and poultry farms in North Brabant (Consulentschap voor de varkens- en pluimveehouderij in Noord-Brabant en Zeeland, 1972).

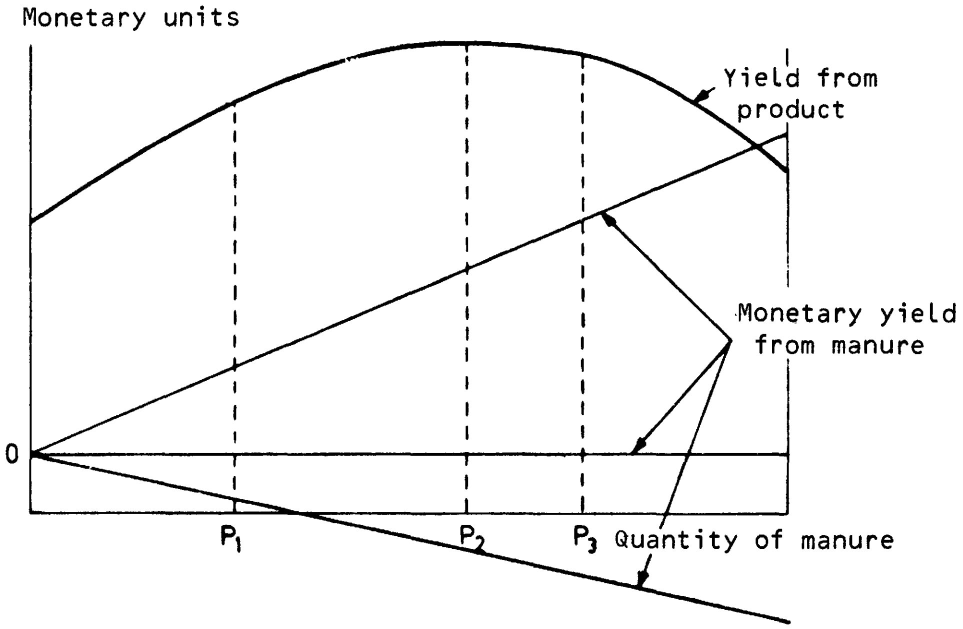

Fig. 1. Economically optimum quantity of manure vs financial yield from manure when sold.

As manure becomes harder to dispose of in the region with increasing livestock concentration, it may have to be transported over longer distances or techniques may have to be used to utilize the manure in other ways or even to destroy it wholly or in part. The resulting higher costs will then be chargeable fully or partially to the manure producer, so that the manure will acquire a negative commercial value for him. An incipient trend in this direction was already revealed by the survey mentioned above, which showed that a charge was made for disposal in 8% of cases.

The use of the physiological optimum for determining the permissible quantities of manure has the advantage that maximum food production can also be achieved at this level. Also, the conflict with environmental interests is most likely to arise when this optimum level is exceeded, particularly as organic manures are composed of a large number of different constituents. By the time the permissible limit to the concentration of one substance is reached, others may be present in excessively large quantities, and although these may not be harmful agriculturally, they may eventually prove detrimental to the environment.

The above introduction suggests that the questions to be studied should be as follows :

1. What quantities of animal manure are appropriate for maximizing the quality and quantity of crop production ?

2. What quantities are permissible as regards soil pollution ?

3. What quantities are acceptable from the point of view of groundwater and surface water pollution ?

These questions will be dealt with in the following sections.

1. Optimum amounts of animal manure for crop production

This Chapter is concerned with the rates of animal manure application required for maximum crop production at which the chemical composition of the crop does not present a health hazard to man and animals. Possible long-term adverse effects of the accumulation of nutrients in the soil or in the groundwater and surface water are discussed elsewhere in this report.

1.1 Arable land

Excess nitrogen is detrimental to most agricultural crops, causing lodging of cereals, reduction of the dry matter and starch content of potatoes, reduction of the sugar content and juice purity of sugarbeets, and nitrate accumulation in vegetables. This does not occur, or occurs only to a far lesser extent, with overdoses of potassium provided that the plant has sufficient magnesium available. Industrial potatoes are an exception here, their starch content being unfavourably affected by excessive doses of potassium. In beets, the refining process is impeded by excessive potassium. Damage to agricultural crops by excessive phosphorus is seldom reported. A few cases of zinc and copper deficiency due to excess phosphorus in fruit-growing and forestry have been reported (Mulder and Butijn, 1963; Oldenkamp and Smilde, 1966); zinc deficiency caused by excess phosphorus has also been reported in maize-growing in the USA.

On the basis of the foregoing, it appears acceptable to base the permissible quantities of animal manure for arable crops on their nitrogen content, even if this entails the possibility of excess phosphorus and potassium dosage. In industrial potatoes, the yield may be depressed by excessive doses of both nitrogen and potassium. The requirement limits (tolerance limits) for these nutrients differ little (150-200 kg N or K_2O per ha in both cases). The commonest types of manure (except cattle slurry) contain roughly equal amounts of available nitrogen and potassium, so that it makes little difference which element is taken as the basis.

The nitrogen requirement of a plant here means the optimum quantity of nitrogen, in the form of chemical fertilizer, needed for a maximum yield (potatoes, sugar cereals, etc.) and administered at a time (spring) when losses due to climatic conditions are minimum.

Optimum nitrogen doses vary with the type of soil (organic matter, structure, and depth of the zone that may be exploited by the roots), management (organic matter regime) and climatic conditions (rainfall and temperature) (see Kuipers (1961)). To convert optimum nitrogen doses to permissible quantities of animal manure, therefore, averages calculated from the results obtained in a large number of field trials extending over many years are used. Data obtained in this way for the Netherlands are set out in Table 1.

The optimum nitrogen dose for a crop rotation system can easily be calculated by multiplying the optimum doses for the different crops by their proportion in the rotation (as a decimal fraction) and adding these products together.

Table 1. Average optimum nitrogen doses (kg N per ha) for different crops in long-term field trials.

	Clay soil	Sandy soil
Ware potatoes	215	190
Industrial potatoes		160
Sugarbeets	130	170
Wheat	125	170
Barley/oats/rye	90	105
"Commercial" crops[1)]	150	150
Silage maize	200	200
Leys (cut only, no grazing)	450	450

For sandy soils in the Netherlands (arable land) with 12% ware potatoes, 14% sugarbeets, 3% wheat, 37% other cereals, 1% "commercial" crops, 27% silage maize and 6% ley, the optimum nitrogen dose is $190 \cdot 0.12 + 170 \cdot 0.14 + 170 \cdot 0.03 + 105 \cdot 0.37 + 150 \cdot 0.01 + 200 \cdot 0.27 + 450 \cdot 0.06 = 173$ kg per ha.

[1)] See definition Appendix III

Similarly, an optimum nitrogen dose of 164 kg/ha can be calculated for clay soils with, for example, 25% ware potatoes, 25% sugarbeets, 25% wheat, 10% other cereals, 10% "commercial" crops and 5% ley. Approximately 110 and 200 kg N per ha can be taken as maxima for cropping systems with 100% cereals and 100% root and tuber crops (silage maize) respectively, on both sandy and clay soils. In countries or regions with much less or much more winter precipitation than in the Netherlands, the crops may have a smaller or larger nitrogen requirement owing to differences in N leaching. With abundant rainfall (e.g. 300-400 mm) from November to February, the requirement may be 25 kg N per ha higher, whereas if precipitation amounts to less than 150 mm, it may be about 50 kg lower. However, such differences are not to be expected in the EEC (see Table 25 in Chapter III).

Using the Dutch "Adviesbasis voor Landbouwgronden" ("Fertilizer Guide for Agricultural Land"), average phosphorus and potash requirements of 67.8 kg P_2O_5 and 108.5 kg K_2O per hectare respectively can be calculated for arable land with sandy soil; on clay soils, the average requirement is 61.5 kg P_2O_5 and 102.5 kg K_2O per hectare respectively. All this applies if the fertility status of the soil is rated as "good".

The production and composition of the principal types of manure per animal are set out in Table 2. For cattle slurry, the production relates to one adult dairy or slaughter animal for an entire year; the amounts for the other animals are also on an annual basis, per animal place (one place represents 2.2, 1, 5.5 and 2.2 animals per year for fattening pigs, laying hens, broilers and fattening calves respectively).

The manure production of (a) heifers (up to about one year old) and heifers in calf and of (b) bulls (up to about two years old) can be taken as equal to 0.5 and 0.7 times that of the adult animals respectively. Fattening pigs here means all pigs defined as such and weanlings. The manure production of sows and adult boars is equal to that of 2.5 pig places. Breeding sows produce about 1.25 times as much manure as fattening pigs. The manure production of laying hens less than five months old is taken as 0.3 times that of adult hens.

Table 2. Production and composition of different types of animal manure (from Dutch figures)
Production and composition based on manure ready for use (stored for 1-2 months)

	Production	Dry matter	Organic matter		N	P_2O_5		K_2O	
	kg	%	%	%	kg	%	kg	%	kg
Cattle slurry[1]	20,200	95	60	4.4	89	2.0	40	5.0	100
Pig slurry[2]	1,600	80	63	7.0	11.2	4.7	7.5	4.0	6.4
Poultry slurry[3]	80	160	115	9.0	0.72	9.4	0.75	4.5	0.36
Poultry manure (solid)[3]	40	322	230	12.5	0.50	18.7	0.75	9.0	0.36
Broiler manure (solid)[4]	7	560	460	23.0	0.16	21.0	0.15	16.0	0.11
Calf slurry[5]	2,200	20	15	3.0	6.6	1.3	2.9	2.4	5.3

1) one adult cow per year

2) per pig place = 2.2 animals delivered per year

3) one laying hen per year

4) per broiler place = 5.5 broilers delivered per year

5) per fattening calf place = 2.2 calves delivered per year

The production and composition of animal manure depends not only on the animal species but also on the feed and the system of manure collection and storage. The differences in the relevant data appearing in the literature may be due to variations in these factors.

The degree of dilution with water in the case of slurry and of drying of solid manure is an important factor in the composition, as well as the period of decomposition of solid manure. This gives rise to variations in the dry matter content and mineral composition of the manure which can only be determined by sampling. The average composition is thus subject to substantial variations. The production per animal of most of the elements in the manure can be calculated relatively accurately from the quantity of feed eaten during the growth period. In the case of nitrogen only, considerable variations may be caused by differences in nitrogen volatilization due to the method of manure collection, storage and treatment. Losses are substantially less with mixed than with separate storage.

In the latter case they increase with the amount of bedding material used. The nitrogen content may also be greatly reduced where slurry is aerated for odour control and by the various forms of biodegradation.

All this means that, depending on working conditions, the manure composition may differ substantially from the Dutch averages given in Table 2, particularly as regards nitrogen.

The figures in Table 2 can be used to calculate the cattle equivalents for the manure of other animal species for the various constituents (see Table 3).

Table 3. Cattle equivalents for manure of other animal species calculated for the different constituents.

	Cattle (one adult animal)	Pig slurry (number of pig places)	Poultry manure (number of laying hens)	Broiler manure (solid) (number of broiler places)	Calf slurry (number of fattening calf places)
Dry matter	1.0	14.8	148	485	44
Organic matter	1.0	11.9	130	373	37
N	1.0	7.9	121[1] 176[2]	546	13.3
P_2O_5	1.0	5.3	53	272	14.0
K_2O	1.0	15.6	278	893	18.9

1) slurry

2) solid manure

The efficiency of nitrogen in animal manure is less than that of chemical fertilizers, for the following reasons. Part of the nitrogen in animal manure is present in the form of ammonium and can readily volatilize. Application of animal manure in autumn and winter, as often practised for reasons of labour economy and lack of storage capacity, leads to additional losses due to leaching. Another part of the nitrogen is present in the organic fraction and is liberated from this only after mineralization. Where this occurs after the plant has completed its nitrogen uptake, the nitrogen liberated is not effective and subsequent crops benefit only partially from it. Finally, part of the nitrogen is fixed in the humus which is formed. Eventually, however, the soil attains an equilibrium, after which the humus content no longer increases. Thereafter, the amount of nitrogen fixed in the humus is equal to that liberated from the humus by mineralization. It is estimated that over 70% of the equilibrium level is achieved after 20 years, and approximately 90% after 40 years.

The nitrogen efficiency of animal manure relative to that of chemical fertilizers is indicated by the "efficiency index". To calculate this index, it is assumed that the total quantity of nitrogen (N_t) in animal manure is made up of three fractions: a mineral fraction N_m (NH_4-N; urea and uric acid), an organic fraction N_e which is mineralized in the year of application, and a residual organic fraction N_r whose nitrogen is liberated only in the course of the subsequent years. For cattle slurry, N_m is equal to 0.4 N_t (Kolenbrander and De La Lande Cremer, 1967). According to Kolenbrander (1974), half the organic matter applied, which includes half the organically bound nitrogen (0.3 N_t), is mineralized in the year of application.

The fractions N_e and N_r are thus equal to 0.3 N_t. The partitioning of nitrogen into the three fractions for other types of manure is set out in Table 4, which makes use of data from purification plants in which manure is broken down biologically. The fraction remaining in the purification sludge is regarded as not readily decomposable and is taken as equivalent to N_r.

Table 4. Partitioning of nitrogen in animal manure into the fractions N_m, N_e and N_r (percentages)

Type of manure	N_m	N_e	N_r	Source
Cattle slurry	40	30	30	Kolenbrander and De la Lande Cremer (1967)
Pig slurry	50	22	28	(unpublished)
Poultry slurry	70	20	10	Van Dijk (1975), Ten Have (1971)
Calf slurry	80	9	11	Van Faassen (1975) Ten Have (1971)
Pig liquid manure	94	3	3	Ten Have (1971)

Since these figures are only approximate, N_e will be taken as equivalent to N_r for each type of manure in the subsequent calculations.

1.1.1. Application in spring[1]. Of the fraction N_m (0.40 N_t for cattle slurry), 20% is lost on application (less in the case of direct injection of slurry or liquid manure). The remaining 80% ($0.80 \cdot 0.40\ N_t = 0.32\ N_t$) is just as effective as chemical fertilizer. Of the fraction N_e (0.30 N_t), only the part already mineralized during the growth period is available for the crop. For cereals, which have a short growth period, this is estimated at 50%; for potatoes, beets, and maize, it is put at 70%. If an average of 60% is assumed, $0.60 \cdot 0.30\ N_t = 0.18\ N_t$ is thus available for the crop. The remaining 40% of N_e is lost after the harvest or remains for the following crop. According to figures presented by Van der Paauw and Ris (1963), the residual effect under Dutch conditions is about 13.5%; i.e. for cattle slurry, $0.135 \cdot 0.40\ N_e$ or $0.135 \cdot 0.40 \cdot 0.30\ N_t = 0.015\ N_t$. Of the fraction N_r, finally, when the humus content has reached equilibrium, $N_r = 0.30\ N_t$ is liberated annually. This fraction then behaves in the same way as N_e, i.e. 0.18 N_t becomes available for the first crop and 0.015 N_t for the next. Summation of the above fractions of N_t gives a nitrogen efficiency index in cattle slurry of $0.32 + 0.18 + 0.015 + 0.18 + 0.015 = 0.71$. With long-term, annual application of this manure, therefore, the nitrogen efficiency is thus 71% of that of chemical fertilizer nitrogen applied in spring.

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[1] For clarity, the method of calculation used here is shown diagrammatically on page 16.

In general the efficiency index (spring application) can be calculated from the formula $N_{ei} = 0.80\ N_m + 0.30\ (N_t - N_m)$ (first year); in the equilibrium condition the formula becomes $N_{ei} = 0.80\ N_m + 0.65\ (N_t - N_m)$.

The method of calculating the efficiency index of nitrogen for other types of manure is shown in Table 5.

The indices vary widely in the year of application, but not in the long term. Assumption of an average value of 75% for the long-term indices is quite acceptable.

N_t (total nitrogen) *

N_m

Mineral nitrogen

N_e

Mineralized nitrogen in the first year

N_r

Residual nitrogen available in equilibrium condition

Spring application

0,20	NH_3 volatilization on application
0,80	available for plant

0,60	for plant
0,40	0,4 x 0,135 = 0,05 for plant (residual activity)
	0,4 x 0,665 = 0,27 leaching
	0,4 x 0,20 = 0,08 denitrification

0,60	for plant
0,40	0,4 x 0,135 = 0,05 for plant (residual activity)
	0,4 x 0,665 = 0,27 leaching
	0,4 x 0,20 = 0,08 denitrification

Autumn application (about 1 November)

0,20	NH_3 volatilization on application
0,80	0,8 x 0,40 = 0,32
	0,8 x 0,40 = 0,32
	0,8 x 0,20 = 0,16

0,20 autumn	0,2 x 0,4 = 0,08 for plant
	0,2 x 0,4 = 0,08 leaching
	0,2 x 0,2 = 0,04 denitrification
0,80	0,8 x 0,6 = 0,48 for plant
	0,8 x 0,4 x 0,135 = 0,05 for plant (residual activity)
	0,8 x 0,4 x 0,665 = 0,21 leaching
	0,8 x 0,4 x 0,20 = 0,06 denitrification

0,60	0,6 for plant
0,40	0,4 x 0,135 = 0,05 for plant (residual activity)
	0,4 x 0,665 = 0,27 leaching
	0,4 x 0,20 = 0,08 denitrification

* For partitioning into N_m, N_e and N_r, see Table 4.

Table 5. Calculation of the efficiency index of N_t in animal manure

Structure of efficiency index	Slurry				Liquid Manure
	Cattle	Pigs	Chickens	Calves	
First year : $0.8 \cdot N_m$	0.32	0.40	0.56	0.64	0.75
First year : $0.6 \cdot N_e$	0.18	0.15	0.09	0.06	0.02
Subtotal, first year	0.50	0.55	0.65	0.70	0.77
Residual activity, first year ($0.05 \cdot N_e$)	0.015	0.01	0.01	0.005	0.00
Long-term effect ($0.6 \cdot N_r$)	0.18	0.15	0.09	0.06	0.02
Residual activity of long-term effect $0.05 \cdot N_r$)	0.015	0.01	0.01	0.005	0.00
Total effect	0.71	0.72	0.76	0.77	0.79

1.1.2. Autumn application[1]. Of the fraction 0.08 N_m remaining after volatilization in cattle slurry (0.32 N_t) when applied about 1 November, it is estimated that 40% is lost by leaching and 20% by denitrification, so that $0.4 \cdot 0.32\ N_t = 0.13\ N_t$ remains. The leaching percentage of 40 is based on data presented by Kolenbrander (1969). Of the fraction N_e (0.30 N_t), a further portion (e.g. 20%) can be mineralized in the autumn, 60% of the nitrogen liberated being lost by leaching and denitrification. The balance is then $0.30 \cdot 0.20 \cdot 0.40\ N_t = 0.02\ N_t$. The non-mineralized fraction of N_e (80%) behaves as if the manure had been applied in the spring and thus has an efficiency of 0.8 (0.18 + 0.015 N_t) = 0.16 N_t. The fraction N_r also behaves in the same way as with manure application in the spring, the activity thus being (0.18 + 0.015) N_t. Summation of the fractions of N_t gives an efficiency index for nitrogen in cattle slurry of 0.13 + 0.02 + 0.16 + 0.195 = 0.50. Efficiency indices of 0.48, 0.41, 0.38 and 0.34 have been calculated for pig slurry, poultry slurry, calf slurry and liquid manure respectively. An average efficiency index of 45% is assumed below, where manure is applied annually in autumn.

The general formula for the efficiency index of N in the case of autumn application is $N_{ei} = 0.32\ N_m + 0.28\ (N_t - N_m)$ for the first year after application and $N_{ei} = 0.32\ N_m + 0.63\ (N_t - N_m)$ for the equilibrium condition. It is assumed here that $N_e = N_r$.

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[1] See note to Section 1.1.1.

To satisy a nitrogen requirement of 100 kg N in the form of chemical fertilizer, according to the foregoing, 100 ÷ 75 · 100 = 133 kg N in the form of animal manure must be applied in the case of spring application and 100 ÷ 45 · 100 = 222 kg N animal manure in the case of autumn application. Table 6 sets out the equivalent quantities of manure (in tonnes) of the different types of animals, the relevant stocking rates, and the total quantities of nutrients applied. The amounts given in Table 6 are based on the figures presented in Table 2. Changes in the treatment of the manure and feed of the animals could result in different levels and different permissible quantities of animal manure.

Thus, given separate storage of solid and liquid manure, in which case losses of N are greater than with mixed storage, a higher stocking intensity could be permissible. However, this also exposes the soil to a heavier load of P, Cu and other manure constituents, contrary to the intention of possible official regulations. This can be prevented by defining the term "cattle equivalent (nitrogen)" as the annual nitrogen production of one livestock unit (LU)1), i.e. one adult cow, in the form of untreated slurry, assuming a normal storage period of 1-2 months during the winter (housed) period. Production on an annual basis, calculated from the figures for the 180-day winter period, amounts to 89kg N, which is in good agreement with the sum of the totals of the winter period and the grazing season (87 kg N); see also Kolenbrander and De La Lande Cremer (1967).

The figures in Table 6 make calculation possible of the permissible quantities of manure and stocking rates for the different animal species with different cropping systems. In the case of cropping systems with cereals only, these figures roughly correspond to the values set out in Table 6; in systems with root and tuber crops (and maize) only, the values should be doubled.

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1) See also definitions in Appendix III.

Table 6. Quantities of animal manure equivalent to 100 kg N in the form of chemical fertilizer for nitrogen efficiency indices of 75% and 45%, the corresponding stocking rates per ha, and amounts of P_2O_5 and K_2O applied (efficiency index 100%)

Type of manure	Amount (t)		Total N (kg)		P_2O_5 (kg)		K_2O (kg)		Stocking rate	
	Efficiency index N									
	75%	45%	75%	45%	75%	45%	75%	45%	75%	45%
Cattle slurry[1]	30	50	132	220	60	100	150	250	1.5	2.5
Pig slurry[2]	19	32	133	224	89	150	76	128	12	20
Poultry slurry[3]	15	25	135	225	141	235	68	112	188	312
Poultry manure (solid)[3]	11	18	138	225	206	337	99	162	275	450
Broiler manure (solid)[4]	6	10	138	230	126	210	96	160	860	1430
Calf slurry[5]	44	74	132	222	57	96	106	178	20	34

[1] number of cattle; annual basis

[2] number of pig places

[3] number of laying hens

[4] number of broiler places

[5] number of fattening calf places

In practice, manure will normally be spread not only in autumn or spring but throughout the period between these seasons. In this case manure amounts and stocking rates must be calculated for an efficiency index of 60%.

1.2 Grassland

On grassland, excessive manuring with potassium, especially at high nitrogen doses, can adversely affect the mineral composition of the grass with respect to magnesium and calcium. Magnesium deficiency can lead to hypomagnesemia in cattle, for which, however, preventive measures are available. Nevertheless, the permissible quantities of animal manure on grassland should obviously be matched to the mineral composition of the grass, for which potassium is the limiting factor, and not to herbage production.

During the grazing period, the grassland is manured, if unevenly, with the potash present in feces and urine. This potash must be supplemented by a quantity depending on the potash content of the soil, the type of soil and the cutting frequency.

To provide roughage over a 180-day winter feeding period, 0.4 ha per LU is cut (In the Netherlands). A maximum cutting frequency of 1.2 times per annum is considered feasible, so that a stocking rate of 3 LU is possible without buying roughage.

If the potash status of the soil is good and the grassland is used exclusively for grazing, an additional 60 kg K_2O per ha on sandy soil and 20 kg per ha on clay soil is recommended. A further 80 kg K_2O must be added each time the grass is cut. Together with the potash accruing to the land during grazing from feces and urine, the total requirement is thus :

for sandy soil : $60 + 0.4\ LU \cdot 80 + 50\ LU$ and
for clay soil : $20 + 0.4\ LU \cdot 80 + 50\ LU$ kg K_2O per ha.

In this formula, LU is the number of LU of cattle per ha of grassland. The term 50 LU is the number of LU multiplied by the potash production per LU in a 180-day grazing period. For a stocking rate of, for instance, 2 LU per ha of grassland, the formulae thus give a total K requirement of 224 kg K_2O on sandy soil and 184 kg on clay soil.

If the animals are housed for a shorter or longer period than the 180 days mentioned above, this has no effect on the total potash requirement, which is made up of a basal dressing to compensate for, in particular, leaching losses and a dose to offset the amount of potash removed with the grass consumed by the animals (whether grazing or housed). If it is assumed that the cow, when housed, consumes just as much grass as it would if it were grazing on the same day, it makes no difference to the potash requirement whether the animals are housed in summer or not. Hence the above formulae are also valid for grazing seasons that are longer or shorter than 180 days.

Part of the manure produced on livestock farms will be applied in autumn and winter, so that potash is liable to be lost by leaching. Assuming that 25% of the total annual production is applied in autumn and winter and that

25% of this leaches out on sandy soil (nil on clay), the manurial value of the potash in cattle slurry will be 0.75 · 1.0 + 0.25 · 0.75 = 0.94 for livestock farms on sandy soil (annual basis). The equivalent figure for clay soil is 1.0.

These considerations are summarized in Table 7 for different stocking rates.

Table 7: Relationship between stocking rate and potash requirement of grassland (kg K_2O)

Cattle stocking rate per ha	Total K requirement on sandy soil	K requirement on clay	Annual production in manure	Effective K in annual production	
				Sandy soil	Clay soil
1	60 + 0,4.1.80 + 50.1 = 142	102	100	94	100
1,5	60 + 0,4.1,5.80 + 50.1,5 = 183	143	150	141	150
2	60 + 0,4.2.80 + 50.2 = 224	184	200	188	200
2,5	60 + 0,4.2,5.80 + 50.2,5 = 265	225	250	235	250
3	60 + 0,4.3.80 + 50.3 = 306	266	300	282	300

The table shows that with a stocking rate of 1 LU per ha, 48 kg K_2O per ha (on sandy soil) can be accommodated in addition to the potash in the manure of the farm's own cattle (produced both during the housed period and when grazing). At higher rates the margin decreases, becoming negative at about 3.5 LU.

The limit of self-sufficiency in roughage is reached at a stocking rate of 3 LU per ha. At higher rates, not only an increasing quantity of concentrates but also roughage must be purchased. The changed feeding regime (relatively more concentrates) increases potash production in the manure to more than 100 kg K_2O per animal on an annual basis.

Clay soils can accommodate only the manure of the farm's own herd even at low stocking rates.

The margin mentioned above, which thus exists only on sandy soil, can be made up with K from chemical fertilizer or other animal manure. Table 8 shows the amounts of supplementary manure from different animal species that can be applied to grassland, assuming that the primary potash requirement is met from the farm's own cattle manure production.

Table 8: Supplementary quantities of animal manure that can be accommodated on grassland (sandy soil), and the corresponding number of animals or animal places (annual basis)

Cattle stocking rate per ha	K_2O requirement kg/ha net	Pig slurry		Poultry manure		Broiler manure(solid)		Calf slurry	
		t/ha	number of pig places	t/ha (1)	number of laying hens	t/ha	number of broiler places	t/ha	number of calf places
1 LU	48	13	8	5	130	3,0	430	20	9
2 LU	36	10	6	4	100	2,2	320	15	7
2,5 LU	30	8	5	3	80	1,9	270	13	6
3 LU	24	6	4	3	70	1,5	210	10	5

(1) Solid manure; the amounts are twice as high for slurry. The number of laying hens is the same in both cases.

The amounts of animal manure set out in Table 8 can be increased by, for example, 50% if the preventive measures against hypomagnesemia are considered acceptable; this is already done in the case of heavy applications of nitrogen. Since measures to prevent hypomagnesemia must normally be taken on clay soils anyway, practical experience suggests that in this case too - although no potassium is required - the application of 10 tonnes of pig slurry (40 kg K_2O) per ha (or equivalent quantities of calf or poultry manure) is acceptable.

The phosphorus requirement of grazed-only grassland is estimated at 25 kg P_2O_5 per ha if the soil phosphorus status is good (for all types of soil in the Netherlands). This amount should therefore be applied in addition to the quantity of phosphorus accruing to the land with the feces and urine, which is estimated at 20 kg P_2O_5 per LU over a 180-day grazing period. An additional quantity of about 30 kg P_2O_5 per ha is considered necessary each time the grass is cut. Analogous to the calculation for potash, the phosphorus requirement for grassland can be expressed by the formulae:

$$25 + 0.4\ \mathrm{LU} \cdot 30 + 20\ \mathrm{LU} \qquad \text{in kg } P_2O_5 \text{ per ha}$$

This yields the figures set out in Table 9.

Table 9: Relationship between stocking rate and phosphorus requirement of grassland (kg P_2O_5 per ha)

Cattle stocking rate per ha	Total P_2O_5 requirement	Annual production in manure (1)
1	25 + 0,4 . 1 . 30 + 20 = 57	40
1,5	25 + 0,4 . 1,5. 30 + 30 = 73	60
2	25 + 0,4 . 2 . 30 + 40 = 89	80
2,5	25 + 0,4 . 2,5. 30 + 50 = 105	100
3	25 + 0,4 . 3 . 30 + 60 = 121	120

(1) Efficiency index 100%

Where the stocking rate exceeds 2.5 LU per ha of grassland, no extra phosphorus need thus be applied. At lower stocking intensities, the requirement is in the order of 10-20 kg P_2O_5 per ha. The figures in Table 9 apply when the cattle are out on pasture in summer as well as when the system of zero-grazing (1) is used.

The nitrogen requirement of grassland is complicated, being determined by the stocking rate, the system of grazing, the method of obtaining roughage, and the use of concentrates, among other factors. Table 10 gives an overall impression of the nitrogen requirement for different stocking rates, the figures having been taken from a study of 18 grassland farms on clay soil (Tiesema, 1975). Of course, stocking rates of more than 1 LU per ha quoted for the different doses of N from chemical fertilizer are possible only if concentrates are used. Note, too, that the applications of chemical fertilizer N are given in addition to the cattle manure, at the rate of 89 kg N per LU (annual basis), with an efficiency index of 75% relative to chemical fertilizer, as explained below in more detail.

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(1) See Appendix III

Table 10: Consumption of chemical fertilizer N, starch equivalent production and starch equivalent requirement at different stocking rates

Stocking rate/ha	Starch equivalent requirement(kg/ha)	N dose (kg/ha)	Starch equivalent production (kg/ha)
1,0 LU	2800	0	2800
1,5 LU	4200	100	3400
2,0 LU	5600	200	4100
2,5 LU	7000	300	4600
3,0 LU	8400	400	5200

Tiesema (1975) also shows that when about 300 kg N per ha is applied, the starch equivalent production may vary from 4 200 to 5 500 kg per ha. The starch equivalent yield increases as grazing is limited (less trampling), especially at high stocking rates.

Grassland in the Netherlands under normal conditions is generally assumed to be capable of producing 5 000 kg of starch equivalent (about 10 tonnes of dry matter) per ha, which is sufficient for 1.8 LU. Finally, Table 11 sets out the starch equivalent requirement for different stocking rates, the potential production of grassland, and the amount of starch equivalent required to be purchased in the form of concentrated feeds (1 200 kg per LU is normally used) and silage maize.

Table 11: Starch equivalent requirement at different stocking rates, grassland production, and starch equivalent purchase requirement

	Number of LU per ha				
	1,5	2,0	2,5	3,0	3,5
Starch equivalent requirement (kg/ha)	4200	5600	7000	8400	9800
Starch equivalent production (kg/ha)	5000	5000	5000	5000	5000
Starch equivalent purchase requirement (kg)	-	600	2000	3400	4800
Starch equivalent of 1 200 kg of concentrate (per LU) (kg) (1)	1170	1560	1950	2340	2730
Balance of starch equivalent requirement (kg)	-	-	50	1060	2070
Conversion to kg of silage maize (2)	-	-	320	6800	13300

1) 650 g starch equivalent per kg product

2) 156 g starch equivalent per kg product

Although not relevant to the establishment of criteria, an analysis of the nitrogen efficiency of animal manure is given below (see page 26).

1.2.1. Spring application

An estimated 20% of N_m is lost by volatilization of ammonia during the application of animal manure. Another 12% or so on average is lost by volatilization because the manure lies on the surface and cannot be ploughed under in grassland; this is the "urea effect", so-called because it also occurs when urea is used. The remaining 68% of N_m is just as effective as nitrogen from chemical fertilizer.

The plant can utilize 90% of the fraction N_e in permanent grassland. The remaining 10% is not utilized in the first year because crop growth has then ceased (see figure 2). Of this 0.10 N_e, 40% is lost by leaching and 20% by denitrification (both during winter), so that the residual activity is $0.10 \cdot 0.40 = 0.04\ N_e$.

N_r behaves in exactly the same way as N_e: 90% becomes available during the growing season and $0.10 \cdot 0.40 = 0.04\ N_r$ becomes available as residual activity in the following year. Hence, in the case of annual application in spring, the long-term total nitrogen efficiency index is $0.68\ N_m + 0.90\ N_e + 0.04\ N_e + 0.90\ N_r + 0.04\ N_r$. The formula can also be written $N_{ei} = 0.68\ N_m + 0.94\ (N_t - N_m)$. For cattle slurry (see Table 4) this gives an efficiency index of $0.68 \cdot 0.40 + 0.94 \cdot 0.60 = 84\%$; the equivalent figures for pig slurry, poultry slurry and calf slurry are 81%, 76% and 73% respectively.

N_t (total nitrogen)

N_m N_e N_r

Spring application

N_m	
0,20	NH_3- volatilization on application
0,12	urea effect
0,68	for plant

N_e	
0,90	for plant
0,10	0.1 · 0.40 for plant (residual activity)
	0,1·0,40 leaching
	0,1·0,20 denitrification

N_r	
0,90	for plant
0,10	0.1 · 0.40 for plant (residual activity)
	0,1·0,40 leaching
	0.1·0.20 denitrification

Autumn application

N_m	
0,20	NH_3- volatilization on application
0,12	urea effect
0,68	0,68·0,40 for plant
	0,68·0,40 leaching
	0,68·0,20 denitrification

N_e	
0,20	0,2·0,40 for plant
	0,2·0,40 leaching
	0,2·0,20 denitrification
0,80	0,8·0,90 for plant
	0.8 · 0.10 · 0.40 for plant (residual activity)
	0.8·0,10·0,40 leaching
	0,8·0,10·0,20 denitrification

N_r	
0,90	for plant
0,10	0.1 0.40 for plant (residual activity)
	0,1·0,40 leaching
	0,1·0,20 denitrification

Grazing season

N_m	
0,20	NH_3- volatilization on application
0,30	urea effect
0,25 av. 15/5	for plant
0,25 av. 15/8	0,25·0,70 for plant
	0,25·0,10 leaching
	0,25·0,20 denitrification

N_e	
0,50 1st year	0,50–0,10 for plant
	0.10 · 0.40 for plant (residual activity)
	0,10·0,40 leaching
	0,10·0,20 denitrification
0,50 2nd year	0,5·0,90 for plant
	0.5 · 0.10 · 0.40 for plant (residual activity)
	0,5·0,10·0,40 leaching
	0,5·0,10·0,20 denitrification

N_r	
0.90	for plant
0.10	0,1·0,40 for plant (residual activity)
	0,1·0,40 leaching
	0,1·0,20 denitrification

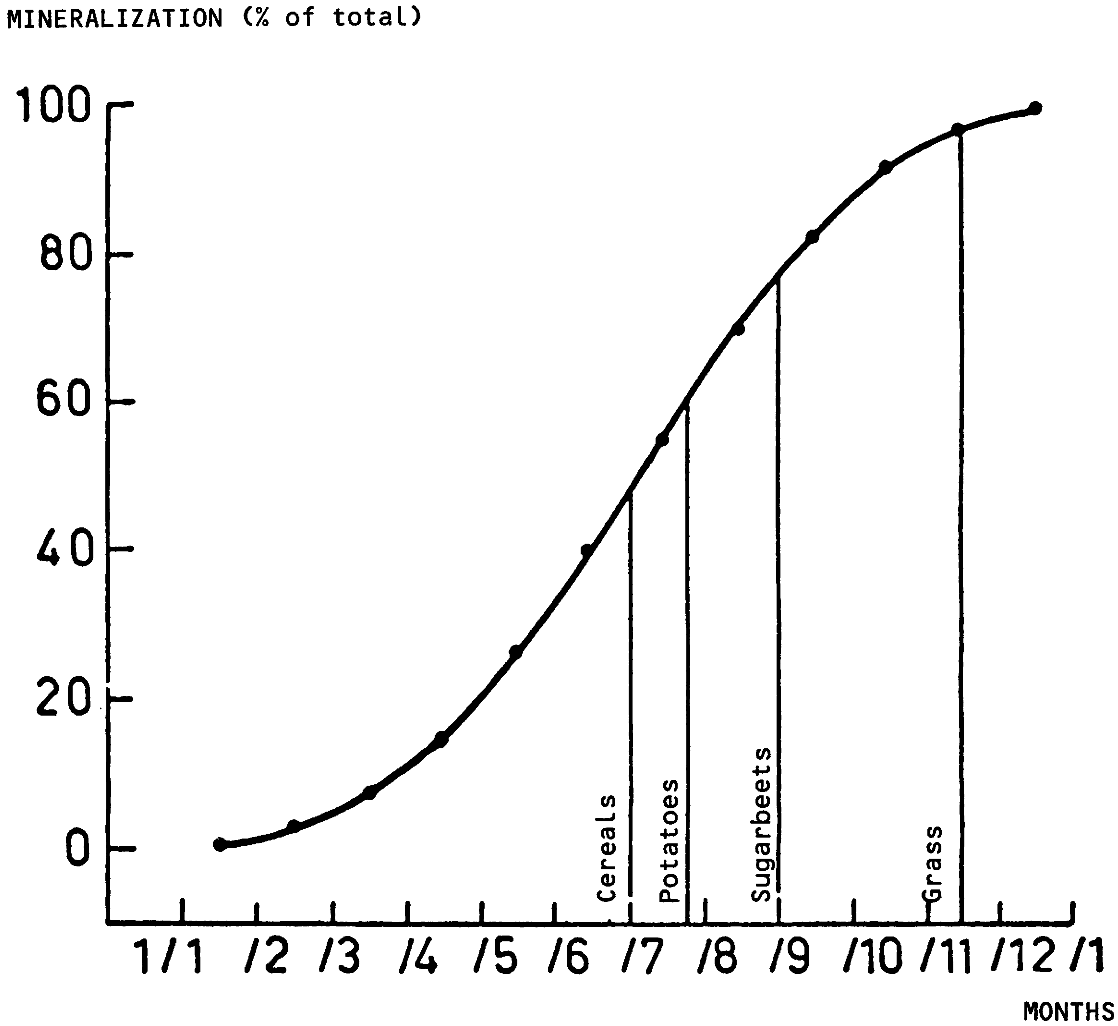

Figure 2: Course of mineralization of organic matter as a fraction of total mineralization (Sluijsmans and Kolenbrander, 1976).

1.2.2. Autumn application

Of the 68% of N_m remaining after volatilization, 40% is lost by leaching and 20% by denitrification, so that $0.68 \cdot 0.40 = 0.272\ N_m$ remains for the crop.

Of the fraction N_e, a further 20% mineralizes in the autumn, 60% being lost by leaching and denitrification. The remainder is $0.20 \cdot 0.40 = 0.08\ N_e$, which becomes available to the grass in the spring. The fraction N_e not mineralized in the autumn behaves as if it had been applied in the spring. Of this fraction, 90% becomes available in the growing season ($0.80 \cdot 0.90 = 0.72\ N_e$). The remaining 10% mineralizes after the growing season and 60% of it will be lost by leaching and denitrification in winter. The residual activity in the following year is then $0.80 \cdot 0.10 \cdot 0.40 = 0.032\ N_e$. The fraction N_r behaves in exactly the same way as N_e in spring application, 90% becoming available during the growing season and 40% of the remaining 10% as residual activity in the following year. Hence the integral nitrogen efficiency index of animal manure when applied to grassland in the autumn is:

$$0.272\ N_m + 0.08\ N_e + 0.72\ N_e + 0.032\ N_e + 0.90\ N_r + 0.04\ N_r =$$
$$0.272\ N_m + 0.832\ N_e + 0.94\ N_r$$

Assuming that $N_e = N_r$, this formula can also be written as follows:

$$N_{ei} = 0.272\ N_m + \frac{0.832 + 0.94}{2}(N_t - N_m) \text{ or } 0.272\ N_m + 0.886\ (N_t - N_m).$$

For cattle slurry (see Table 4) this gives an efficiency index of $0.272 \cdot 0.40 + 0.886 \cdot 0.60 = 64\%$; the equivalent figures for pig slurry, poultry slurry and calf slurry are 58%, 46% and 39% respectively.

1.2.3. Excretion by the animal during the grazing season

During the grazing season about 20% of N_m is immediately lost by volatilization of ammonia. In addition, if the excreta lie on the surface, about 30% more on average is lost during the summer as a whole through the urea effect. This value is considerably higher than the 12% for spring or autumn application owing to the higher summer temperatures. Assuming that the grazing season extends from 1 April to 1 October, 15 May can be taken as the average date on which all manure in the first half of this period is produced. The part of N_m remaining after volatilization is then completely available to the grass, i.e. $1/2 \cdot 0.50 = 0.25\ N_m$. The average date of manure produced in the second half of the grazing season is 15 August. On that date leaching already occurs (see figure 5), estimated at 10% of the N_m still remaining. A denitrification loss of 20% will also occur. The balance remaining for the crop is then $1/2 \cdot 0.50 \cdot 0.70 = 0.175\ N_m$. Hence $0.25 + 0.175 = 0.425\ N_m$ is available over the grazing season as a whole. To calculate the N efficiency index of N_e, it is assumed that all the manure excreted in the grazing season arises on the average date of 1 July. The annual mineralization curve (figure 2) indicates that only 50% of the fraction N_e can still be mineralized in that year. Further, because the last 10% falls outside the growing season, 40% of N_e is available to the grass during the relevant year. Of the nitrogen mineralized after the growing season, 60% is subject to leaching and denitrification during the winter, so that the residual activity is $0.10 \cdot 0.40 = 0.04\ N_e$. The other 50% of the N_e is mineralized only in the following year and 90% of this is then available for the crop. The remaining 10% provides a residual activity of $0.50 \cdot 0.10 \cdot 0.40$, or 2%, in the second year.

Once again, N_r behaves in the same way as N_e applied in spring. Hence a total of 94% of N_r is available to the crop.

Hence the integral nitrogen efficiency index of the manure excreted by the animal during the grazing season is:

$$N_{ei} = 0.425\ N_m + 0.40\ N_e + 0.04\ N_e + 0.45\ N_e + 0.02\ N_e + 0.94\ N_r$$

$$\text{or } N_{ei} = 0.425\ N_m + 0.925\ (N_t - N_m).$$

Calculation using Table 4 shows that the nitrogen efficiency index of cattle slurry during the grazing season is $0.425 \cdot 0.40 + 0.925 \cdot 0.60$ or 73%.

Assuming that half of the animal manure produced in the housed period is applied in the autumn and half in the spring, the average integral nitrogen efficiency index is as follows:

cattle slurry (including grazing season)	$(\frac{84 + 64}{2} + 73) \div 2 = 74\%$
pig slurry (no grazing period)	$(81 + 58) \div 2 = 70\%$
poultry slurry (no grazing period)	$(76 + 46) \div 2 = 61\%$
calf slurry (no grazing period)	$(73 + 39) \div 2 = 56\%$

2. Use of animal manure and soil pollution

This section discusses whether animal manure presents a soil pollution hazard and, if so, in what amounts. The soil will be deemed to be polluted if it undergoes changes of such a kind that the possibilities for crop production are substantially and adversely affected quantitatively and/or qualitatively over a period of many years or if the soil is in any other way put into a condition which severely impedes normal farm management. The discussion covers the effect of manure application on soil contents of organic matter, nitrogen, phosphorus, potash, copper and zinc and on pH, and the significance to farm management of the changes occurring.

2.1 Content of organic matter in the soil

Given a constant supply of organic matter over the years, the content of soil organic matter (humus) eventually reaches an equilibrium level. A change in the supply, e.g., through increased use of farmyard manure, leads to a new equilibrium level. It is then necessary to consider the extent to which this differs from the original level and the consequences to soil fertility. Kortleven (1963) showed that an increase in the level of residual organic matter under the influence of an annual application of x units of fresh organic matter can be described by the formula

$$s_t = s_{max} (1 - e^{-mt})$$

in which s_t represents the increase in humus content after t years, s_{max} the increase from the original to the equilibrium level, e the base of the natural logarithm and m the coefficient for the rate of humus decomposition; s_{max} is directly proportional to the value of x and also depends on the nature of the material applied.

The most recent research indicates that also the value of m depends on the nature of the organic matter supplied.

Kolenbrander (1974) calculated s_{10} for different values of x for a number of Dutch experimental fields. With annual applications of organic matter in the form of farmyard manure in amounts constituting 1% of the weight of the arable layer, he obtained a value of over 3% (absolute) for s_{10}. Values of

s_{20} and s_{100} of approximately 5% can be calculated from the same experimental field material. The value of s_{max} differs only insignificantly from s_{100}. The test results, obtained under widely varying conditions, show substantial agreement, which suggests a high degree of validity.

The amount of organic matter supplied by manure, of course, depends on the quantity of manure and its content. Adult cows produce approximately 1 200 kg of organic matter in the slurry per year. Table 3 sets out the numbers of other animal species corresponding to this production. Table 12 shows the increase in the humus content of the soil if the manure of, for example, 1.5, 3 and 4.5 adult cows or equivalent numbers of a different animal species is applied annually to 1 ha of arable land. It is assumed that the weight of the arable layer is 3 million kg and that the organic matter in the manure of all animal species breaks down in the soil at the same rate (which is questionable).

Table 12: Increase in the humus content (% absolute) of the soil with annual manuring of 1 ha of arable land

Adult cattle (1)	1.5	3	4.5
Increase after 10 years	0.2	0.4	0.6
Increase after 20 years or more	0.3	0.6	0.9

(1) or equivalent numbers of other animal species (see Table 3).

Changes of this order of magnitude are generally found to be favourable on arable land. The biological and physical aspects of fertility are improved, while the soil is enriched as a supplier of plant nutrients. A subsequent section discusses whether it is possible for the soil to be excessively enriched.

If the manure is applied to permanent grassland, an accumulation of organic matter occurs in the top few centimetres of the soil owing to the absence of tillage. In the layer from 0 to 5 cm, the increase in the humus content may be as much as five times that given in Table 12 for arable land.

At a stocking rate of 1.5 adult cows this is equivalent in the long run to 1.5% (4-5% with 4.5 cows). Such changes may adversely affect the firmness of the sward, especially under wet conditions. Land which is wet by nature because of an excessively high water table (higher than 0.8-1 m below the surface in winter) then becomes less passable in early spring, autumn and winter.

The humus content of a given type of soil under permanent grassland is generally higher than on arable land. As regards supplying organic matter to the soil, farmyard manure should for this reason, and because of the adverse effect on the firmness of the sward mentioned above, preferably be applied to arable land.

2.2. Nitrogen status of the soil

The accumulation of residual organic matter discussed in the previous section is accompanied by formation of a store of nitrogen fixed within it. This nitrogen only becomes available to the plant after a process of mineralization extending over many years. Nevertheless, large doses of animal manure may enrich the soil to such an extent as to prejudice the growing of sensitive crops. To make an evaluation of this risk possible, an indication will be given of the expected increase in the nitrogen content of the soil and the resulting effect of the supply of nitrogen to the crops.

According to Table 12 in the previous section, annual application of the manure of 1.5 adult cows to 1 ha of arable land eventually increases the humus content of the top layer by about 0.3%. The C content of this organic matter will be between that of fresh organic material (50%) and that of soil humus (58%). The C/N ratio was determined by Van Dijk (1968) for the mineralizable organic matter in sandy soil with 3-4% organic matter and found to average 15.5.

Hence the manure of 1.5 cows increases the nitrogen content by $0.3 \cdot 0.54 \cdot \frac{1}{15.5}$ = approximately 0.01% absolute. This represents 300 kg N in an arable layer weighing $3 \cdot 10^6$ kg. At higher stocking rates the increase is, of course, proportionately larger. It is difficult to say whether a corresponding increase in the nitrogen level occurs with the manure of other types of animals if applied on the basis of equal quantities of organic matter (see previous section). The value of 300 here is more likely to be too high than too low.

As long as the humus content is still increasing owing to applications of organic matter, the nitrogen content of the soil also increases. Eventually, if the same manuring regime is always followed, the nitrogen content will also reach an equilibrium. In this condition just as much nitrogen is mineralized from the stock in the soil as is added to it. This quantity can be fairly easily predicted. The nitrogen in the manure can be regarded as composed of three fractions differing in mineralizability (see Section 1). Nitrogen present as ammonia, urea and uric acid is almost totally mineralized. In cattle slurry this fraction amounts to 40% of the nitrogen present according to Kolenbrander and De La Lande Cremer (1967). Half of the remaining nitrogen is considered not readily mineralizable. This fraction will be added to the soil and thus contains about 30% of the total nitrogen present in the manure. The remaining 30%, also bound in organic form, is already mineralized in the year of application.

In the equilibrium condition, the amount liberated from the soil annually is equal to the supply - i.e., to 30% of the nitrogen supplied by the manure. With a stocking rate of 1.5 adult cows per ha, this amounts to $1.5 \cdot 89 \cdot 0.30 = 40$ kg N per ha. The corresponding figures for 3 and 4.5 adult cows are 80 and 120 kg N per ha respectively.

When assessing these quantities in the context of soil pollution, it should be remembered that the nitrogen liberated from the organic matter is less effective to the plant than the readily available nitrogen applied in spring (see also Section 1), as part of it is liberated only after the plant's uptake has been completed. Early-harvested crops such as cereals will therefore benefit less from this nitrogen than late-harvested ones such as potatoes, beets or maize. We estimate that only 50% is available for cereals, about 70% for potatoes and beets, and 95% for ley. This means that a stocking rate of 1.5 or 4.5 adult cattle per ha will eventually give rise to a soil that supplies to cereals an additional 20 and 60 kg N (calculated as chemical fertilizer equivalents) respectively each year from its residual reserve. This gives no cause for alarm even for crops such as these, which are sensitive to excess nitrogen, as generally higher doses are applied in the form of chemical fertilizer. Soil pollution thus does not arise at such stocking rates; rather, the soil is enriched with nitrogen. (If the manure of 4.5 cows is applied annually, the total N supply to the crop from this manure amounts to 180-300 kg effective N per ha per annum. This is too much for cereals, but does not permanently limit the possibilities for cereal production).

The figures must probably be slightly modified for manure from other animals, but if this manure is applied on the basis of the same supply of organic matter as stated above for cattle, the final conclusion will be the same.

2.3. Phosphorus levels in the soil

If a given fertilization regime is changed to higher phosphorus applications, the result will be an increase in the phosphorus level of the soil. Both the total content and the amount of phosphorus available to the plant increase until an equilibrium condition is reached, whose level strongly depends on the amounts applied. Not enough is yet known to enable us to state after how long a period and at what level equilibrium will be established for different soils. The following table is based on partly published data from Prummel (1974) taken from field trials on arable land with superphosphate over periods of five to ten years.

Table 13: Annual changes in total P (mg P_2O_5/100 g soil) and P_w value (mg P_2O_5 per litre of soil when extracted with water) due to phosphorus fertilization on sandy and clay soils (over 60% cereals in the rotation)

	kg P_2O_5 as superphosphate			
	0	50	100	200
Total P sandy soil (14 tests)	-1,7	-0,2	+1,6	+4,7
Total P clay soil (18 tests)	-0,5	+0,7	+1,9	+4,5
P_w- value sandy soil (21 tests)	-1,3	-0,2	+1,0	+3,5
P_w- value clay soil (19 tests)	-0,8	+0,1	+1,0	+2,9

A quantity of 50 kg P_2O_5 per ha was apparently sufficient to maintain the existing level, roughly coinciding with the average annual quantity removed with the crops. It may thus be expected that little or no increase in the phosphorus level will occur upon application of the manure of 1.5 adult cows (see Table 2) or equivalent numbers of other animals. On permanent grassland, where the soil is not tilled and where the fertility status is normally measured in the top 5 cm, the phosphorus level in this layer may be expected to remain constant at a stocking rate of 3 adult cows per ha. At higher stocking intensities an increase will occur.

The criterion for determining whether this increase is harmful and possibly constitutes soil pollution is whether or not the choice and growth of crops in the long term will remain unimpeded. So far as is known, a high phosphorus level on arable land is never unfavourable to crops. In tests extending over many years, Van Der Paauw (1960) found that yields were at least as high with an annual application of 200 kg P_2O_5 as with only about 50 kg. More caution is necessary in the case of permanent grassland. Isolated instances of a somewhat lower yield at high phosphorus levels have been reported (Pieters, 1971). Also there have been indications that availability of trace elements for cattle in the case of abnormally high phosphorus ingestion is reduced. (Commissie Onderzoek Minerale Voeding TNO, 1970). In both cases, there has been no adequate proof or confirmation. However, these findings do suggest that a more cautious attitude is appropriate than appears justified for arable land.

2.4. Potash status of the soil

The application of a given annual dose leads to equilibrium in the potash status of the soil, this equilibrium generally being reached faster than in the case of phosphorus. The desired level depends on the cropping system and soil characteristics. A lower potash level is sufficient for cereals than for root and tuber crops, while crops on heavy soils require a higher potash content than on light soils. However, less potash is necessary on heavy than on light soils in order to achieve and maintain a good level.

Prummel (1970) shows that an average application of less than 100 kg K_2O per ha is sufficient for arable land on heavy clay soils; an amount of between 100 and 200 kg K_2O is necessary on light clay soils. An average amount of 150 to 200 kg, depending on the rotation, is sufficient on sandy soils.

Applications of 200 kg or more can result in ample to high potash levels on arable land. A high stocking rate may lead to high potash levels also on grassland, as is indicated by the relationship existing between potash status and the distance between the field concerned and the farmstead. Vermeulen (1954) showed that much of the nearby land - which receives more manure than more distant fields - has an absolutely and relatively high level. De Vries (1966) reports that a satisfactory potash level in grassland is maintained at a dose of 150 kg fertilizer K_2O per ha per annum. This result was obtained with standard utilization of grassland, i.e., cutting once followed by grazing, as often practised at a stocking rate of 2.5 LU per hectare of grassland. During the 180-day grazing period, about 125 kg K_2O is dropped on the land in manure and urine, so that the total to maintain the status amounted to 275 kg K_2O per hectare. This is in good agreement with the figure given earlier for sandy soil (Table 7, for sandy soil at 2.5 LU).

On permanent grassland in particular, a high soil level of potash presents a risk of hypomagnesemia at least if the need to take additional preventive measures is considered to be objectionable. On arable land, a high potash level is sometimes considered favourable (for ware potatoes) or at least not disadvantageous, except where industrial potatoes occupy an important place in the rotation. However, there is little justification for regarding this situation as an instance of soil pollution, because an excessively high potash level caused by fertilization can be quickly brought back to normal proportions again by the omission of fertilizer or manure.

2.5. Copper and zinc in pig manure

To increase growth rate and improve feed conversion, copper is added to the feed of fattening pigs in a number of countries. Copper is also considered to have a chemotherapeutic effect. According to standards proposed by the EEC(1), the feed of young slaughter pigs (first to seventh week) may contain no more than 200 mg Cu per kg dry matter, the upper limit for older fattening pigs (eighth to nineteenth week) being 125 mg. Only 1% of the added copper is resorbed, the remaining 99% being excreted with the feces, principally as copper sulphide. The amount of copper that is "recycled" is thus 38 g per pig delivered (110 kg), or 86 g per pig place.

On the basis of the above ration, it can be calculated that the slurry contains about 50 ppm Cu if the dry matter content is 8%. Annual application of pig slurry, e.g., of 20 tonnes per ha(2), will lead to accumulation of copper in the topsoil, as mobility in the soil is slight and the quantity removed with the harvested product is small (50 and 15 g Cu per ha per annum on arable land and grassland respectively - the latter assuming recycling through the grazing animals).

Owing to its low mobility, copper will accumulate on grassland, unless ploughed up, in the 0-5 cm layer and on arable land in the plough layer (Henkens, 1962). This is confirmed by a test performed by Schmid et al. (1972) with copper-containing sewage sludge and by chemical analysis of samples taken from different layers of vineyard soils sprayed with large quantities of copper (Bucher, 1966).

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(1) Not yet implemented.

(2) This quantity is often applied in practice; it is not far from the minimum quantity which can be applied with a vacuum spreader.

According to Batey et al. (1972), 50% of the copper applied in pig manure occurs in a form available to the plant (soluble in EDTA). On arable land and sandy soil, a Cu (EDTA) content of 40 ppm is liable to cause yield reductions in legumes due to excess copper (Purves, 1972). According to Batey (1972), the limit for other arable crops and grass is 80 ppm Cu (EDTA) in the soil, but Henkens (1975) reports yield reductions already at 50 ppm Cu (HNO_3), corresponding to 40 ppm Cu (EDTA). In any event, starting from a normal, good level, i.e., a Cu (HNO_3) content of 5 ppm in the soil, the application of an annual dose of 20 tonnes of pig slurry may after about 150 years lead to soil pollution serious enough to impede growth of a large variety of arable crops. It is assumed here that the arable layer weighs 2 600 000 kg, and that 75% of the copper in the manure is soluble in dulute HNO_3. If the initial level is higher, the critical situation will be reached correspondingly earlier. It is not known whether the risk on clay soil, where the initial level is generally higher, is also greater.

For sheep, a Cu content exceeding 15 ppm (dry-matter basis) in the ration is considered undesirable. Cattle have a greater tolerance (80 ppm, Ferguson, 1943). Grass polluted with pig manure is unsuitable for sheep. On grassland, not only the grass but also the contaminated soil constitutes a hazard for sheep (Hartmans, 1974), as the animals ingest a fair amount of soil (up to 75 kg per annum). A content in excess of 15-20 ppm is considered undesirable. The copper available to the plant also seems to be a good measure of the quantity to be utilized by the animal (Healy, 1974). The limit of 15 ppm Cu (HNO_3) is reached in about eight years at an annual dose of 20 tonnes of pig slurry where the initial copper level of the soil is 5 ppm Cu (HNO_3).

Pig feed contains not only copper but also zinc - on average about 175 ppm. The slurry then contains an average of 75 ppm. At an annual dose of 20 tonnes, the (total) Zn content of the soil in the abovementioned period of 150 years increases by about 90 ppm on arable land. Given an initial level of 30-100 ppm (total) Zn, this need not give cause for concern, as arable crops tolerate 250-300 ppm (total) Zn in the soil. On grassland (0-5 cm layer; 600 000 kg), the (total) Zn content increases over this period by 375 ppm. This is not considered harmful for grassland and the livestock grazing on it. However, it is not known whether the combination of (high) zinc and copper doses has other effects (due to interaction) than when these elements are applied separately.

2.6. Soil pH

If the composition of a manure is sufficiently well known, its eventual effect on the pH, or, better, the lime requirement, of the soil can be calculated by means of a formula published by Sluijsmans (1966). If the effect on the lime requirement is called E, E is expressed in kg CaO per 100 kg manure used, and the contents (%) of nitrogen, phosphorus, etc., are indicated by N, $P_2 O_5$ etc., the formula is:

$$E= -1.0 \times CaO - 1.4 \times MgO - 0.6 \times K_2O - 0.9 \times Na_2O + 0.4\ P_2O_5 + 0.7 \times SO_3 + 0.8 \times Cl + n \times N.$$

The coefficient n for the nitrogen content can be taken as 0.8 for grassland and 1.0 for arable land. The calculation will be performed for the slurry from pigs and poultry. It is known that cow manure has little effect on soil pH.

Table 14: Composition of pig and poultry slurry (%)

	ds	N	P_2O_5	SO_3	Cl	CaO	MgO	K_2O	Na_2O
Pig	8.0	0.70	0.47	0.20	0.20	0.35	0.10	0.40	0.10
Poultry	16.0	0.90	0.94	0.25	0.20	1.66	0.14	0.45	0.10

On the basis of this composition, the formula indicates for pig manure an increase in the lime requirement of 2.3 kg (grassland) and 3.7 kg (arable land) CaO per tonne and for poultry manure of -8 kg (grassland) and -6 kg (arable land) CaO per tonne. Pig manure thus has a slightly acidifying effect on the soil, while poultry manure has an alkalizing effect which is appreciably stronger.

The slightly acidifying effect of pig manure gives no cause for concern. A soil that has become too acid can be quickly brought back to an appropriate pH level by application of lime. If a soil becomes too rich in bases - which may be unfavourable to crop yield and composition - this must be corrected by acidifying fertilizers such as ammonium sulphate or sulphur.

According to Bakker and Loman (1973), the optimum pH-KCI for sandy soils is in the range of 4.8 to 5.8 depending on the crop rotation. At the average of these values (pH 5.3), the annual lime loss on a soil with 4% humus and an arable layer 20 cm in thickness works out according to Loman (1973) to be 170 kg CaO per ha. This loss can thus be offset by a dose of 28 tonnes of poultry slurry, corresponding to the annual production of over 350 birds. Such a stocking rate per ha of arable land is therefore acceptable as regards the maintenance of a satisfactory pH, and is indeed desirable as additional liming is then no longer necessary. Heavier applications will cause the pH of such a soil to increase; in some crops (potatoes) this may reduce yields and possibly impair quality (potato scab). Heavy soils and humus-rich sandy soils lose more lime than the sandy soil considered above, and can therefore tolerate rather more poultry manure.

Not enough is known about the annual lime loss on grassland; given otherwise normal fertilization, it is estimated at 50 kg CaO per ha for the 0-5 cm layer. To offset this, only 6 tonnes of poultry slurry can be applied - i.e., the production from about 75 laying hen places. The pH will increase at higher stocking rates, although it is impossible to predict how much. Values of pH-KC1 exceeding 5.5 are considered unnecessary in the Netherlands. As long as the pH-KC1 does not exceed 6.0 or perhaps 6.5, little damage is likely to be done.

However, to ensure that satisfactory pH levels are maintained, poultry manure should be preferred on arable land rather than on grassland.

3. Use of animal manure and water pollution

Enrichment of surface water with plant nutrients stimulates the growth of algae and also of bacteria, which in turn use the organic matter accumulated by the algae as a source of energy. The processes occurring may substantially reduce the oxygen content of the water, making it less suitable for many purposes. The elements phosphorus and nitrogen, in particular, are considered responsible for the increased growth. Phosphorus has this effect because it is the minimum quantity under natural conditions and is thus the determining factor for the growth rate of the organisms. Nitrogen can be the limiting factor in phosphorus-rich water. However, the importance of nitrogen should not be overestimated, because an undesirable proliferation of organisms can also occur under low-nitrogen conditions. This applies in particular to blue-green algae, which are able to fix atmospheric nitrogen. For drinking-water produced from groundwater or surface water, the nitrogen content is more important than the phosphorus content as regards public health: excessive nitrate levels are considered to be responsible for the "blue baby" condition in children less than six months old.

In addition to the nitrogen and phosphorus occurring in manure, the organic matter, in so far as it reaches the water, may also adversely affect quality because it is used as a source of energy by microorganisms, the consequence being oxygen depletion. However, organic matter pollution is only to be expected if solid or liquid manure is discharged direct into surface waters. It is assumed here that such direct discharges are or will be prohibited, as they have been in the Netherlands since 1970. For this reason, only nitrogen and phosphorus are considered in this section, since they are the most important constituents of solid and liquid manure as regards pollution of groundwater and surface water.

3.1 Soil as a filter

By virtue of its porous structure, adsorption capacity and ability to form relatively insoluble chemical compounds from the combination of added substances and existing constituents, the soil has the character of a filter.

Owing to the porous structure, only water-soluble substances can penetrate to greater depths. The mechanical filtration effect prevents the penetration of organic matter from farmyard manure to depths of more than a few centimetres in moderately to finely structured soils (Mosier et al., 1972).

Adsorption is important principally with respect to cations. Nitrogen in the form of NH_4 is readily fixed by this process, but not in the form of NO_2 and NO_3. Precisely because NO_2 and NO_3 compounds are readily soluble, they are, like chlorides, easily transported with the water in the soil.

The orthophosphate ion, after initial adsorption on soil particles, readily participates in reactions with Ca, Fe and Al ions to form relatively insoluble compounds, thus making room for more adsorption (Lindsay and Moreno, 1960).

The filtration effect of the soil is very important for the contamination of deeper groundwater with pathogenic microorganisms. Worms and their eggs, protozoa and their cysts are so large that they may be regarded as unlikely to penetrate as far as the groundwater. Bacteria and viruses can penetrate more easily, but do not in general reach depths greater than 60-120 cm. Erickson et al. (1974) report a considerable reduction in a 180 cm thick (artificial) sand profile, the last 60 cm of which is anaerobic. In this "Barriered Landscape Water Renovation System" (BLWRS), the number of fecal coli was reduced from 10^6-10^7 per 100 ml in pig manure to less than 3 per 100 ml in the effluent. This value in the effluent is far below the EEC's A_2 standard for surface water intended for potable water production, and is also considerably below the "acceptable" level for fishing water (less than 50 per 100 ml).

It may be concluded that contamination of the deeper groundwater with pathogenic microorganisms through the application of solid and liquid manure is virtually impossible. The fact that septic tanks not connected to sewers are in widespread use without harmful consequences to public health brears out this conclusion.

The thinner the profile, the greater the probability of transport of pathogens, as revealed, for example, by the number of fecal coli found in potable water. O'Callaghan and Pollock (1976) applied pig slurry to grassland on loam soils in quantities corresponding to the water holding capacity of the soil. The doses ranged from 55 to 125 tonnes/ha in the period April to September. It was found that only a small quantity of manure reached the drains (about 90 cm deep), through worm holes and small cracks in the ground. This effect was somewhat increased by rainfall immediately after application. Evans and Owens (1972) found that because of such "leaks" the number of fecal coli in the drainage water increased by a factor of 30-900 within two hours of application. After two to three days, however, the concentration of fecal coli had fallen again to the original level. For E. coli this was 80-100 per 100 ml and for the smaller enterococci 15-20 per 100 ml, the level in the manure being about 10^8 per 100 ml.

The base level for E. coli in the drainage water was found to vary from 2 to 10 000 per 100 ml in the period from October to February, when the animals were housed and no organic manure was applied. The higher the drainage water flow, the larger, too, was the number of fecal bacteria; this indicates that bacteria are flushed out of the sward.

Often the presence of pathogenic organisms is not determined directly, but the determination of the number of fecal coli gives an indication that disease infection is possible. Criteria have therefore been established for fecal coli in surface water, as follows:

Surface water for:	Class	Fecal coli MPN[1] per 100 ml	Source
Swimming water	I acceptable	< 100	Spaander (1975)
Swimming water	II suspect	100-1000	Spaander (1975)
Swimming water	III unacceptable	> 1000	Spaander (1975)
Fishing water[2]	I acceptable	< 50	Interim report "aquatic animals" (1975)
Fishing water	II suspect	50-150	
Fishing water	III unacceptable	> 150	
Drinking water preparation	EEC standard A_2	< 2000	EEC Official Journal (1975)
Irrigation for horticulture[2]		< 100	Schaeffer (1975)

[1] Most probable number

[2] Basis: products eaten raw

Comparison of these criteria with the numbers of E. coli found in the drainage water shows that this water, which is discharged direct into the surface water, often fails to satisfy the requirements set for surface water. This is certainly the case during a few days after application of a dose of slurry which exceeds the water holding capacity of the soil. However, these standards may also be exceeded in wet periods giving a high flow of drainage water on land which has not recently received an application of slurry but is regularly organically manured.

It is self-evident that any filtration effect ceases to be relevant where runoff is concerned.

The authors are unable to evaluate the significance for public health of possible contamination of the surface water with pathogenic microorganisms through drainage water and runoff.

The ability of the soil to filter out organic matter and phosphates under actual field conditions is brought out by a number of observations by Steenvoorden and Oosterom (1973), which are reproduced in Table 15. The "natural land" comprises unmanured sandy soils, while 75-95% of the manured land consists of sandy grassland with a stocking rate of 1.7-2.2 cattle, 4-16 pig places, 0.7 calf places and 20-70 hens per ha. This table shows that there is little difference between natural land and manured cultivated land with respect to the organic matter content of the filtered groundwater (measured as $KMnO_4$ -value) and the orthophosphate content in the layer down to a depth of 2.5 m. The nitrate content, however, is higher under manured cultivated land than under natural land.

Table 15. Groundwater composition (mg/l) at different depths and under different manuring conditions on sandy soils (Steenvoorden and Oosterom, 1973)

	Depth 0.50 m			Depth 2.50 m		
	$KMnO_4$	$N-NO_3$	P-ortho	$KMnO_4$	$N-NO_3$	P-ortho
Natural land	13	0,3	0,05	12	0,3	0,05
Manured land	13	5,3	0,07	13	1,0	0,11

The purifying capacity of the soil is even better illustrated by irrigation tests with waste water in which large quantities of plant nutrients are applied (De Haan, 1972). Table 16 shows the reduction in levels found on sandy soil in the drainage water (Tilburg) or groundwater (WTM) at a depth of about 1 metre expressed as percentages of the level in the effluent applied.

Table 16. Reduction in level after irrigation of sandy soil with waste water on four different irrigation fields (De Haan, 1972)

	Tilburg[1]			WTM[2]	Average
	Witsie	Zandeleij	Trappistenklooster		
BOD_5	81%	98%	95%	99%	93%
P_t	-%	96%	92%	99%	98%
N_t	75%	83%	72%	97%	82%
K	-%	16%	37%	71%	41%
Cl	14%	-%	-%	58%	36%
Dose (mm/year)	4200	4200	3900	250	---

[1] Sewage
[2] Potato flour industry process water

The Trappistenklooster irrigation field has been in use for only five years, but the other fields have already existed for more than 40 years. Even so, a high degree of purification is still achieved, especially for readily decomposable organic matter (BOD_5) and phosphorus.

It should not be concluded from these encouraging results that the purifying capacity of the soil is unlimited.

Moreover, if the filter is overloaded with water, it may break down. This appears to have happened in the example illustrated in fig. 3, where a single dose of waste water of 420 mm was applied (De Haan, 1972). The situation illustrated was measured two months after application and suggests that the effluent penetrated to a depth of nearly 4 m.

The relatively poor filtration effect for nitrogen is also revealed by tests by Foerster (1973) with large quantities of manure (two applications of 600 tonnes of slurry). After two years, the nitrate content of the groundwater had increased down to a depth of about 6m, the maximum being 400 mg $N\text{-}NO_3$ per litre at a depth of 2-2.5 m.

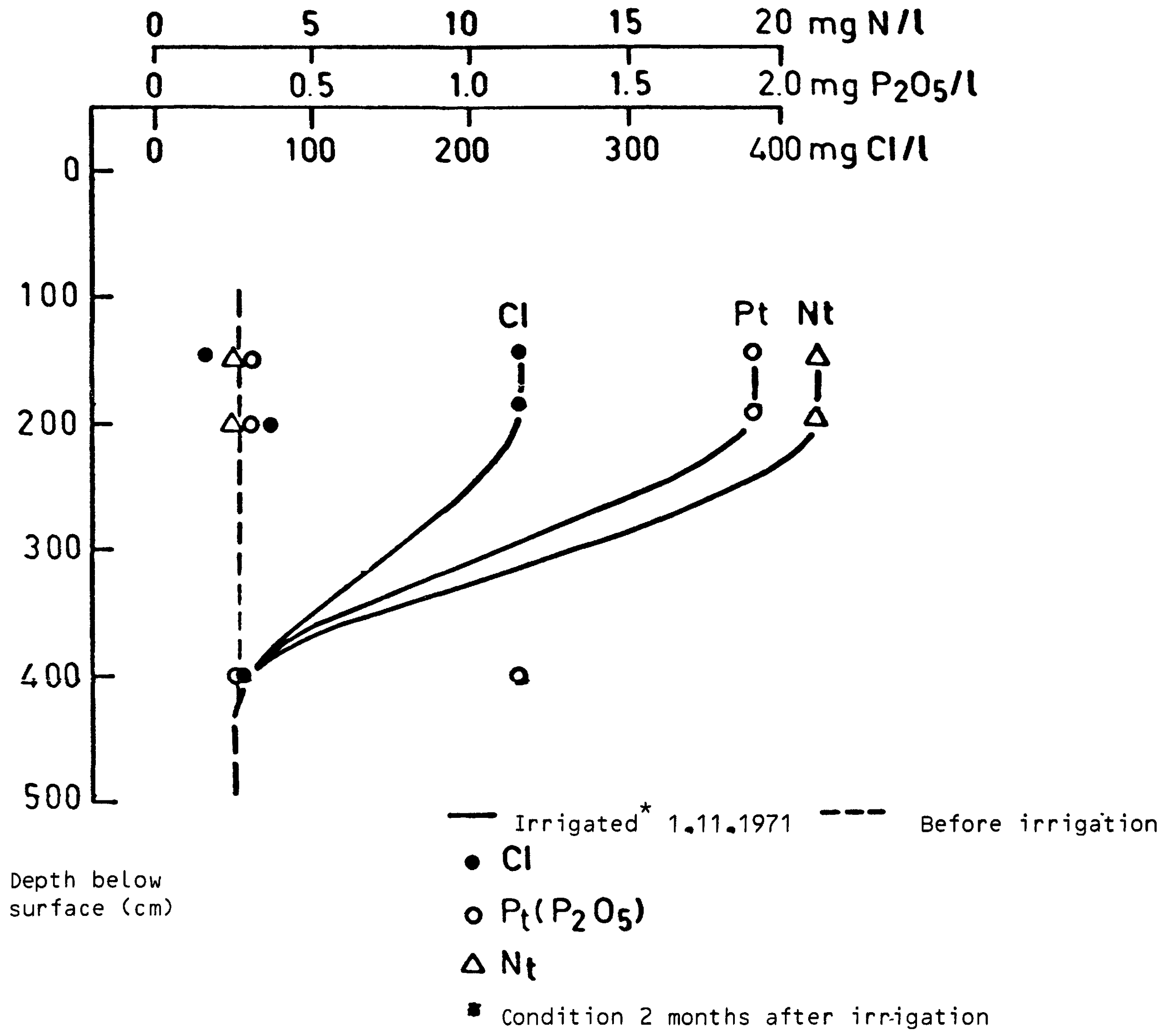

Figure 3. Effect of a single application of 420 mm of potato flour industry process water on groundwater concentrations (De Haan, 1972).

The P content, however, was increased only in the upper part of the profile. No increase in P due to manuring was detected over the range 110-180 cm.

On undrained land, therefore, irrigation not consistent with the water holding capacity of the rhizosphere may give rise to 'pollution' of the shallow groundwater, in particular with nitrate and chloride.

There is also quite a difference in purifying capacity among the various types of soil. For instance, fixation of phosphorus from potato flour process water on peat soil amounted to only 70%, against 98% on sandy soil (De Haan, 1972).

3.2 Losses of nitrogen and phosphorus from the rhizosphere

As explained in the previous section, the soil is in general an excellent filter for organic matter and phosphorus, but is less good for nitrogen. We shall now consider to what extent annual applications of animal manure affect the amount of nitrogen and phosphorus entering the groundwater and surface water.

3.2.1 How the pollutants reach the water

The two principal methods of transport of plant nutrients into the water are leaching and surface runoff (Kolenbrander, 1973). In the first case, the soil acts as a filter, this effect being, however, completely absent in the second. In this way water-soluble substances and substances suspended in water can be transported direct into surface water; in severe cases particles of soil are also moved along (water erosion). However, such erosion is of little significance in western Europe, and where it does occur it can be controlled by use of appropriate cultural practices. For this reason the discussion will be limited to leaching and ordinary runoff.

3.2.2 Leaching of nitrogen on arable land[1]

Kolenbrander (1969) analysed a large number of lysimeter tests reported in the literature. All his results apply to leaching from an approximately

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[1] See also Appendix I.

1 m thick layer of soil, chemical fertilizer being used exclusively in each case.

Leaching of nitrogen was found to be directly proportional to the amount of drainage water in the range 0 to about 600 mm per year. On cultivated land (sandy soil) which had not been fertilized with nitrogen for a number of years, the loss was about 45 mg N per ha per year at 250 mm drainage water. The application of an optimum dose of chemical fertilizer increased this loss by about 14% of the fertilizer applied. The heavier the soil, the less the leaching of nitrogen.

Under average western European climatic conditions, overdosage of nitrogen will cause increased leaching. In principle, the leaching may even approximate the level of the excess applied.

Little information is available on the leaching of nitrogen from farmyard manure. To evaluate this, the method of approximation already chosen in Section 1 is followed. It was assumed in that paragraph that 60% of the N fraction mineralized in the first year (N_e) becomes available to arable crops (in the case of spring application). The remaining 40% is mineralized outside the growing season. According to Van der Paauwen and Ris (1963), 13.5% of this nitrogen remains available for the crops in the following year (residual effect). If it is assumed that 20% volatilizes after denitrification (Broadbent and Clark, 1965), the remaining nitrogen (66.5%) will be lost by leaching. This thus amounts to $0.665 \cdot 0.4 \cdot N_e = 0.27\ N_e$.

The same applies to the residual nitrogen (N_r) once equilibrium has been reached. The portion of this fraction which leaches out can thus also be taken as $0.27\ N_r$. Hence a total of $0.27\ N_e + 0.27\ N_r$ of the nitrogen mineralized outside the growing season will be lost by leaching. Since it is assumed in the relevant section that the fractions N_e and N_r are approximately equal, it can also be stated that under equilibrium conditions leaching of the nitrogen mineralized outside the growing season is equal to $0.27\ (N_t - N_m)$, in which N_t is the total quantity of nitrogen and N_m the mineral fraction already present at the time of application (see Table 4).

With autumn application, it was assumed that about 40% of the mineral nitrogen (N_m) would leach out in autumn and winter, after 20% had already been lost by volatilization of NH_3 at the time of application. Leaching of this fraction will therefore be $0.40 \cdot 0.80 \cdot N_m = 0.32\ N_m$.

It was also assumed that a further 20% of the fraction mineralized in the first year (N_e) will be liberated in the autumn immediately after application. About 40% of this nitrogen is lost by leaching - i.e., $0.40 \cdot 0.20 \cdot N_e = 0.08\ N_e$.

Of the remainder ($0.80\ N_e$), as in the case of spring application, 40% is mineralized in the following year outside the growing season, while again 66.5% of this nitrogen will be lost by leaching - i.e., $0.665 \cdot 0.40 \cdot 0.80\ N_e = 0.21\ N_e$. Of the N_e fraction, therefore, the total leached out in the autumn and the following autumn is $(0.08 + 0.21)\ N_e = 0.29\ N_e$.

The residual fraction (N_r) will behave in the same way as with spring application, so that the amount leached out will be $0.27\ N_r$.

Total leaching in the case of autumn application can now be calculated as:

$0.32\ N_m + 0.29\ N_e + 0.27\ N_r$ or $\underline{0.32\ N_m + 0.28\ (N_t - N_m)}$

The considerable difference in leaching as between spring and autumn application is due to the nitrogen leaching loss from the mineral fraction already present in the animal manure (N_m). Of the nitrogen bound in the organic matter ($N_t - N_m$), 27-28% is lost by leaching on arable land because this nitrogen is mineralized outside the growing season.

The degree of leaching to be expected on the basis of the above relations is set out in Table 17.

Table 17. Percentage of nitrogen lost by leaching from animal manure on arable land (equilibrium condition)

	Time of application	
	Spring	Autumn
Cattle slurry	16	30
Pig slurry	13	30
Poultry slurry	8	31
Calf slurry	5	31
Liquid manure	2	32

The above figures all relate to nitrogen which did not become available to the crops because it leached out too early or was mineralized too late. Of the nitrogen which did become available to the plants, as much is lost as from the same quantity of chemical fertilizer nitrogen. This amount was calculated from lysimeter analyses. By combining these results with the figures in Table 17, leaching losses from farmyard manure can be compared with those from an equal quantity of chemical fertilizer nitrogen.

The effect on the crop of 100 kg of farmyard manure N applied in spring, assuming an efficiency index of 75%, is the same as that of 75 kg of chemical fertilizer N. Hence, to achieve the same N effect as with 100 kg of chemical fertilizer N, $\frac{100}{75} . 100 = 133$ kg of farmyard manure N (equal to the production of 1.5 adult cattle per year) is necessary. Leaching loss from 100 kg of chemical fertilizer N was estimated by lysimeter measurements at 14 kg; hence the leaching loss from an equivalent amount of farmyard manure will be $14 + 0.16 . 133 = 35$ kg for cattle manure or $14 + 0.05 . 133 = 21$ kg for calf slurry.

In the case of autumn application, the efficiency index is 45%. To obtain the effect of 100 kg of chemical fertilizer N, the amount of farmyard manure N required is then $\frac{100}{45} . 100 = 222$ kg N, which is equal to the production of 2.5 adult cattle per year. Leaching losses from 100 kg of chemical fertilizer nitrogen are 14 kg as before, but the loss from an equivalent dose of farmyard manure now becomes $14 + 0.30 . 222 = 81$ kg N. This value holds for all types of manure.

It may therefore be concluded that replacement of chemical fertilizer by a quantity of farmyard manure providing the same amount of N on sandy soil eventually leads, in the case of spring application, to 1 1/2 to 2 1/2 times the leaching losses from the rhizosphere, and to about 6 times the losses in the case of autumn application. In practice, owing to lack of storage capacity and considerations of economy of labour, manure will be applied throughout the autumn, winter and spring, so that the average loss will be four times the amount lost from an equivalent quantity of chemical fertilizer applied in spring just before the onset of plant growth and adjusted to the requirements of the plant.

3.2.3 Leaching losses of nitrogen from grassland

Unlike arable land, grassland has a vegetative cover throughout the year capable of taking up nitrogen as long as the temperature is above 6-7°C. According to tests by Pfaff (1963), over 90% of the mineral nitrogen present in the soil during the course of a year is taken up, whereas the figure for cereals is less than 50%. Leaching losses are generally correspondingly small. Williams and Jackson (1976) consider that the losses only become significant at N doses that are so high as to be excessive from the point of view of dry matter production. Kolenbrander (1973) mentions an average loss of 3 kg N per ha per year for unfertilized land, plus a loss of 1 to 2% of the chemical fertilizer N applied. These results are supported by those of Garwood and Tyson (1973), illustrated in figure 4, in so far as the amounts applied are below 250 kg N per ha per annum. Above this level a sharp increase occurs, eventually reaching a maximum slope of 45° on the X-axis.

Garwood's and Tyson's results (1973) are in turn supported by figures collected in the region of the Hupsele Beek (Kolenbrander and Van Dijk, 1972), which is a catchment area featuring a thick layer of clay impermeable to water at a shallow depth. The hydrology of this region is therefore comparable with that of a lysimeter where there is no deeper groundwater.

It is found that the figures for this catchment area, represented by one point in fig. 4, fit in well with the overall picture if not only the usual chemical fertilizer application of 230 kg N per ha per year but also the nitrogen produced in the organic manure during the housed (winter) period is taken into account. This was calculated at approximately

165 kg N per ha per year, so that the total dose was 395 kg N.

The curve in fig. 4 shows that the maximum absorption capacity of the grass is reached at about 450 kg N per ha per year, and that at higher rates of application the excess can leach out.

N leaching losses from grassland do not differ in principle from those from arable land; the difference is that on grassland, owing to the nature of the crop, severe leaching does not commence until much higher doses are applied.

Fig. 4 enables us to estimate N leaching losses from grassland for different levels of manure application. If the manure of no more than 1.5 LU, containing approximately 130 kg N, is applied to grassland, leaching losses are no higher than with an equal dose of chemical fertilizer applied at the same time. According to fig. 4, this leaching loss is slight, but would increase sharply if the total amount of N from farmyard manure and chemical fertilizer were to exceed about 350 kg. With farmyard manure only, this level is reached at 4 LU.

With regard to nitrogen leaching, livestock farms are often at a disadvantage compared with arable farms. Part of the manure is spread in autumn and winter owing to lack of storage capacity and for reasons of labour economy. Because the crop then has insufficient capacity to take up the nitrogen supplied, considerable leaching losses may occur. This is illustrated for nitrogen fertilizer applications in fig. 5 (Kolenbrander, 1969).

Nitrogen leaching losses from animal manure can easily be calculated from the diagram in Section 1.2.1. If the manure is applied in spring, these losses amount to $0.04\ N_e + 0.04\ N_r = 0.04\ (N_t - N_m)$; with autumn application they are $0.272\ N_m + 0.112\ N_e + 0.04\ N_r = 0.272\ N_m + 0.076\ (N_t - N_m)$. Nitrogen leaching losses for cattle manure excreted during the grazing period are $0.025\ N_m + 0.06\ N_e + 0.04\ N_r = 0.025\ N_m + 0.05\ (N_t - N_m)$. The leaching losses for different types of manure can be calculated from Table 4.

In the case of spring application these losses amount to 2.4, 2.0, 1.2 and 0.8% for cattle, pig, poultry and calf slurry respectively. With autumn application these losses increase to 15.4, 17.4, 21.3 and 23.3% respectively. Nitrogen leaching losses for cattle manure produced during the grazing period amount to 4%.

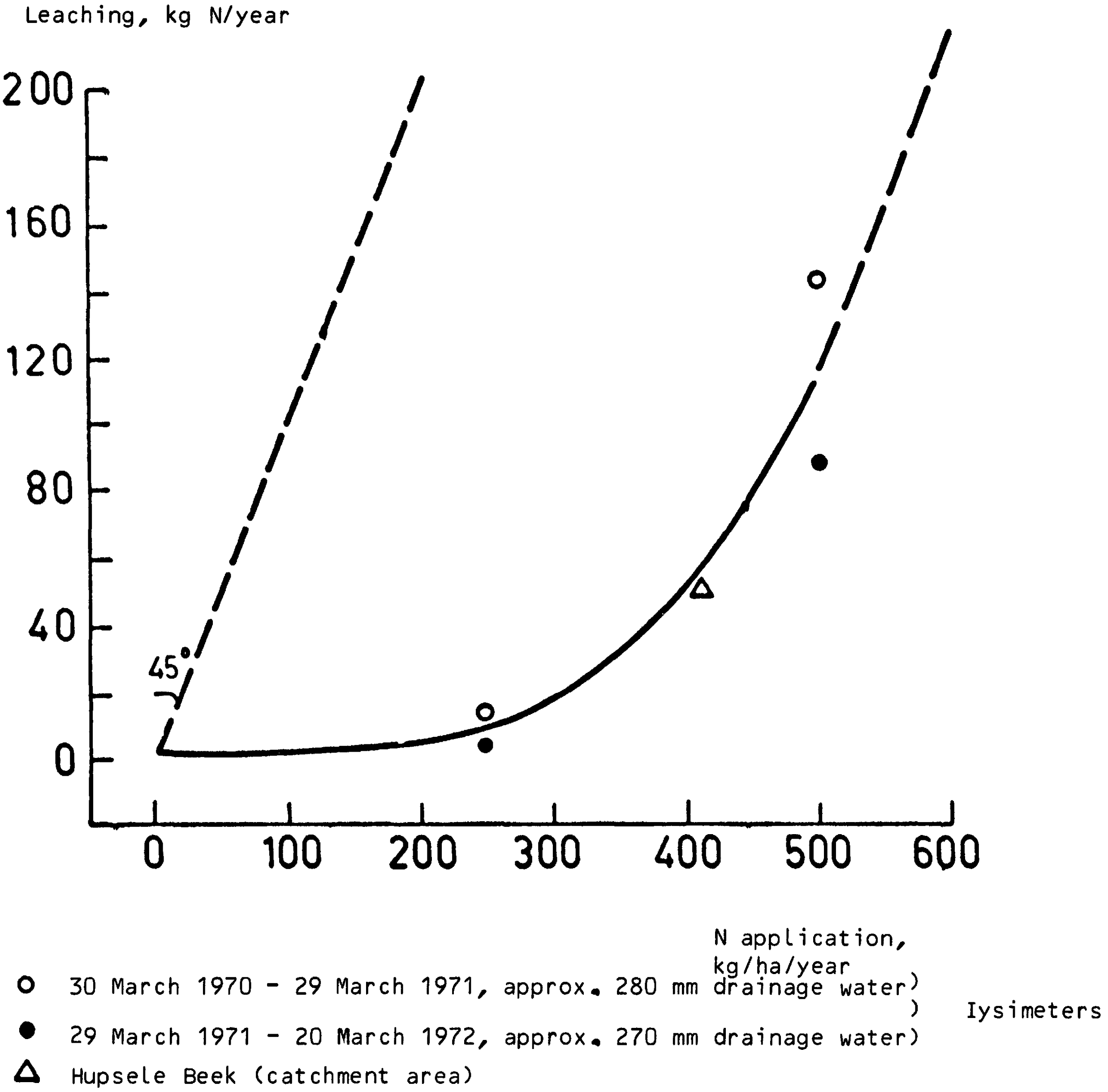

Figure 4. Nitrogen losses on grassland vs annual quantity of chemical fertilizer nitrogen applied (Iysimeter tests: Garwood and Tyson, 1973)

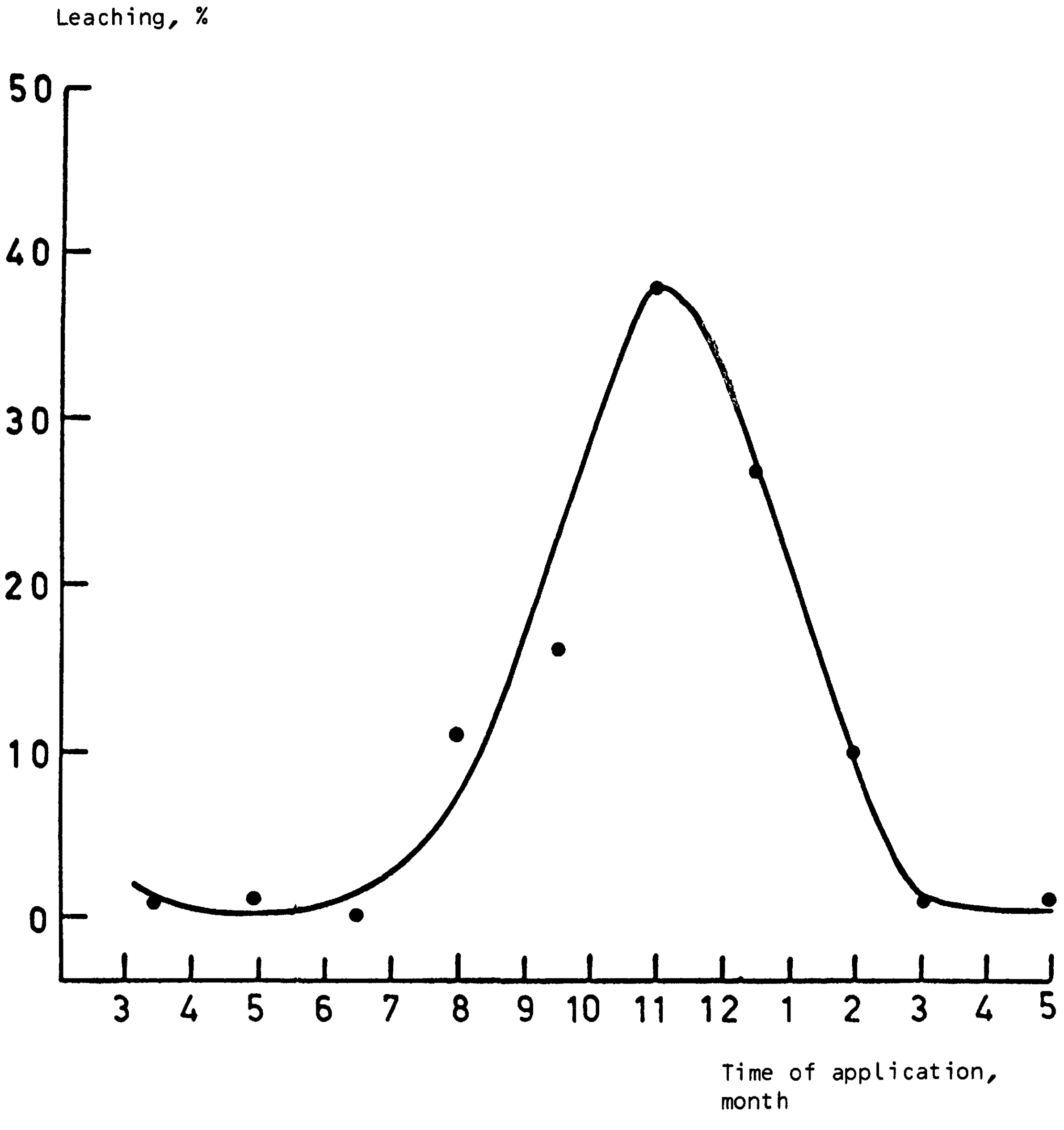

Figure 5. Nitrogen leaching losses as a percentage of the chemical fertilizer nitrogen applied to grassland on sandy soil in the course of the year.

3.2.4 Leaching of phosphorus

3.2.4.1 Chemical fertilizer

Figure 6 shows that the P_t content of the arable layer first increases and then levels off when 60 kg P per ha per annum as superphosphate is applied. This indicates that equilibrium eventually is established between P applied and the supply of P in the soil. Phosphorus not taken up by the crop and removed with it (about 30 kg P per ha per year) will be leached out to deeper layers.

Drainage water and groundwater analysis shows that on normally fertilized sandy and clay soils in which the amount of P applied corresponds to the P requirement of the plants, the leaching loss at a drainage depth of about 1 m is slight, amounting to about 0.2 kg P_t per ha per year. Peat and soils on cut-over peat are exceptions, as losses here may be ten times as high - about 2 kg P_t per ha per year (Kolenbrander, 1973).

Owing to adsorption of inorganic phosphorus on the mineral soil particles and the formation of Ca, Fe and Al compounds of low solubility, the P concentration in the soil moisture is low (averaging about 0.08 mg P_t per litre) so that leaching is slight. On peat and cut-over peat soils, however, where the P concentration is ten times as high, this is not the case.

It may be concluded from the material available that inorganic P fertilization will not in general result in high P leaching losses if the amount applied corresponds to uptake by the crop.

Excess application may eventually lead to higher leaching losses, although this depends very much on the nature of the soil. Insufficient information is available as to the extent to which excess application would result in penetration to deeper layers and from there to the surface water, and how long this process may take.

3.2.4.2 Irrigation with waste water

Compared with the application of chemical fertilizer phosphorus, irrigation with waste effluents is a very extreme case of fertilization through the application of large quantities of phosphorus in large quantities of water.

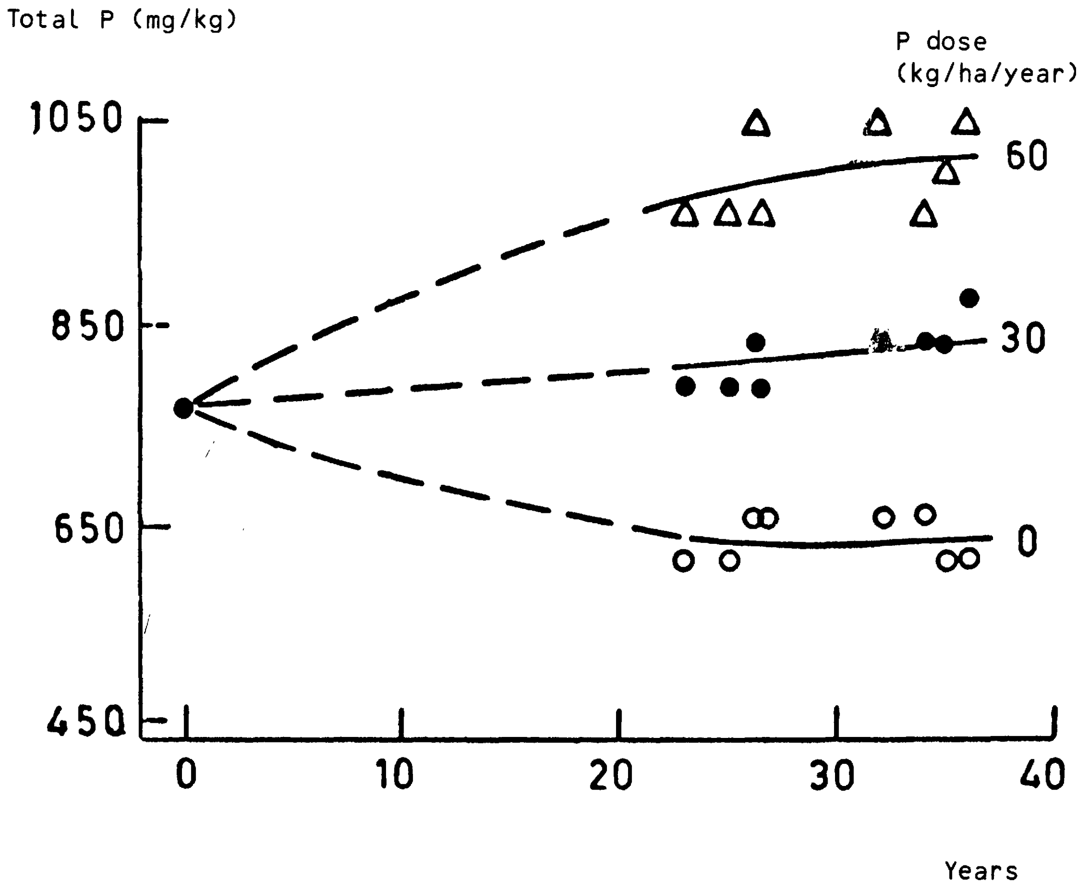

Figure 6. Phosphorus content of the arable layer in the course of time when fertilized with chemical fertilizer.

It has already been shown that the mineral soil is an excellent filter. However, even with a purification capacity of 98% (Table 16) it is still possible for the 2% not retained in the soil to represent appreciably more phosphorus than the soil originally supplied before irrigation. For instance, in a case of irrigation with potato flour process water, De Haan (1972) reports a P_t concentration, measured at a depth of 1.45 m, of about 17 times as high as the original level of 0.07 mg P_t per litre before irrigation. From the Tilburg irrigation fields, De Haan (1972) estimates an annual loss of 17 kg P_t per ha via drains to the surface water, which is 80 times as much as the land would have lost naturally.

As a result of irrigation during more than 40 years, an "equilibrium" concentration of 0.37 mg P_t per litre has been found in the groundwater under potato flour industry irrigation fields (sandy soil) at a depth of about 150 cm; the figure for the drainage water in the Zandeleij irrigation field complex at Tilburg is about 0.46 mg P_t per litre. The original concentration prior to irrigation is not known, but a field that had never been irrigated in the vicinity of the potato flour plant irrigation field had an "equilibrium" concentration of about 0.07 mg P per litre, which is in good agreement with the average for mineral soils (0. 08 mg P_t per litre).

This analysis shows that long-term irrigation with P-containing effluent gives rise to a permanently higher P concentration in the drainage water or groundwater (here measured at a depth of 1-1.5 m). This permanently higher level is maintained by increased adsorption of phosphorus on the soil particles and a larger quantity of chemically precipitated phosphorus compounds, with which the soil moisture is in equilibrium. It results in a loss about five times as high as under natural conditions where the amount of drainage water is 250 mm per annum. In addition, further losses occur on irrigation - i.e., of phosphorus not adsorbed on the particles.

3.2.4.3 Farmyard manure

In his 15-year lysimeter tests (depth 1 m), Pfaff (1963) found no appreciable difference in P leaching between the NPK-treatment on the one hand and the (solid) farmyard manure + NPK-treatment on the other. Cooke and Williams (1970) also found no difference after 100 years of application of farmyard manure (35 tonnes per ha per annum).

With slurry, however, there are indications that penetration is faster. For instance, Vetter and Klasink (1972) observed a doubling to tripling of the phosphorus content in the subsoil (60-90 cm) in the profiles of 20 farms on sandy soil in Lower Saxony to which 65 to 255 m^3 of slurry per ha per annum was applied over 15 years.

Using a lysimeter analysis, De la Lande Cremer (1972) observed an increase at a depth of 1 m on sandy soil after only one year after eight applications of 30 tonnes of pig slurry applied within a few weeks.

A volume of 250 m^3 of slurry per ha contains about 23 mm of water. Compared with irrigation with 250 mm or more of waste water applied all at once, this quantity of water can readily be held in the 1 m root zone in a soil which is not too wet. However, part of the moisture can penetrate even deeper through the larger pores, taking with it water-soluble P compounds which are not adsorbed on the soil complex, such as inositol phosphate and glycerol phosphate. According to Gerritse (1975), 5-25% of the total phosphorus in farmyard manure may consist of such compounds.

Unfortunately, it is not yet possible to indicate on the basis of tests with slurry the extent to which the P leaching losses will increase over the years if excess doses are applied. In this respect this type of organic manure occupies a position between chemical fertilizer and waste effluent, so that increased leaching is likely in the long term. Neither the onset of this increase nor the level which these leaching losses will reach can at present be predicted.

3.2.5 Phosphorus losses through runoff

In steep terrain, not all the rainwater will travel downwards through the soil; some of it will flow off over the surface, carrying water-soluble substances and sometimes particles of soil with it. It is difficult to say what quantities of phosphorus are involved. These will, of course, depend on the amount of water flowing off and its phosphorus concentration, which in turn depends on the condition and fertility of the soil. Where the land is predominantly flat, runoff will occur only if the soil has insufficient water holding capacity, as may be the case during a heavy shower in a prolonged wet period, when the water table is high, or in winter when the land is frozen. The probability of runoff is relatively high if frozen or snow-covered land is manured in winter.

For cultivated land, Ryden et al. (1973) give runoff values in the United States of 0.12 to 1.23 kg total P per ha per year. Menzel (1974) reports that in the northern United States about 2% of the precipitation reaches the surface water as runoff; this would amount to 15 mm, given 750 mm rainfall. To obtain a rough impression, this quantity can be combined with the average P content of approximately 1.24 mg P per litre found by Cooke and Williams (1970) in rain puddles on the land; this would result in a runoff of 0.18 kg total P per ha per annum. A rough estimate can also be made from figures for catchment areas, for which Kolenbrander (1973) reports a contribution per ha of 0.40 kg total P to the surface water, leaching (in the case of shallow drainage as in the Hupselse Beek region mentioned above) being put at 0.22 kg. The difference of 0.18 kg can then be attributed to runoff. These values are of the same order as leaching from the rhizosphere. This is also the case with figures quoted by Harms et al. (1974), who report 0.30 for arable land and 0.24 for grassland, thus also demonstrating that the probability of runoff of plant nutrients is higher in the former case than in the latter.

The higher the concentration of plant nutrients in the topsoil, the higher the quantity lost by runoff. Fig. 7 demonstrates this for Swiss conditions. As the percentage of cultivated land increases at the expense of woodland and fallow land, so that the soil fertility increases correspondingly, the more the losses to the surface water also increase. The substantial losses in the foothills of the Alps are attributed to a higher proportion of runoff and erosion.

Excess application of phosphorus with manure, as may occur on arable land with the manure of more than 1.5 cows (P_2O_5 production 60 kg on an annual basis), increases the phosphorus content of the topsoil and hence also the contribution of runoff to surface water pollution. It is to be expected that the share from runoff to pollution will respond to increased fertility of the topsoil much earlier than that from leaching.

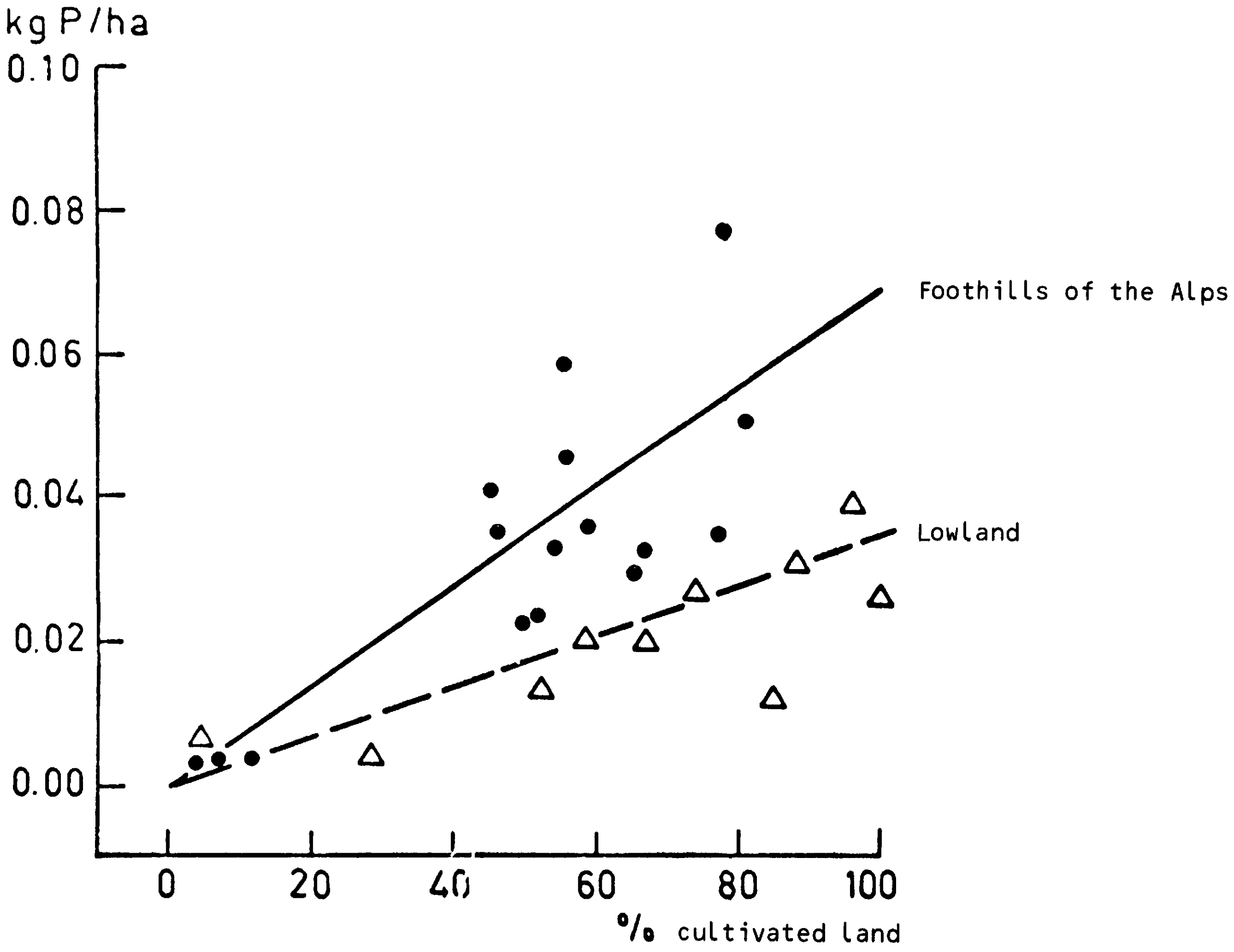

Figure 7. Phosphorus entering surface waters in two parts of Switzerland (Gächter and Furrer, 1972)

3.3. Importance of the subsoil for nitgrogen and phosphorus losses

The leaching of nitrogen and phosphorus intensified by the use of large doses of farmyard manure does not in itself necessarily entail a substantial increase in the concentration of these substances in the groundwater and surface water, as part of the nitrogen could still volatilize out of the topsoil by denitrification ofnitrates, while dilution of the downward-flowing water with groundwater reduces its concentration. Phosphorus leached out of the rhizosphere could still be fixed in the subsoil or, like nitrate, be diluted with water containing less phosphorus. These possibilities are reduced on drained land, where the drains discharge the downward flow of water direct to the surface water, in which case the soil filter underneath the rhizosphere is much less utilized.

3.3.1. Nitrate nitrogen[1)]

It was calculated in an earlier section that the amount of nitrogen leaching out of the rhizosphere upon application of farmyard manure is about four times that occurring when a dose of chemical fertilizer, equivalent in terms of plant availability, is used. From the environmental point of view, it is important to know what happens to this nitrogen in the subsoil.

The organism responsible for denitrification of the percolating nitrates require energy to carry out the denitrification; this energy is derived from organic matter present. Sufficient organic matter is present in the rhizosphere, but not generally in the layer underneath it. On the basis of the BOD concentration of drainage water, Kolenbrander (1975) calculated a denitrification loss of 3-5 mg $N\text{-}NO_3$ per litre. However, if the residence time in the subsoil were substantially increased, even the less readily decomposable organic compounds would be able to serve as a source of energy, thereby increasing denitrification in the subsoil by an additonal factor of not more than 4.

In additon considerable dilution may occur. The raw water pumped up by the water supply authorities from depths of 25-125 m in Pleistocene sands usually contains little or no nitrate (Kolenbrander, 1972); the same applies

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[1)] See also Appendix 1

to the water found at depths of 20 to 50 m in the peat region of the west-central Netherlands (Toussaint et al., 1973). Dilution will be greatest where pore volumes are highest and will therefore be greater in peat soils than in sandy and clay soils. The fact that residence time in the subsoil greatly affects the nitrate content is clearly demonstrated in the area drained by the Hupselse Beek (650 ha). A nitrogen content of 15 mg/1 was measured in this sandy area with an impermeable clay layer at a depth ranging between 0.4 and 8 m, while 3 km away, where the clay layer dips down much deeper, Steenvoorden and Osterom (1973) found only about 3 mg N per litre. The much deeper penetration caused dilution and/or denitrification resulting in a fivefold reduction in the nitrogen content.

It is therefore clear that not only the type of soil byt also the hydrology of a region affects the concentration of nitrate nitrogen occurring in the groundwater. Nevertheless, increased leaching will raise the concentration if denitrification is insufficient and nitrate levels in the groundwater will in the very long term approximate those of the infiltrating water.

3.3.2. Phosphorus

3.3.2.1. Mineral soils

At a depth of 1-2 m in sandy and clay soils, the drainage water and groundwater are found to contain about 0.08 mg P_t per litre. On the way down, depending on the P concentration of the water in the deeper layers, the P_t content may be reduced through dilution, adsorption and chemical precipitation.

An analysis dating from 1949 of the raw groundwater from 43 water supply authority pumping stations in the Netherlands showed that the orthophosphate content ranged from less than 0.01 to 0.086 mg O-P per litre, the average being 0.036 mg O-P per litre. However, this level is not directly comparable with the P_t content measured in shallow groundwater and drainage water. According to Steenvorden and Oosterom (1973), an O-P/P_t ratio of 0.40 can be calculated in shallow groundwater (depth 0.50-2.50 m) in unfertilized and fertilized soils. A content of 0.08 mg P_t per litre is then equivalent to 0.032 mg O-P per litre. This value is found to be in good agreement with that measured in the deep groundwater (0.036 mg/l O-P). This suggests that on normally treated cultivated land the natural concentration is already encountered immediately below the rhizosphere, and changes only slightly with increasing depth.

In the case of the increased equilibrium concentrations measured after 40 years' irrigation with potato flour process water and Tilburg sewage, levels of 0.14 and 0.33 mg O-P per litre are found in the groundwater and drainage water respectively. These concentrations are 4-9 times as high as the concentration in the deeper groundwater. Those data show that the phosphorus concentrations of water which has passed through the rhizosphere may still be reduced in the deeper subsoil. This probably also applies in the case of increased leaching of phosphorus from slurry.

Failing detailed analysis of the chemical characteristics of the soil in the deeper layers, it is impossible to ascertain whether the reduction will occur through dilution only or also through adsorption and chemical precipitation. If dilution alone is the determining factor, the phosphorus concentration will slowly but surely increase also in the deeper groundwater. However, since leaching is slow, this will be negligible in the short term.

3.3.2.2. Peat soils

Relatively high phosphorus (and also NH_4) levels are found in the deep groundwater in peat regions in the Netherlands, due to the presence of eutrophic peat down to fairly considerable depths. Toussaint et al. (1973) found the values given below.

Table 18. Frequency distribution (%) of orthophosphate and N-NH_4 levels in the deep groundwater (predominantly 20-30 m) in peat regions of the western Netherlands in mg/1

Ortho-P		N-NH_4	
Frequency	Class	Frequency	Class
39	0 -0.5	11	0 -0.3
23	0.5-1.0	25	0.3-2.3
24	1.0-2.0	27	2.5-7.5
12	2.0-4.0	19	7.5-15
2	>4.0	18	>15

Clearly, even a concentration of 0.33 mg/l O-P, as found in drainage water on the Tilburg irrigation fields (De Haan, 1972) would not be unusual in these areas because 60% of the groundwater already has a content exceeding 0.50 mg. It is impossible to say to what extent leaching on peat soil will increase in consequence of excess doeses of phosphorus. However, in view of the high orthophosphate contents of the deeper groundwater, due to the presence of eutrophic peat, increased leaching will probably have less effect on the quality than on sandy and clay soil. On the other hand, the quality of this groundwater is such that it is not always appropriate to use it for certain purposes untreated; indeed, in some places this would be very inadvisable (Toussaint et al., 1973).

3.4. Requirements as to nitrogen and phosphorus levels in groundwater and surface water

Groundwater is used for a variety of purposes, but this report is principally concerned with its significance as a source of drinking water. It is utilized as such in the Netherlands in the dune regions and in Pleistocene sandy soils. We are interested here only in the nitrate and not in the phosphorus content. As stated earlier, high nitrate levels are thought to be responsible for the "blue baby" condition, which occurs, according to Trines (1952) and Viets and Hageman (1971), incidentally, through simultaneous bacterial activity whereby nitrate is reducėd to nitrite. Archer (1972) states that nitrate may also lead to the formation of nitroso compounds, which were found to be carcinogenic in rats. The WHO has laid down the following levels (Schaeffer, 1975).

Table 19.

	mg NO_3 per l	mg $N\text{-}NO_3$ per l
Recommended	$\angle 50$	$\angle 11$
Acceptable	50-100	11-22.5
Not recommended	> 100	> 22.5

In the Official Journal of the European Communities (1975), the Council of the European Communities proposes that the maximum permissible levels in water intended for human consumption, of whatever origin, be fixed at the values given in Table 20.

Table 20. EEC guide for drinking water (maximum permissible levels)

Nitrate	50 mg NO_3 per l	(= 11.3 mg $N\text{-}NO_3$ per l)
Nitrite	0.1 mg NO_2 per l	(= 0.03 mg $N\text{-}NO_2$ per l)
Ammonia	0.5 mg NH_4 per l	(= 0.4 mg $N\text{-}NH_4$ per l)
Phosphorus	2000 µg P per l	(= 2 mg P per l)
Chloride	200 mg Cl per l	(= 200 mg Cl per l)

The nitrate level stipulated in this table corresponds to the WHO "recommended" level.

For surface water from which drinking water is to be prepared, the EEC's Directorate General of Social Affairs distinguishes three quality classes, A1, A2 and A3. Quality A1 is suitable for the preparation of drinking water by simple filtration and disinfection; A2 calls for more intensive purification; A3 demands even more advanced treatment techniques. Table 21 reproduces the Community A2 standard levels for nitrate, ammonia, phosphorus and chloride;

Table 21. EEC standard A2 for surface water intended for drinking water production (Official Journal of the European Communities, 1975)

Nitrate	50 mg NO_3 per l	(= 11.3 mg $N\text{-}NO_3$ per l)
Ammonia	1 mg NH_4 per l	(= 0.8 mg $N\text{-}NH_4$ per l)
Phosphate	0.7 mg P_2O_5 per l	(= 0.31 mg P per l)
Chloride	200 mg Cl per l	(= 200 mg Cl per l)

Leentvar (1975) quotes levels relating to the eutrophication of fens and waters (Table 22). As long as the content is below the level stated, the water conforms to the relevant designation.

Table 22. Phosphate standards for eutrophication classes of surface water in mg (ortho-)PO_4 per l

Oligotrophic	Fens	up to 0.01
Mesotrophic	Fens	up to 0.05
Eutrophic	Waters	up to 0.10
Hypertrophic	Waters	over 0.10

The standards for swimming water relate to facterial contamination only, and do not cover nitrate, nitrite, phosphate and ammonia levels.

The following levels are applicable to fishing water :

	Fishing water (maximum)	
	Salmonoids	Carp
NO_3 mg/l	≤ 3	≤ 6
NO_2 mg/l	≤ 0.05	≤ 0.5
NH_4 mg/l	≤ 1	≤ 1
PO_4 mg/l	≤ 0.2	≤ 0.4

These levels are substantially lower than the EEC's A2 standard for drinking water preparation (see Table 21). The latter does not claim to be sufficiently low to avoid eutrophication, but is based on the possibilities of chemical purification, thereby limiting eutrophication in reservoirs.

The above levels have no legal force (in the Netherlands) as regards the composition of water flowing on agricultural land from the rhizosphere to the deeper groundwater or direct into the surface water through drains. Nevertheless, they are given here to facilitate an assessment of whether and to what extent this drainage water is today considered to have an adverse effect on the quality of groundwater and surface water. This aspect is discussed in the next section.

3.5. Evaluation of the contribution of agriculture to nitrogen and phosphorus pollution of water

3.5.1. Groundwater

Since the phosphorus content of the groundwater is irrelevant to the preparation of drinking water from the public health point of view, only the nitrate content will be discussed here.

The deep groundwater (25-125 m) as pumped up by the water supply authorities in the Pleistocene sand regions of the eastern and southern Netherlands and in the dunes is found to contain practically no nitrate (Kolenbrander, 1972), so that it fully satisfies the requirements stipulated for nitrates.

This is far less true of the shallow groundwater (6-25 m) used for private drinking water supplies. For instance, Trines (1952) found that in the south of the Netherlands 32-38% of wells had levels below 10 mg/1 $N-NO_3$, while 39-48% had a content exceeding 22.5 mg/1 $N-NO_3$. He also found that about 46% of the wells were contaminated with bacteria.

It is difficult to say now how far this contamination was caused by septic tanks or manure heaps in the vicinity, but at least the possibility cannot be ruled out that the excessively high level was due to leaching of nitrate from the top layer of the cultivated land; even on unfertilized sandy soil, lysimeter measurements have revealed a leaching loss of 45 kg N per ha from the rhizosphere with 250 mm of drainage water (equivalent to a concentration of 18 mg/1 N).

Under practical conditions, as in the Hupselse Beek catchment area with an impermeable clay layer at shallow depth, a level of 15 mg/l N-NO_3 was found. A two fold or even greater increase in nitrate leaching due to the use of farmyard manure as the sole source of nitrogen for the crops is bound to lead to increased concentrations in the shallow groundwater. It is difficult to predict whether and to what extent this will be detectable in the deep groundwater, bacause it strongly depends on the possibilities of denitrification and the degree of dilution in the subsoil, and hence on the hydrology of the soil.

Where groundwater is not used to produce drinking water, nitrogen + leaching is, of course, irrelevant from this point of view, as, for example, in the peat regions of the western Netherlands and the clay soils on the coast, where the groundwater is too salty to be readily usable for making drinking water. Although the groundwater in areas with eutrophic peat down to great depths is low in nitrate, it contains a high level of ammonium-N - in excess of the EEC's standard A2 (Table 21) in at least 75% of cases according to Toussaint et al. (1973).

For the assessment of (excessively) high nitrate levels in the groundwater and possible measures thereby necessitated in the agricultural sector, it is necessary in our opinion to consider the frequency of cases of the "blue baby" condition and what measures could be taken to reduce excessive nitrate levels to acceptable values before water is used as drinking water (e.g., anion exchangers). Less than ten cases of methemoglobinemia have been reported in the UK in the last 20 years (Goodman, 1976). On the other hand, in the very long term increased leaching of nitrate may eventually lead to a considerable increase in the level even in the deep groundwater, although it is impossible to say how long this may take.

3.5.2. Surface water

3.5.2.1. Nitrogen

Although nitrogen may play a part in the eutrophication of surface water, greater importance is generally attributed to phosphate. For this reason the importance of livestock farming for eutrophication by way of increased leaching (and runoff) of nitrate nitrogen to the surface water is not elaborated here. It is merely pointed out that this increase per ha may be very considerable.

Another question is the extent to which the increased leaching affects the usability of surface water for drinking water preparation. The composition of the relevant water in the Netherlands is set out in the following table.

Table 23. Nitrogen content of surface water in 1973 and the EEC's A2 standard

	mg/1 NO_3 per l	mg/1 NH_4 per l	Total NO_3 mg per l (1)
Rhine :			
Maximum	19	7.8	45.8
Average	13	2.9	23.0
Meuse :			
Maximum	21	3.6	33.4
Average	14	1.85	20.4
Ijsselmeer (west) :			
Maximum	17.3	1.74	23.3
Average	7.1	0.31	8.2
EEC standard A2	50	1.0	53.4

(1) After oxidation of NH_4 present

This shows that excessive NH_4 levels are more of a problem than excessive NO_3 levels. However, the contribution of agriculture, where occurring by way of leaching, is predominantly in the form of nitrate. In the longer term, N-NH_4 could also reach the water through runoff shortly after manuring or at low temperatures.

The main nitrogen pollution from agriculture is to be expected on drained land, where the water passing through the rhizosphere flows direct into the surface water. On arable land with sandy soil receiving an average of 170 kg fertilizer-N per ha, about 24 kg of this amount will leach out. If an equivalent quantity of cattle manure N is applied in the spring instead of chemical fertilizer, the loss will be about 50 kg N per ha. Without manuring, leaching would amount to about 45 kg, so that the total burden reaching the surface water will be about 100 kg per hectare of arable land manured in this way. Assuming a drainage water production of 250 mm, this gives a concentration of 40 mg/1 $N-NO_3$ (180 mg/1 NO_3). This drainage water thus falls far short of the EEC's A2 standard for surface water for drinking water production. If only chemical fertilizer N were applied, leaching would be approximately 28 mg/1 $N-NO_3$ (about 124 mg/1 NO_3) - still far above the EEC standard. It is obvious that manuring in autumn or winter would aggravate the situation still further.

It may therefore be concluded that the nitrate content of water on arable land (sandy soil) after passing through the rhizosphere is greater than the permissible level for drinking water, or surface water intended for drinking water preparation. This conclusion applies in the case of optimum application of chemical fertilizer, and is even more valid if an equivalent quantity of farmyard manure N is used instead of chemical fertilizer. In the evaluation of this conclusion it should be borne in mind that the water penetrating into the deeper layers of the soil, before it is processed into drinking water, is diluted in the ground with groundwater and partially denitrified, so that it can do little damage in the short term. Where it is discharged through drains direct to the surface water, it also sustains a substantial reduction in concentration through denitrification (Van Kessel, 1976) and dilution (compare concentrations set out in Table 23).

3.5.2.2. Phosphorus

There is no unambiguous, generally acceptable standard for the permissible phosphorus content of surface water. In fact, standards must be set separately for each water depending on the use for which it is intended.

The EEC's A2 standard for surface water for drinking water preparation (0.31 mg/1 P as orthophosphate) is relatively high. Groundwater at a depth of 2.5 m below natural land and heavily fertilized land (Table 15) has far lower levels. This is even the case with the concentrations found in the irrigation complexes of the potato flour industry (0.14 mg/1 orthophosphate), but no longer so as regards the Tilburg irrigation fields (0.33 mg/1).

However, if the levels quoted by Leentvaar (1975) in Table 22 are taken as the basis, even the groundwater found below natural land must be regarded as eutrophic.

In our opinion, the contribution of agriculture to eutrophication can best be evalued by investigating the levels thereby arising per m^2 of fresh surface water and comparing them with the contributions from other sources.

Scholte Ubing (1972) calculated an average level in surface water in the Netherlands of 6.3 g total P per m^2 water; Kolenbrander (1974) reported 5.8 g/year. For shallow surface water as in the Netherlands, these values are more readily comparable with figures quoted by Brezonik (1972) for shallow lakes in Florida than with the standards given by Vollenweider (1970), drawn up for deep lakes in Europe and North America. A "permissible" level of 0.28 g P_t per m^2 per year can be calculated from Brezonik's material, while 0.50 g is considered "dangerous" as regards eutrophication. This standard is more severe than the level of 1 g P_t per m^2 proposed as the provisional limit by the Royal Netherlands Chemical Association's working group on phosphates (not yet published).

Kolenbrander (1974) apportions the pollution of surface water in the Netherlands among the different sources as follows.

Table 24. Contribution of different sources to phosphorus pollution of fresh surface water in the Netherlands in 1970

	P_t per m^2 per year	
Rivers	2.67 g	
Households	2.13 g	point discharges
Industry	0.40 g	
Agriculture :		
a. Direct discharges	0.28 g	
b. Runoff	0.10 g	
c. Leaching losses from manuring	0.00 g	diffuse discharges
Soil	0.18 g	
Rain	0.07 g	
Total	5.83 g	

The two (natural) sources, rainfall and soil, together contributed 0.25 g, thus remaining below Brezonik's suggested standard. A further 0.38 g was added by the three agricultural sources, direct discharge, runoff and manuring, thus exceeding both the safe and the "dangerous" level. Nevertheless, the total contribution of these five sources was only 0.56 ÷ 5.93 = 10% of the total pollution.

The contribution of agriculture by way of direct discharges should meanwhile have ceased, thus reducing pollution by 0.28 g. If the contribution of runoff now increases with increasing concentration in the topsoil, as is to be expected at high stocking rates, the 1970 situation is only reached again if runoff is increased by a factor of 3.8. Our data do not indicate that this is likely to occur in the short term.

On the basis of the situation discussed above, there appears to be little point in taking measures in agriculture, apart from the control of direct discharges to surface water already instituted, for the purpose of reducing eutrophication. However, completely different factors could change the situation. On the one hand, the contribution of agriculture could become relatively larger if that of households, industry and rivers is reduced, and on the other hand it is conceivable that in the long term phosphorus over and above the crop requirements on cultivated land could reach the surface water after all. If the excess phosphorus were in fact eventually to reach the surface water quantitatively, this would inevitably result in a multiple of the current total pollution load in a country such as the Netherlands.

It is not known whether this will occur, and if so when. In our opinion research on this point is urgently called for.

4. Summary

The first section of this chapter discusses the amounts of animal manure to be applied in order to maximize crop production without the chemical composition of the crop constituting a health hazard to man and beast.

On arable land, limits are set to the use of animal manure by the quantity of nitrogen; potassium is an additional limiting factor in the case of industrial potatoes. Excess phosphate is seldom harmful. The amount of animal manure to be applied is determined on the basis of the nitrogen requirements of the various crops, i.e., the quantity of nitrogen, in the form of chemical fertilizer, applied in spring, required for maximum yield. The nitrogen requirement can easily be calculated for any cropping programme on the basis of the nitrogen requirement of each crop and the share of each crop in the cropping programme. The nitrogen requirement ranges from approximately 110 to 200 kg N per ha for cropping systems which comprise only cereals and only root and tuber crops (and maize) respectively.

The quantity of manure which can be applied in a given cropping programme can be calculated from the composition of the various types of manure and the "efficiency index" for the nitrogen. The acceptable stocking rate can be determined from this. It is suggested that the efficiency index, i.e., the factor which indicates what proportion of the nitrogen present in the manure is equally effective as chemical fertilizer nitrogen applied in spring, is 0.75 in the case of regular application in spring and 0.45 with continued application in autumn. At an average efficiency index of 0.60 (manuring in the entire period between autumn and spring), a permissible stocking intensity of 1.9 LU or equivalent numbers of other animal species (Table 3) per 100 kg N requirement (as chemical fertilizer N) can be calculated.

On grassland, amounts of animal manure are based on potassium, to avoid hypomagnesemia. Assuming a satisfactory level of potassium in the soil, it can be calculated that grassland on clay soil has no capacity for any manure additional to that produced by the farm's own herd unless measures to prevent hypomagnesemia are taken. Grassland on sandy soil can accommodate manure from other animal species provided that the stocking rate does not exceed about 3 LU (Table 8) and no action is taken to combat hypomagnesemia.

According to the second section of this chapter, which deals with soil pollution, regular application of high doses of animal manure has both favourable and unfavourable effects on the soil as the habitat and nutrient source of agricultural crops. Arable land experiences more of the advantages and less of the disadvantages than permanent grassland.

On arable land, at a stocking rate of 1.5 or more LU or equivalent numbers of other animal species (see Table 3, "organic matter"), the humus content is likely to increase substantially, with concomitant improvements in the physical and biological condition of the soil. Its ability to supply nitrogen increases, but, at the stocking rate stated, not to such an extent that it becomes unsuitable for long periods for growing sensitive crops such as cereals. The increasing phosphorus level is favourable, or at least harmless. The expected increase in potash levels is favourable to a crop such as ware potatoes but unfavourable to industrial potatoes. A high potash level which has arisen through animal manuring may, however, be expected to fall back to an acceptable value if potash application ceases. The effect of hen manure on the pH of the soil is valuable up to a point, as it eliminates or reduces the need for liming. However, if the manure of more than about 350 hens is applied per ha, the resulting increase in pH in sandy soils with relatively little buffering capcity will cause difficulties in the growing of sensitive crops such as potatoes. Assuming that the soil has a normal, satisfactory copper content, the use of copper-containing pig manure in doses of, for example, 20 tonnes of slurry per ha (about 12 pig places) may result in an excessive accumulation after about 150 years, harmful to the growing of all kinds of agricultural crops.

On grassland, the use of copper-containing pig slurry is undesirable particularly if the land is to be used at the same time or in the future for sheep grazing. At doses of 20 tonnes of pig slurry, land with a normal satisfactory copper content can very quickly become hazardous grazing for sheep. The high potash content of the sward liable to occur with heavy doses of manure is also unfavourable because of the risk of hypomagnesemia. This does not mean that an excessive level which has arisen through manuring cannot quickly be reduced again by ceasing to apply further potash, but this is not very likely to occur on cattle farms. The increase in the humus content of the sward to be expected on application of the manure of more than 1.5 LU produced when the animals are housed has an adverse effect on the firmness of the sward on wet grassland, thus impeding access in early spring, autumn and winter. It is uncertain whether the high phosphorus level to be expected constitutes a risk to yields and health of grazing animals. An unnecessarily high pH can arise where hen manure is applied to grassland even at low stocking rates (over 75 birds per ha).

It may be concluded from the above that soil pollution definitely occurs if copper-containing pig slurry is used regularly. It is considerably less desirable from the point of view of soil fertility to apply animal manure to grassland intended to remain such than to arable land.

The third section of this chapter discusses animal manure with reference to plant nutrient losses through leaching out of the rhizosphere and runoff.

Phosphorus occupies a key position in the process of eutrophication of surface water by stimulation of algal growth. For this reason every effort is made to reduce phosphorus concentrations to such an extent that the element becomes growth-limiting.

High nitrogen losses in the form of nitrate can lead to high nitrate concentration in the groundwater and surface water, causing difficulties in drinking water preparation.

The danger is the occurrence of methemoglobinemia (the "blue baby" condition) in infants less than six months old. Similar symptoms have been observed in livestock.

Research with waste waters shows that the soil is in general a good filter for organic matter and phosphorus. An average of 93% of the BOD_5 and 98% of the phosphorus was found to be retained in the topmost metre of the profile. Nitrogen, potash and chlorides are appreciably less well adsorbed. On peat soils, however, adsorption of phosphorus is also found to be considerably lower than on mineral soils.

Analogous to irrigation with waste water, it is to be expected that heavy application of animal manure will eventually lead to increased leaching of phosphorous out of the rhizosphere. However, too little quantitative information is available as yet on this point. A small number of tests have shown that with large doses of slurry a quantity of phosphorus has penetrated down to a depth of 1 m or more after only a few years. This may be taken as a warning to take account of the water holding capacity of the soil whenever slurry is used. With nitrogen it may be expected that where chemcial fertilizer on arable land with sandy soil is replaced by a dose of farmyard manure equivalent from the point of view of N supply, leaching will eventually increase by a factor of 2 if the manure is applied in spring only and by a factor of 6 with autumn application. Since both forms of application are current in practice for reasons of labour economy, the average increase on arable land with sandy soil is estimated to amount to a factor of 4. The nitrogen concentration of the water infiltrating from the rhizosphere in sandy soil with normal chemical fertilizer application already exceeds the standard laid down for drinking water preparation; the permissible level is exceeded to a much greater extent if equivalent doeses of farmyard manure are used.

On grassland, N leaching will increase substantially if the amount of nitrogen applied (in chemical fertilizers and farmyard manure) exceeds 350 kg.ha/year. Below this level, nitrogen losses are slight and relatively insignificant provided that the manure is applied in spring only.

In drained land, the surface water will be polluted directly by the water that has passed through the rhizosphere with its increased levels of phosphorous, nitrogen and pathogenic organisms. If the land is not drained, considerable dilution may occur with the deep groundwater (25-125 m) which is pumped up by the water supply authorities in the Netherlands from below Pleistocene sandy soils. This deep groundwater mostly contains no nitrate, while its orthophosphate concentration is equivalent to that occurring below the rhizosphere on natural and normally manured land. The risk of contamination of the deep groundwater with pathogens is considered slight.

No difficulties are to be expected in the short term as regards the quality of the deep groundwater for drinking water preparation in these Pleistocene sandy regions. The risk of an increase in concentration in the deeper groundwater, at worst equalling that of the leachate, exists only where processes such as denitrification, phosphorus adsorption and chemical fixation of phosphorus contribute insufficiently to reducing the concentration in the descending water. However, it is impossible to indicate, even approximately, where, when and to what extent this may occur. The groundwater at a depth of 20-30 m and deeper in the peat regions of the western Netherlands is by nature already so rich in phosphorus, ammoniacal nitrogen and chloride that it is unsuitable for drinking water preparation, so that increased leaching losses will be insignificant as regards groundwater quality.

In the short term, an increase in P pollution by way of runoff appears more important. Excess manuring with phosphorus will cause the contribution through runoff to increase with increasing soil phosphorus content. This may be expected on arable land at a stocking rate of more than 1.5 adult cattle per ha or equivalent numbers of other animal species (Table 3). On the other hand, however, the cessation of direct discharges in agriculture has relieved phosphorus pollution of surface waters, so that even a tripling of the contribution through runoff does not cause the previous total pollution load to be exceeded. The relative proporiton of P pollution accounted for by runoff will increase substantially only if the contriubtion of large rivers, population and industry, which in 1970 together accounted for nearly 90% of P pollution in the Netherlands, is drastically reduced. Obviously, it will then be more sensible to introduce measures to combat excessive leaching of phosphorus.

It may be concluded from the third section of this chapter that the permissible dose of manure from the point of view of water pollution (called the ecological optimum dose in this report) is lower than the physiological (economic) optimum dose. With regard to the chemical composition of the shallow groundwater, this is the case, in particular, with nitrogen on arable land with sandy soil. As regards the composition of the surface water, this is true for phosphorus, particularly on soils sensitive to runoff.

III Discussion and choice of simple criteria for possible official control of permissible doses

Introduction

An undeniably important criterion for possible official control is the crop's requirement of plant nutrients in order to maximize production and achieve good quality. The corresponding dose of animal manure was termed the physiological optimum in the previous chapter. This optimum was found to be related to the nitrogen contained in the manure for arable crops, and to potash in the case of grassland. The stocking rate per ha was introduced as a simple measure of this optimum. This criterion is already used in several European and North American countries. This cahpter does not again discuss the importance of manuring to the crop, but deals rather with the consequences for the environment.

The principal objections to the use of high doses of manure are environmental and relate to air, soil and water pollution.

Air pollution and odour nuisance are not considered in this study. As regards soil pollution, as shown in Chapter II, only the accumulation of copper in the soil due to Cu-enriched pig manure need give cause for concern.

With regard to water pollution, a distinction is made between groundwater and surface water, owing to the different uses to which the two are put. Groundwater may be deemed to be polluted if it does not satisfy the requirements laid down for drinking water, and surface water if it is too eutrophic for certain applications; it must remain usable as fishing and swimming water, but also, as in the case of groundwater, as a raw material for the preparation of drinking water, as is likely to become increasingly necessary in the future.

It is necessary to consider possible environmental criteria for the drafting of regulations governing manure application.

1. Soil pollution

The regular use of Cu-enriched pig manure may increase the copper content of the soil to such an extent that the unimpeded growth of various crops will no longer be possible on arable land and that a health hazard is presented to sheep on grassland. According to Chapter II, a risk is found to arise at a Cu (HNO_3) content of approximately 50 ppm and above; even lower values already constitute a hazard to sheep.

The Cu content of the soil would be the most direct criterion for regulation, as it is easy and cheap to determine and constitutes a direct measure of the degree of pollution and the accompanying hazard. This method is to be preferred to, for example, the number of pigs per ha, because the latter takes no account of the effect of the type of soil or, for instance, of the distribution of the manure over the farm's land as a whole.

2. Groundwater pollution

Standards are set for groundwater in connection with its use for drinking water preparation. For the purposes of the study, only the standard for the nitrate content of drinking water is relevant; the danger here is the possible occurrence of nitrate reduction in infants less than six months old (methemoglobinemia or cyanosis - also known as the "blue baby" condition).

It may be asked whether it is desirable to use the requirements now applicable to groundwater as the basis for possible official regulation of manure application or whether an increase in the nitrate content should be accepted, since the nitrate content of drinking water can be reduced by ion exchangers. If nitrate elimination were limited to the amount of water that is actually consumed (about 2% of total domestic consumption), this makes it possible to match drinking water quality substantially to individual requirements, e.g., by the installation of an ion exchanger in the kitchen. The resulting costs can be compared with the consequences of limitation of manure utilization in agriculture.

If it is nevertheless assumed that the NO_3 content of the groundwater must not be substantially increased, the most immediate criterion is then, of course, the extent to which manuring affects the NO_3 content of the groundwater. However, this criterion cannot be used, because this effect cannot be measured simply.

The effect on the nitrate content of the groundwater is directly related to the quantity of nitrate leaching out of the rhizosphere, although this relationship is extensively modified by such factors as differences in the hydrology of the land. But even the quantity of nitrate leaching out of the rhizosphere is difficult to measure, and therefore cannot serve as a criterion. Even the nitrate content of the drainage water cannot be used owing to the big fluctuations liable to occur in it over a short period.

The quantity of nitrate leaching out of the rhizosphere in turn depends on the quantity of nitrogen applied(1). This is measurable and could therefore be used as a criterion. However, it would not be feasible to enforce compliance with a standard based on this parameter. For this reason it is better to adopt a relatively simple measure of the amount of nitrogen used, in the form of nitrogen input by way of the stocking rate and application of chemical fertilizer. Choice of the stocking rate per ha as the sole criterion admittedly provides a relatively convenient measure of the effect of NO_3 content on the groundwater, but no more than a rough measure, as the relation between the two is affected by a number of factors - e.g., the time and manner of manure application, nitrogen uptake by the crops, degree of denitrification, type of soil, hydrology of the land, and amount of precipitation in excess of evaporation.

For practical purposes, however, this complication must be taken into account. It may, for example, be questioned whether it is necessary to introduce control measures on low peat soils where the groundwater and surface water are in any case naturally unsuitable for drinking water preparation.

3. Surface water pollution

Although nitrogen may play an important part in the eutrophication of surface water - especially where phosphorus is no longer at a minimum - the emphasis is primarily on phosphorus pollution. The nitrogen requirements of aquatic life can normally be satisfied by nitrogen fixation from the atmosphere (blue-green algae) and from nitrogen supplied by rainwater (10-15 kg per

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(1) Also, the amount of nitrate leaching out is roughly linearly related to precipitation in excess of evaporation up to 600 mm. The amounts of surplus precipitation in the various regions of high livestock concentrations in the EEC vary only from about 250 to 330 mm (Mohrmann and Kessler, 1959), so that leaching losses due to this factor are not greatly different.

ha in the Netherlands). For this reason efforts are directed towards reducing phosphorus pollution so as once again to minimize phosphorus as a growth factor.

As in the case of groundwater, it is preferable to adopt as our criterion the effect of manure dosage on the P_t content of the surface water. On drained land, the phosphorus content of the drainage water, together with the quantity of water, is, of course, a good criterion here. Even the P_t content as such could be used if stable, as is to be expected on land which receives predominantly inorganic fertilizer at a long-term constant level; with large doses of animal manure (slurry), however, relatively substantial fluctuations will occur. The content in the drainage water is then usable only if it is measured very frequently and combined with estimates of the corresponding quantities of drainage water. On undrained land, the P_t content of the groundwater is a measure of the potential enrichment of the surface water, but this criterion cannot easily be applied owing to the varying depth of sampling that would be necessary, quite apart from deficiencies in sampling and analytical techniques.

As with nitrate pollution of the groundwater, the stocking rate per ha could also be contemplated as a simple criterion of P pollution of the surface water by manure. However, it was shown in chapter II that phosphorus leaching from the rhizosphere is affected only slightly, if at all, by manuring, except perhaps for organic phosphorus. For this reason, the stocking rate per ha is for the time being of little or no relevance as a criterion of the contribution of <u>leaching</u> to the P_t load. If a stage is ever reached where all the surplus phosphorus applied is leached out, the stocking rate will be a good criterion. But it is impossible to say whether this will ever be the case, and if so when.

The stocking rate can, however, already be significant if runoff is also considered.

Runoff occurs where the supply of water in the form of precipitation exceeds the infiltration or water-holding capacity of the soil. On frozen ground, this capacity may be practically nil. The melt water from accumulated snow will flow primarily over the surface, dissolving mineral compounds out of the soil and taking organic matter and/or particles of soil with it.

During the growing season, runoff may occur after heavy showers. About 20 mm of water is required to saturate an arable layer of 20 cm on moderately dry soil, so that the absorption capacity in the growing season will range from 0 to 20 mm, depending on the moisture content, with an average of 10 mm. Hence a shower in excess of 10 mm will only be taken up by the soil if the rainfall intensity does not exceed the permeability of the soil, in which case the rainwater penetrates directly to deeper layers. It therefore appears possible to group soils into different runoff sensitivity classes on the basis of the permeability factor of the soil (K_0 in mm per day) and the amount and intensity of precipitation in the different seasons.

In the conditions prevailing in the Netherlands, runoff in winter occurs only during an 8-14 day period of frost, which is experienced on average once a year. At this time the ground is frozen and the 25 mm average precipitation in this period (about 3% of total annual precipitation) accumulates as snow and is possibly largely eliminated as runoff. In the regions of high livestock concentration of the other countries of the EEC, the lowest measured temperature and the mean daily minimum temperature in the coldest month differ only slightly from those in the Netherlands (except in Brittany (Table 25)), so that runoff amounts in winter may be expected to be of the same order of magnitude everywhere.

Under Dutch climatic conditions, runoff is virtually confined to winter. Rainfall amounts to between 20 and 35 mm per day on only five days in the year, the intensity in 88% of these cases remaining below 6 mm/h. During the period of high evaporation, most types of soil are perfectly capable of absorbing this quantity at the prevailing groundwater level. In the last ten years, rainfall of 20 mm per day with an intensity approaching erosion velocity (over 25 mm/h) has occurred only once; in all other cases the intensity was below 12 mm/h.

It is necessary to examine whether conditions in other EEC countries differ significantly. The authors consider this to be unlikely, as precipitation amounts vary relatively slightly, except in Lombardy.

The likelihood of puddle formation and runoff outside the frost season increases sharply only in soils with a permeability factor K_0 of less than 6 mm/h since this permeability is less than the rainfall intensity that often occurs. These soils fall into the categories "impermeable" (K_0 less than 0.4 mm/h), "relatively impermeable" (K_0 = 0.4-4 mm/h) and sometimes also "moderately permeable" (K_0 = 4-20 mm/h).

In addition to soil permeability, the topography of the land also affects runoff. The slope on which the precipitation falls is one of the principal characteristics of the land. If the rainfall does not penetrate quickly into the soil or the soil layer is very thin, a part of the water will flow down the slope or over the hard substratum to lower levels, thus causing runoff. The steeper the slope, the greater this effect is likely to be.

However, according to the review of the literature by Ryden et al. (1973), land use is also an important parameter. Runoff remained small even on 10-20% gradients if the slope was covered with grass. In winter, the amount of precipitation accumulating as snow is more important than the gradient.

Hence the slope is not an unequivocal criterion, but it must nevertheless be taken into account, while it is essential to consider also whether the land has vegetation cover or not.

It was already pointed out in Chapter II that with increasing applications of phosphorus, the P_t load of the surface water by way of runoff is likely to increase faster than by way of leaching, because the amount of water-soluble phosphorus in the arable layer will increase to a greater extent than in the layers below the rhizosphere. The increase in the quantity of P in the soil depends directly on the amount of P applied with manure, which in turn depends on the stocking rate. For this reason the stocking rate per ha is a simple and convenient measure of the P_t load of the surface water by way of runoff. The more sensitive the soil to runoff and the more climatic conditions favour runoff,

Table 25: Climatic characteristics of some regions of the EEC with stocking rates of 130 LU/100 ha or more

EEC regions	Mean annual temperature °C	Mean daily minimum temperature in coldest month °C	Lowest measured temperature °C	Annual rainfall mm	Annual water surplus mm	Livestock units per 100 ha
1. Denmark	7.5	- 2.6	- 20,5	640	257	170
2. North Rhine-Westphalia	8.2	- 2.6	- 23,3	795	300	136
3. Lower Saxony	8.4	- 1,4	- 21,7	725	275	132
4. Netherlands	8,4	- 1,4	- 21,7	705	245	189
5. Belgium	9,9	- 0,3	- 19,0	810	330	185
6. Brittany	11,4	+ 3,0	- 11,1	780	315	130
7. Lombardy	12,1	- 1,4	-	1000	310	141
Average	9,4	-	-	780		155

the lower should be the stocking rate per ha in principle, while more severe limitations could also be imposed on the amount and timing of manuring. On soils which are highly sensitive to runoff, it may even be appropriate to consider the possibility of imposing limitations on soil fertility (in particular, with regard to phosphorus). In such a case, the unlimited use of chemical fertilizer phosphorus will, of course, also not be permissible.

Obviously, as in the case of nitrogen, the criterion of the stocking rate per ha is a rough one. The phosphorus content of the arable layer could be used as a supplementary criterion, applied to P pollution by runoff.

In the author's opinion, the question as to whether limits should be set on phosphorus pollution of the surface water by agriculture should be considered in the light of the already existing pollution of the water from other sources. If, for example, the total pollution of surface waters in the Netherlands (Chapter II, Table 24) is considered, then there is for the present no reason to take P pollution by runoff as a criterion, particularly as a high phosphorus level can be slowly reduced to more normal proportions by correct manuring practices. Phosphorus pollution due to runoff is also of little importance in low level peat regions where the P pollution level is already high through natural leaching, seepage and the presence of marsh gas.

4. Summary

The parameters which could be used as criteria for possible official control of manure application are discussed. The possibility of using the crop's nutrient requirements as such a criterion was already dealt with comprehensively in Chapter II. The emphasis in Chapter III is mainly on possible pollution of the soil, groundwater and surface water.

As stated earlier, soil pollution is liable to occur virtually only where copper-enriched pig manure is used. The copper content, determined by chemical analysis of the soil, is considered a serviceable criterion for determination of the degrees of this pollution and possible limitation of manuring.

The groundwater may be said to be polluted if its nitrate content, owing to leaching, exceeds the level set for drinking water. The factors, upon which the quantity of leached nitrate depends, include the amount of nitrogen applied in the manure, which in turn depends on the stocking rate. The latter is thus a serviceable, if only rough, criterion of pollution of the groundwater. For that matter, it is necessary to consider whether the strict standard applicable to the nitrate content of drinking water constitutes a reasonable basis for the regulation of manuring and hence for possible serious interference with the interests of agriculture. With regard to the pollution of surface water, particular importance attaches to phosphorus. Leaching of phosphorus in the rhizosphere bears little or no relation to manuring, so that such a criterion of surface water pollution is for the time being inappropriate. More relevant is pollution due to runoff. The adoption of the sensitivity of the soil to runoff, climatic characteristics and the stocking rate as criteria is suggested, possibly supplemented by determination of the phosphorus content of the topsoil on the relevant farms.

Existing pollution must be taken into account in any decision as to whether or not to impose standards for phosphorus pollution of the surface water.

IV. Elaboration of standards for official control of permissible doses

Introduction

It was explained in Chapter II that the crop's nutrient requirements can be used as a criterion for the possible regulation of permissible quantities of manure. The physiological optimum for arable crops and grassland was related to amounts of nitrogen and potassium respectively in the manure. A suitable criterion here is the stocking rate.

It was also shown that soil pollution is liable to occur only where copper-containing pig manure is used. The copper content of the soil can be used as a criterion in this case.

The groundwater may be deemed to be polluted if the nitrate content exceeds the levels specified for drinking water. The stocking rate can be used as a rough measure of this parameter.

Phosphorus, primarily in runoff, is the main factor to be considered in the pollution of surface water. For this reason it was suggested in Chapter III that the runoff sensitivity of the soil be used as the criterion in this case, together with the stocking rate, climatic conditions (frequency and intensity of rainfall, frost, etc.) and possibly the phosphorus content of the soil.

1. Maximum crop production

From the data in Chapter II, the optimum stocking rate from the production point of view can be calculated for a farm or agricultural region, nitrogen being the limiting factor for arable land and potassium for grassland. This will now be illustrated by an example.

The following permissible stocking rate can be calculated for a farm with sandy soil with a nitrogen requirement for the arable crops of 170 kg N per ha and a stocking rate of 3 livestock units per hectare of grassland (potash requirement 306 kg/ha K_2O - see Table 7):

Per hectare of arable land: $170/89 \cdot 100/60 = 3.18$ livestock units (LU) on a nitrogen equivalent basis, 1 LU N-equivalent representing the N production of one adult cow per year (89 kg), at an efficiency index of 60% for the nitrogen in the manure (see Table 2).

The number of animals of other species (on the basis of nitrogen equivalents) can be calculated from the figures for cattle from Table 3 or Table 26.

Per hectare of grassland: 24/100 = 0.24 LU on a K_2O-equivalent basis, 1 LU K_2O-equivalent representing the K_2O production of one adult cow per year (100 kg). (Annual-basis production determined from the production during the 180-day housed period is in good agreement with the sum of the amounts in the housed and grazing seasons respectively; see also Kolenbrander and De La Lande Cremer, 1967). The figures are taken from Table 8, which shows that, in addition to the land-dependent stocking rate of 3 adult cattle per ha of grassland, there is also room for 0.24 LU K_2O equivalents in the form of pigs and poultry (see Tables 3 and 27). If suitable measures are taken to combat hypomagnesemia, it is estimated that this can be increased by as much as 50%, to 0.36 LU K_2O equivalents (see Chapter II, Section 1.2.).

With an arable land/grassland ratio of 50:50, the permissible stocking rate for this farm per hectare of arable land is:
0.5 (3.18 + 3 + 0.24) = 3.21 or 0.5 (3.18 + 3 + 0.36) = 3.27 LU
made up of 1.5 adult cattle, 0.12 or 0.18 LU on a K_2O equivalent basis (pigs, poultry) and 1.59 LU on an N equivalent basis. It is assumed here that the cattle manure produced during the housed period is spread on grassland. This is generally true for moderate cattle stocking rates, i.e., three adult cattle or less per ha of grassland.

At higher stocking rates, the potash production in the manure will exceed the potash requirements of the grassland owing to the purchase of concentrated feeds (and roughage), so that the surplus must be applied to arable land, unless appropriate measures to combat hypomagnesemia are taken (see also Chapter II, Section 1.2.). This situation is illustrated in figure 8.

The above calculations are based on an efficiency index of the nitrogen in manure of 60%, which is valid if manure application is distributed approximately uniformly over autumn, winter and spring. However, if the time of application is also to be controlled, e.g., by confining it to spring, the efficiency index will be higher, resulting in a lower permissible stocking rate.

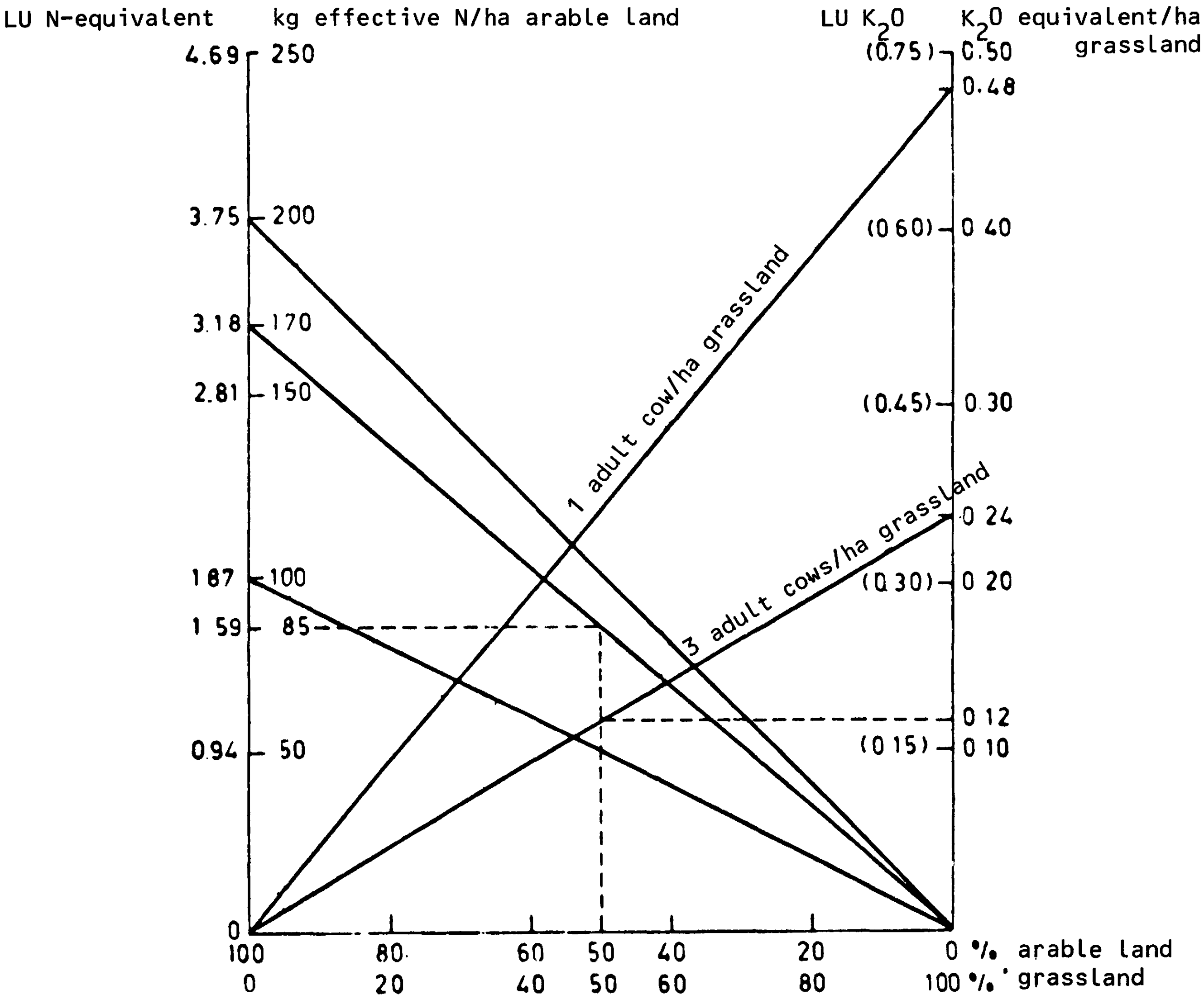

Figure 8: Optimum stocking rate in livestock units (LU) on the basis of N-equivalents per ha of arable land and K_2O-equivalents (additional stocking rate) per ha of grassland, and combinations of these (per ha of cultivated land)

If the fertility management is based on nitrogen (arable land) or potassium (grassland), other elements may be applied in excess. The quantities involved are calculated below for Dutch conditions.

Assuming a conventional cropping system on arable land, the average nitrogen requirement works out at about 170 kg N per hectare (173 and 164 kg N for sandy and clay soil respectively) (see Chapter II, Section 1.1). Similarly, using the Dutch "Adviesbasis voor Landbouwgronden" ("Recommendations for Agricultural Land"), the relevant average phosphorus requirements may be calculated as 65 kg P_2O_5 per hectare (67.8 and 61.5 kg P_2O_5 for sandy and clay soil respectively), and an average potash requirement of 105 kg K_2O per hectare (108.5 and 102.5 kg K_2O for sandy and clay soil respectively), if the fertility status of the soil falls within the "good" category.

See Tables 7 and 9 for figures on the potash and phosphorus requirements of grassland.

Table 26 sets out the weight of manure of different types of livestock corresponding to 100 kg of chemical fertilizer (assuming a nitrogen efficiency index of 60%) and the quantities of nutrients thereby administered. At low numbers of animals (cows, pigs and calves) the values are in fairly good agreement with the averages for the 45% and 75% efficiency indices in Table 6, but in the case of large numbers (poultry) the differences are greater. For this reason, if an average efficiency index of 60% is assumed, it is preferable to use the figures in Table 26.

Table 26: Quantities of animal manure corresponding to 100 kg of chemical fertilizer N at an efficiency index of 60%, the relevant numbers of animals, and the total quantities of nutrients supplied

	Quantity (tonnes)	Total N (kg)	P_2O_5 (kg)	K_2O (kg)	Stocking rate
Cattle slurry (1)	38	167	76	190	1,9
Pig slurry (2)	24	168	113	96	15
Poultry slurry (1)	19	171	179	86	238
Poultry manure (solid) (1)	13	162	243	117	324
Broiler manure (solid) (2)	7	161	147	112	1000
Calf slurry (2)	56	168	73	134	25

(1) Animal numbers on annual basis
(2) Number of animal places (see Table 2)

Table 27 shows the number of tonnes of manure of the different animal species providing 100 kg of K_2O (1 LU K_2O-equivalent), the efficiency index of potassium in animal manure being taken as 100%.

Table 27: Quantities of animal manure required to supply 100 kg K_2O (1 LU K_2O-equivalent), the relevant numbers of animals, and the total quantities of nutrients supplied

	Quantity (tonnes)	Total N (kg)	P_2O_5 (kg)	K_2O (kg)	Stocking rate
Cattle slurry (1)	20	89	40	100	1
Pig slurry (2)	25	175	118	100	15,6
poultry slurry (1)	22	198	207	99	278
Poultry manure solid (1)	11	138	206	99	278
Broiler manure (solid) (2)	6,2	143	130	99	893
Calf slurry (2)	42	126	55	101	18,9

(1) Animal numbers on annual basis

(2) Number of animal places (see Table 2)

The following balance sheet can now be compiled from the figures given in Tables 8, 9, 26 and 27; it is applicable to arable land with a nitrogen requirement of 170 kg N per hectare and grassland stocked with cattle at a rate of 3 LU per ha (sandy soil):

Per hectare of arable land

Supply (Table 26)	P_2O_5 (kg)	K_2O (kg)
Minimum	170/100 · 73 = 124 (calf slurry)	170/100 · 86 = 146 (poultry slurry)
Maximum	170/100 · 243 = 413 (poultry manure-solid)	170/100 · 134 = 228 (calf slurry)
Requirement	65	105
Surplus		
Minimum	59	41
Maximum	348	123

Per hectare of grassland (sandy soil)

Land-dependent livestock (cattle) -	P_2O_5 (kg)	K_2O (kg)
Surplus (production in manure less requirement: Tables 7 and 9)	-1	-24
Supply (Table 27)		
Minimum	(24/100 · 55 = 13 (calf slurry)	24
Maximum	(24/100 · 207 = 50 (poultry manure-solid)	24
Additional supply (50% with measures to combat hypomagnesemia)		
Minimum	6	12
Maximum	25	12
Total surplus		
Minimum	12	0
Maximum	74	12

On grassland with clay soil, the minimum potassium surplus at 3 LU/ha is already 300 - 266 = 34 kg K_2O per hectare (Table 7) without any contribution of manure from elsewhere. If the importation of, for example, 10 tonnes of pig slurry (assuming suitable measures to combat hypomagnesemia), or an equivalent quantity of calf or poultry manure (40 kg/ha K_2O), is considered permissible, the K_2O surplus increases to 74 kg/ha (see also Chapter II, Section 1.2.). The P_2O_5 surplus, which amounts to a minimum of -1 kg/ha, may jump to 82 kg/ha, if the additional 40 kg of K_2O is applied in the form of phosphate-rich poultry manure (Table 27).

The surplus of these nutrients per hectare of cultivated land can easily be calculated by multiplying the surpluses per hectare of arable land and grassland by their respective shares in the total cultivated land, and adding these products.

It is assumed in the above calculation that no cattle slurry is spread on arable land within a farm. If this is in fact done, because cattle manure can no longer be accommodated on grassland at high stocking rates (more than

3 LU/ha grassland), the potassium surplus on arable land may increase to a maximum of (170/100 · 190) - 105 = 218 kg/ha K_2O (Table 26). It is also assumed that no imported (potash-rich) cattle slurry is used on grassland for the supplementary manuring.

The manuring policy outlined above obviously entails overdosage with phosphorus - especially on arable land, and to a lesser extent on grassland. The same applies to potash on arable land. On grassland, the permissible dose of manure is based precisely on this nutrient, but a certain surplus is accepted provided that suitable measures are taken to combat hypomagnesemia (see above). Increased levels of these nutrients in the soil are not regarded as harmful from the point of view of crop yield and quality, except possibly in the case of phorphorus on grassland (see Chapter II).

2. Soil pollution

As stated in Chapter II, Section 2.5., the slurry of pigs fed with feed to which 125 ppm Cu has been added contains 50 ppm Cu. The question to be considered is how much pig slurry can be safely accommodated with a manuring policy based on nitrogen and potassium for arable land and grassland respectively.

2.1. Arable land

Table 26 shows that 24 tonnes of pig slurry is necessary to obtain the effect of 100 kg of chemical fertilizer N, at an efficiency index of 60%. For a cropping system requiring 170 kg N per year, this means 41 tonnes of pig slurry, which contains 2.0 kg Cu (Chapter II, Section 2.5.). If the annual nitrogen requirement is met with pig slurry, the total copper content of a 2 600 000 kg arable layer will increase by about 0.8 ppm/year, because vertical transport of the copper in the soil and the amount removed with the harvested product are small. If an average of 75% of this quantity is soluble in dilute HNO_3, the annual increase is about 0.6 ppm Cu (HNO_3). For some crops, the critical limit is reached at an annual dose of this order after about 75 years.

To maintain an unlimited choice of crops for arable land, the Cu (HNO_3) content of the arable layer must remain below 50 ppm; this can easily be monitored by soil analysis (see tabulation below).

	Arable land	Grassland
	40 tons manure containing 50ppmCu	20 tons manure containing 50 ppm Cu
Annual supply:	2×10^6 mg Cu	10^6 mg Cu
Amount of Cu (HNO_3) (75%):	$1,5 \times 10^6$ mg Cu	$0,75 \times 10^6$ mg Cu
Increase in Cu (HNO_3) in arable layer:	$\frac{1,5 \times 10^6 \text{ mg}}{2,6 \times 10^6 \text{ kg}} = 0,6$ ppm Cu	$\frac{0,75 \times 10^6 \text{ mg}}{0,6 \times 10^6 \text{ kg}} = 1,3$ ppm Cu
Permissible Cu (HNO_3) content:	50 ppm Cu	100 ppm Cu
Initial Cu (HNO_3) content:	5 ppm Cu (-)	5 ppm Cu (-)
Permissible increase in Cu(HNO_3)	45 ppm Cu	95 ppm
Reached after	$\frac{45}{0,6}$ = 75 years	$\frac{95}{1,3}$ = 73 years

2.2. Grassland

Grassland with sandy soil has an additional K_2O requirement of 24 to 48 kg per ha (Table 8) depending on the cattle stocking rate; this is equivalent to 6 to 13 tonnes of pig slurry. These amounts can be increased by a further 50% if measures are taken to prevent hypomagnesemia. At an annual dose of 20 tonnes of pig slurry, about 1 kg Cu is supplied, causing the total Cu content of the sward (0.5 cm; 600 000 kg) to increase by 1.7 ppm per year and the Cu (HNO_3) content to rise by about 1.3 ppm per year. If the critical level is 100 ppm Cu (HNO_3) for grass, this value is reached after about 73 years.

As stated in Chapter 11, Section 2.5., it is undesirable to apply pig slurry to grassland on which sheep are grazed, since these animals have a low tolerance to copper. The critical value for sheep is already reached after a few years at annual doses of the order of 20 tonnes. With regard to possible official control, it will, of course, be necessary to take account of whether the grassland is to be kept suitable for sheep-farming in both the short and long term.

3. Pollution of shallow groundwater (1)

The EEC has fixed the maximum acceptable nitrate level for drinking water at 11.3 mg $N\text{-}NO_3$ per litre (Chapter II, Section 3.4.).

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(1) See also Appendix 1.

At an amount of drainage water equal to about 250 mm/year under average western European conditions, this corresponds to the leaching from the rhizosphere of $2.5 \cdot 10^6 \cdot 11.3$ mg or 28 kg $N\text{-}NO_3$ per hectare per year.

As stated in Chapter II, Section 3.2.2., 45 kg N/ha/year is lost by leaching on unmanured arable land with sandy soil owing to mineralization of nitrogen from organic matter in the soil. This is increased by about 14 kg at a chemical fertilizer dose of 100 kg N per hectare. Total leaching then far exceeds the EEC standard level on arable land with sandy soil. At a dose of 170 kg N per hectare (the physiological optimum for the crop), total leaching losses will amount to about 70 kg, so that the standard is even further exceeded.

Substitution of an equivalent quantity of farmyard manure for the chemical fertilizer increases leaching (with spring application) by a factor of 1.5 to 2.5 (Chapter II, Section 3.2.2.).

On arable land with sandy soil, leaching then amounts to 45 + 1.5 to $2.5 \cdot 24$ kg = 93 kg N/ha/year. With autumn application, leaching increases to $45 + 6 \cdot 24$ kg = 189 kg N/ha/year.

On clay soil with 20-30% particles less than 16 um, leaching is appreciably reduced owing to the occurrence of denitrification.

On unmanured arable land with clay soil, leaching amounts to about 18 kg N/ha/year. At an optimum dose of 170 kg N/ha, this loss can be estimated at about 23 kg, which is still within the EEC standard.

If it is assumed that, when chemical fertilizer is replaced by farmyard manure, leaching increases to the same extent as on sandy soil, leaching losses amount to 25.5 to 30.5 kg N/ha/year with spring application and 48 kg with autumn application. In the first case the losses on arable land with clay soil fall just within the EEC standard, but in the second case they substantially exceed it. These considerations are illustrated by the following tabulation.

Nitrogen leaching losses on arable land at 250 mm drainage water per annum

	Sandy soil		Clay soil	
	kg $N.ha^{-1}$	mg $N\text{-}NO_3.l^{-1}$	kg $N\ ha^{-1}$	mg $N\text{-}NO_3.l^{-1}$
Unmanured land (1)	45	18	18	7,2
Chemical fertilizer 170 kg $N \cdot ha^{-1}$ (2)	24	9,6	5	2,0
Animal manure, equivalent to (2), spring application (3)	48	19,2	10	4,0
As (3) but autumn application (4)	144	57,6	30	12,0
Total (1) + (2)	69	27,6	23	9,2
Total (1) + (3)	93	37,2	28	11,2
Total (1) + (4)	189	75,6	48	19,2
EEC standard	28	11,3	28	11,3
WHO standard	56	22,5	56	22,5

On grassland, the EEC standard (28 kg N/ha/year leaching) corresponds to manuring with about 350 kg/ha N (see Chapter II, figure 4; in this figure manure produced by grazing animals is not taken into account).

At a maximum land-dependent stocking rate on grassland of 3 adult cows per hectare, the amount of effective nitrogen in the animal manure produced in the housed winter period is $3 \cdot 0.74 \cdot 44 = 98$ kg N. The efficiency index of 0.74 is taken from the diagram in Chapter II, Section 1.2.1. (average of autumn and spring application). In all, an additional $350 - 98 = 252$ kg N/ha can then be applied in the form of chemical fertilizer. There is virtually no capacity for nitrogen in the form of animal manure because the potash standard would then be exceeded (Chapter II, Section 1.2., and Chapter IV, Section 1). Under dutch conditions at high stocking rates (2.5 to 3 LU/ha grassland), however, more than 300 kg of chemical fertilizer N per ha must be applied in order to produce sufficient starch equivalent (Table 10), so that the EEC standard cannot be met in such cases. The standard can be met if the stocking rate does not exceed 2-2.5 LU/ha (Tiesema, 1975).

With regard to the shallow groundwater, it is clear that highly productive arable farming on sandy soil will often be unable to meet the EEC standard without yield losses owing to the nitrate concentrations in the drainage water. The standard can be more readily met on clay soil. The same applies to grassland at stocking rates of up to 2.0 - 2.5 adult cattle per hectare, although there is a risk in this case of the stocking rate being increased without appropriate adjustment of N chemical fertilizer application. With regard to the above considerations, it must be recommended that the losses mentioned are from the rhizosphere (the topmost metre of the profile). In the lower layers the nitrogen content of the groundwater will be reduced by denitrification, so that the situation will often be more favourable than may appear from the above.

Again, considering the small amount of water actually used for human consumption (2% of total water consumption) and the low frequency of the relevant disease, it might be possible to solve the problem in cases where the EEC standard cannot be met by technological measures (use of ion exchangers) on the part either of the consumer or of the water supply authorities.

4. Pollution of surface water

As stated in Chapters II and III, phosphorus is the principal factor in the eutrophication of surface water, and in particular phosphorus conveyed by runoff. The criteria suggested for use in possible official control were the runoff sensitivity of the soil, climatic characteristics and the stocking rate, possibly supplemented by determination of the phosphorus content of the topsoil on the relevant farms.

Runoff is determined principally by the permeability and water-holding capacity of the soil, precipitation amounts and intensity, the slope and vegetation cover of the land, and the frequency and timing of manure application.

In our opinion not enough research has yet been devoted to the way in which each of these points should figure in possible regulations, and the degree of importance to be attached to them. However, the guidelines existing in some countries for manure application indicate how it is actually done.

The following three criteria are proposed in guidelines issued in Switzerland in 1974: 1) precipitation intensity; 2) soil permeability; and 3) topography of the land. On this basis, soils can be classified as having "normal tolerance" (single application of up to 60 m^3/ha of slurry), "low tolerance" (up to 40 m^3/ha) or "very low tolerance" (up to 25 m^3/ha). No manure may be applied to land which is frozen, puddled or snow-covered. Soils with good permeability and land with gradients of 10 to 25% with dense vegetation cover (grass) are deemed to have "normal tolerance". Land with the same gradients but little or no vegetation cover and land with slopes of 26 to 45% with dense vegetation cover have "low tolerance". Land with gradients exceeding 45% and land with slopes of 26 to 45% without vegetation cover have "very little or no tolerance".

New York State (USA) has guidelines for manure utilization on dairy farms (1973), specifying that the quantity of manure to be applied must conform to the estimated nitrogen requirement of the crop. Additional criteria are the thickness of the soil layer, drainage (permeability) and slope. Where manure is applied in winter (1 September to 1 April), the following percentages of the quantity required must be observed :

Soil layer thickness (down to bedrock)	$50 - 100^+$ cm			0 - 50 cm		
% gradient	0-3	3-8	8-15	0-3	3-8	8-15
Drainage						
Excessive (sand or gravel layers)	50	50	30	-	-	-
Good to moderate	100	50	30	60	30	20
Rather poor to poor	50	25	15	30	15	10

For manure ploughed under or injected in summer, the slope is not a limiting factor. Where manure is spread on the land (without ploughing under) in spring and summer, the "usual quantity" must be reduced to 50% on slopes of 3-8% and to 30% on slopes of 8-15%. Winter application must preferably take place in November or at the beginning of December, before continuous snow cover. In British Columbia (Canada) (1974) it is recommended that no manure be applied to land with a slope exceeding 15% unless it is ploughed under immediately.

The American guidelines reproduced above take account not only of runoff sensitivity but also of the risk of leaching of components of the manure. Excessively permeable soils and land with a profile depth of less than 50 cm are considered to be more sensitive. As criteria for leaching of phosphorus (and other substances), the Swiss guidelines mention the condition of the soil pores (pore size distribution and filling) and the thickness and exchange capacity of the soil layer. Highly permeable soils and soils with a low profile depth or low exchange capacity count as having "very little or no tolerance" for manure.

A clear distinction is made in the American guidelines according to whether the manure is or is not turned under. These guidelines were, evidently, issued not so much because of fear of the consequences of an excessive increase in the phosphorus content of the soil as because of the possibility of surface runoff of manure constituents. The same impression is given by the Swiss guidelines, since they recommend that the total annual quantity required be divided into two or three doses. Neither the American nor the Swiss recommendations take account of runoff of soil particles on land which may have become too rich in phosphorus, but they certainly suggest the need to take into consideration soil permeability, profile depth, and the slope and vegetation cover of the land.

It may be considered to accept the limit mentioned earlier of 6 mm/h as a possible standard level for permeability. At lower permeabilities, limitation of manure doses could be prescribed or recommended. The limit could, for example, be half the amount acceptable on permeable soils (as in the American guidelines) or quantities of manure corresponding to a phosphorus dose necessary to maintain the normal phosphorus content of the soil. According to Part II, the latter, in the case of arable land, would involve a limitation to the manure of about 1.5 cattle phosphorus equivalents per ha (60 kg P_2O_5 per annum).

In our opinion, more research is necessary than is possible within the scope of our study before standards for the slope of the land can be laid down. The American guidelines suggest that risks already exist on slight gradients, while the Swiss consider land even with a 10-25% gradient to have "normal tolerance" if it has vegetation cover. We have insufficient information to express a soundly based preference for either approach.

Runoff sensitivity is, in fact, relevant only if climatic conditions are such that runoff actually occurs. This is to be expected in winter when the soil is frozen and in summer during heavy rain. However, the differences in climatic conditions with the EEC are not considered to be large enough for any differentiation to be appropriate in possible regulations.

With regard to profile depth, the New York State guidelines specify 50 cm, while the Swiss consider land with a profile depth greater than 60 cm to have "normal tolerance". The 50-60 cm limit seems acceptable because phosphorus infiltration is generally limited to this depth. For this reason, in land with a shallower profile and/or more elevated drains, the possibility of imposing limits on manure doses (to be controlled via the stocking rate) may be contemplated.

If a decision were made to limit the amounts of manure to be applied in the EEC to prevent surface water pollution by runoff, the stocking rate could be used as the relevant parameter. Another possibility, which could be used on a supplementary basis, is measurement of the phosphorus status of the soil. Such a basis is more practicable than the imposition of a maximum stocking rate because, for example, on hilly land the higher parts will probably receive less manure than the lower. Limits would then have to be imposed or recommended if the phosphorus status exceeded that regarded as normal.

Where possible limitations are contemplated, it must, however, be borne in mind that at a population density of 3-4 persons/ha, 90% of the phosphorus pollution of surface waters originates from sewers, so that only 10% can have come from agricultural land (Owens, 1970). The situation may, of course, change in the future if sewage undergoes further ("tertiary") purification.

5. Summary

It has been shown how the permissible stocking rate from the point of view of crop production can be calculated on the basis of the nitrogen requirement of arable land and the potash requirement of grassland for farms or regions. For a normal cropping system in the Netherlands with arable land having a nitrogen requirement of 170 kg H/ha, this rate is about 3.2 LU/ha assuming a 60% efficiency index for the nitrogen in the manure. On grassland with a land-dependent stocking rate of up to 3 adult cattle (3LU) per hectare, 0.4 (and at lower stocking rates on sandy soil, up to 0.7) LU K_2O-equivalents in the form of pig and poultry manure can be accommodated. For grassland, the maximum permissible stocking rate is thus about 3.4 LU/ha, including three cattle, with potassium being taken as the limiting element. With an arable land/grassland ratio of 50:50, the maximum stocking rate is about 3.3 LU/ha. Phosphorus and potash surpluses may occur in this case, their size depending on the types of manure used.

As regards soil pollution, it has been stated that where copper-enriched pig slurry is used, the stocking rate is a less suitable parameter than the copper content of the soil. To retain an unlimited choice of crops, the copper content of the arable layer must not exceed about 50 ppm Cu(HNO_3); the critical level for grassland (sward) is about 100 ppm Cu (HNO_3). The use of copper-enriched pig manure on grassland grazed by sheep is discouraged.

A stocking rate of 2 to 2.5 adult cattle will not present any problems of nitrate pollution of groundwater on grassland with sandy or clay soil. If the land is used more intensively (stocking rate 3 adult cattle per ha or more), this hazard will arise. On arable land with heavier soil, the nitrogen requirement of the crops, corresponding to the manure of 3.2 LU/ha, can just be met provided that the manure is applied in spring. The appropriate level is greatly exceeded in the case of autumn application. On arable land with sandy soil it will be difficult to conform to the EEC's drinking water standards without reducing the physiological optimum dose of nitrogen; the more nitrogen is applied in the form of animal manure, the greater the difficulty will be.

Surface water pollution is caused primarily by runoff water containing phosphorus in solution as well as mineral and organic soil particles which contain phosphorus. It is impossible to specify a simple norm for manure spreading with respect to runoff because not only the phosphorus content of the soil but also such factors as, in particular, the water holding capacity and permeability of the soil, precipitation amounts and intensity, land slope and vegetation cover, and timing of manure application are relevant. It has been explained that broad norms can be set for each of these factors for the prevention or reduction of runoff.

V. Possibilities for regulatory measures

To prevent animal manure from being used excessively or incorrectly, in addition to the provision of intensive information to livestock farmers, the adoption of regulatory measures may be contemplated. This Chapter will be confined to measures which are technically feasible, but this does not mean that there might not be insuperable economic, legal or administrative obstacles to their implementation. The authors are not competent to pass judgement on these points. The details of execution and enforcement of possible controls are also not discussed.

A distinction will be made in this Chapter between possible regulation of the quantity of manure to be applied and control of the method and timing of application.

1. Possibilities of controlling the quantity of manure to be applied

The aim is to achieve a situation in which no more manure is applied than is necessary to maximize crop production with acceptable quality without unacceptable pollution of the environment. It was explained in the previous Chapters that the application of quantities of manure necessary for maximum production need not lead to such pollution in the short term except on land of reduced tolerance where there is a risk of phosphorus runoff (see also Chapter VI) and where large quantities of copper are applied with pig manure.

The manure doses acceptable from the point view of crop production can be related to the area and method of use of the available land. Since manure production is connected with the number and species of animals concerned, the acceptable doses of manure can be translated into terms of acceptable size and nature of the livestock population.

Information and possible controls will need to be directed to avoiding manure surpluses or the disposal of existing ones.

Prevention of surpluses involves the recommendation or imposition of limitations on size of livestock populations when new farms are established or existing ones expanded, thereby considering the area and method of use of the available land.

However, such measures will constitute a serious social handicap to small farms seeking to improve their income by non-land-dependent forms of production.

To achieve the second objective, the abolition of the surplus situation, farmers must be encouraged or compelled to dispose of surpluses to farms which still are in need of manure.

Whichever of these two possibilities is chosen, the basic parameter is the relationship between the size of the manure-producing animal population and the area and method of use of the available land. If maxima are imposed for this, the question arises whether they can be enforced.

The size and nature of the animal population can in principle be determined per farm, and hence also per region, by periodic animal or animal place censuses. However, such a census is no more than a snapshot, which may give a false picture of the average stocking rate owing, for example, to "chance" vacancies. Again, the manpower required for these censuses would be considerable.

The area of land belonging to a farm can in principle also be checked, as well as its method of use, the relevant aspects here being the ratio of arable land to grassland and the relative areas of the different arable crops. A region-by-region inventory of land might be simpler than a farm-by-farm inventorization. In any case, the information required to establish whether or not there is a surplus of manure and, if so, its size on each individual farm or in each individual region can in principle be obtained. Another question is whether, given propaganda in favour of removal of manure surpluses from a farm or from a region, or compulsory requirements to that effect, such removal would in fact take place and whether this would be verifiable. After all, the farmer, although realizing that he has a surplus, might nevertheless prefer to apply this surplus on his own farm for economic reasons. The possibility might occur to one to check such behaviour on the part of the farmer by means of soil analysis. However, the ability of soil analysis to provide a definite verdict in such a case is extremely limited, particularly where it is called upon to do so in respect of a period of a few years only. The limitation of soil analysis as an instrument for monitoring the manuring practices that have been followed can be demonstrated for example, from Fig. 6 (Chapter II). If only a few points in this diagram are considered, it might be concluded that the P content of the arable layer at an annual dose of 60 kg/ha is lower after 35 years than after 25 years, although the trend as a whole indicates precisely the reverse. And, even if intensive soil analysis does reveal a trend, it is still very difficult to determine what quantities of manure have been responsible for it. All in all, therefore, the use of soil analysis as a means of monitoring manuring practices in individual fields, and presumably also on individual farms, must be regarded as inadequate. No other possible means of monitoring are available.

Monitoring might, however, be possible if manure surpluses were disposed of through an independent central administrative body, such as a manure bank. This body would have to keep records of the origin and size of surpluses offered and of their transport and sale. Compulsory registration of the purchaser, however, could deter him from buying excess manure elsewhere. The authors lack the competence to determine whether the registration of supply, transport and sales and authority for inspection should be vested in one and the same body. But whoever is responsible for its implementation, farm-by-farm monitoring would be a particularly labour-intensive and barely feasible task.

Should the objections to the registration of individual farms be excessive, one possibility that could be considered would be to direct regulatory activity towards the livestock concentration region as a whole. Livestock farmers in this region could be taught how to calculate their manure surplus. They would have to be encouraged to deliver this surplus to the central body, and the necessary facilities would have to be created - e.g. central manure stores, startup subsidies, etc. (see Appendix II for an example of the financing of a manure bank). If "insufficient" manure is delivered in such livestock concentration regions, more stringent measures could be contemplated.

The removal of excess manure from livestock concentration regions to other regions with a certain (known) capacity to accept manure would also need to be controlled by the central body. This could possibly be monitored through the transport contractor's waybills or through the relevant custom worker.

It must be emphasized that in regions stocked at the maximum rate considered permissible in their situation, no other organic fertilizers (sewage sludge or domestic refuse compost) should be used and that chemical fertilizer use must be limited to what is appropriate.

A complication arises in areas whose land has little or very little tolerance (Chapter IV), as determined by the permeability and water holding capacity of the soil, the groundwater table, the slope and vegetation cover, and precipitation amounts and intensity. In such a case, not only stocking rate and land use must be taken into account in determining the manure surplus, but also the lower tolerance. This can be done, for example, by assigning a maximum stocking rate to each of the categories of land (normal, low and very low tolerance) and then calculating an average permissible stocking rate for the region as a whole on the basis of the areas of land in each category. It might be more practicable to consider the reduced tolerance only when it has been found that the surface water actually is polluted to a greater extent than normal by the presence of these fields. In general, this will only be the case if the phosphorus status of these fields is too high, which can be determined by soil analysis. It is not a question here of establishing a trend in the phosphorus status of the field as discussed earlier, but merely of determining a level. In such a case, soil analysis is more meaningful, although this technique must be used carefully because of the inevitable errors attaching to figures obtained in this way.

On farms where copper-enriched pig manure is used, soil analysis can serve to check the accumulation of copper in the soil. Where the EEC standard for the addition of copper to the feed of pigs is used, an undesirably high Cu content is in general unlikely to occur in the short term, except where sheep-farming is concerned. If the relevant limit is nevertheless exceeded (50 ppm for arable land and 100 ppm for grassland), further use of such manure could be prohibited. As an emergency measure, the farmer could turn the copper-rich layer by deep-ploughing; considering the low mobility of Cu, this appears acceptable, but may be unattractive from other viewpoints. Of course, it is undesirable to compel farms to take far-reaching measures at very short notice. For this reason, users of Cu-containing pig manure must be advised to have the soil analysed periodically for Cu and if necessary to remove a part of the manure produced on the farm.

2. Possibilities of controlling the method and timing of application

The timing of manuring is relevant both to the effectiveness of the plant nutrients and to groundwater and surface water pollution. The efficiency of, in particular, the nitrogen component of the manure is greatest if it is applied in spring or during the growing season, and the likelihood of water pollution is at its lowest in that case. For this reason, use in these periods of the year is preferable. This can be promoted indirectly by encouraging the construction of sufficient storage capacity, either on individual farms or centrally.

Another possibility is to prohibit manuring in autumn and winter. However, a blanket prohibition is unacceptable because the consequences for livestock farmers and manure purchasers might well be too far-reaching. Such a prohibition would force many farmers to invest large sums in storage capacity, while the day-to-day running of some farms might be seriously upset, especially in the case of arable land with clay soil, which can only be ploughed before the winter and which cannot be manured in spring without the soil structure sustaining considerable damage.

It might be possible to limit such a prohibition to arable land which can be ploughed without difficulty in spring - i.e. primarily to sandy soil. Autumn and winter application leads to relatively high nitrogen losses through leaching precisely on such soils. However, since the relationship between the concentration of the water percolating from the topmost metre of the profile and that of the deeper groundwater - if used for preparation of drinking water - has not yet been clearly demonstrated, there is little basis for a recommendation for such a prohibition. Nor have such drastic measures been taken elsewhere. As a rule, farmers' attention is merely called as much as possible to the objections to autumn and winter application, no express prohibition being imposed.

To reduce the probability of surface water pollution by runoff, the possibility of prohibiting manuring during periods of frost and, for example, on the banks of watercourses might be contemplated. However, this cannot be satisfactorily enforced. A period of frost is not in itself a criterion for the occurrence of runoff, which is substantially determined by other factors. For example, on dry, frozen, flat land without snow there will be little danger of direct runoff; this danger will, however, be extremely high on slopes without vegetation cover, with a frozen top layer and covered with snow. Between these extremes situations are conceivable where the soil has (temporarily) reduced tolerance without, however, warranting a general prohibition on manuring.

3. Summary

To prevent excessive or incorrect use of animal manure, not only intensive information campaigns but also the adoption of regulatory measures must be considered. The aim is to arrive at a situation where no more manure is applied than is necessary for maximum crop production with acceptable quality without unacceptable pollution of the environment. The doses of manure acceptable from this viewpoint, which in most cases are also environmentally acceptable, can be related to the area and use of the available land. The acceptable doses of manure can be "translated" into an acceptable stocking rate, so that the detection and determination of surpluses is largely concerned with the relationship between the size of the animal (or bird) population and the area and method of use of the available land. Reduced tolerance because of the risk of runoff may also be taken into account.

In principle, the size of a possible manure surplus could be determined farm by farm on the basis of livestock censuses or livestock farming licences and data on the farm's land. Soil analysis cannot be used for inspection of what happens to manure surpluses, but this could be done by requiring farmers to dispose of these surpluses through an independent central registering body. If the difficulties and gaps involved in farm-by-farm registration are considered excessive, better prospects might be offered by a system of region-by-region registration in which livestock farmers in regions of high livestock concentration can supply their excess manure to the central body, which will in turn forward it to areas of known capacity to accept it.

The timing of manuring could be inspected, but considerable difficulties stand in the way of prohibiting application at certain times of the year. For this reason the approach suggested is merely to offer the farmer recommendations, supported by due evidence, as to distribution within the farm and the timing of manuring, no inspection, of course, being carried out.

Excessive accumulation of copper where copper-enriched pig manure is used can be controlled through soil analysis.

The authors are not competent to deal with the legal, economic and political aspects of the proposed measures.

VI. Proposal concerning the technical and administrative organization of the system of control

To limit the organization required, the central bodies mentioned in the previous Chapter should be required to register the size of any manure surplus and organize its disposal only in areas (or on farms) whose stocking rate exceeds a certain threshold. This threshold is thus lower than the maximum permissible stocking rate, or may in individual cases at most equal it.

Concerning the fixing of the threshold for these areas of livestock concentration (or the farms situated therein), it is recalled that nitrogen is the limiting factor for arable land of normal tolerance (Chapter II, Section 1). About 100 kg N per hectare is acceptable both environmentally and as regards crop production, even in agricultural regions with crops having a low nitrogen requirement only. This quantity corresponds to the N production in the slurry of two adult cattle (2LU) on an annual basis (2 · 89) kg at an efficiency index of 60%. The number of livestock units (LU) must be determined from the actual numbers of animals on the basis of nitrogen equivalents (see Table 28).

On arable land with low or very low tolerance, a threshold of 2 LU/ha would result in too high a supply of phosphorus (2 · 40 kg P_2O_5 on an annual basis). On such land any increase in the phosphorus content must be avoided and the phosphorus supply must be limited to about 60 kg P_2O_5 per hectare (on an annual basis) (Chapter II, Section 2.3; Chapter IV, Section 4). This entails reducing the threshold from 2.0 to 1.5 LU/ha. Numbers of other animals must be converted to livestock units on a P_2O_5 equivalent basis; calculations based on N or K_2O equivalents would lead to too high a P_2O_5 supply (see Table 28).

Potassium is the limiting factor for grassland (Chapter II, Section 1). At a land-dependent stocking rate of 3 adult cows per hectare, a further 0.4 LU K_2O equivalents can be accommodated in the form of pig and poultry manure (Chapter II, Section 1.2). At lower cattle stocking rates - at least on sandy soil - this quantity can be increased to 0.7 LU K_2O equivalents. It is suggested that the threshold for the quantity of manure, other than cattle manure, to be applied be set at 0.4 LU K_2O equivalents irrespective of the land-dependent cattle stocking rate provided that this does not exceed 3 LU/ha. At higher stocking rates, the threshold will always be exceeded.

Table 28. Conversion of livestock units (LU) on annual basis to numbers of other animal species; figures taken from Table 3 (Chapter II)

Equivalents on basis of	Number of fattening pig places corresponding to stated number of LU			Number of laying hens[1] corresponding to stated number of LU			Number of broiler places corresponding to stated number of LU			Number of fattening calf places corresponding to stated number of LU		
	1,5	2,0	3,0	1,5	2,0	3,0	1,5	2,0	3,0	1,5	2,0	3,0
N	11,8	15,8	23,7	183	244	366	819	1092	1638	20,0	26,6	39,9
P_2O_5	8,0	10,6	15,9	80	106	159	408	544	816	21,0	28,0	42,0
K_2O	23,4	31,2	46,8	417	556	834	1340	1786	2679	28,4	37,8	56,7

[1] slurry

To enable them to perform their registration and control function, the relevant authorities in regions where the stocking rate exceeds the above thresholds should have information on the following at their disposal:

1; Size and nature of livestock population in the region.
2. Area of cultivated land and arable land/grassland ratio.
3. Relative areas of the different arable crops.
4. Relative areas of soil with normal, low and very low tolerance.
5. The official bodies should have the power to inspect the above points if necessary, and to have the copper content of the soil as well as the phosphorus content of the soil and the surface water determined.

The following basis can be used for a broad calculation to determine whether the stocking rate in a region exceeds the threshold, so that the region is subject to registration. The land-dependent stocking rate (cattle) is assigned to the grassland. If the result does not exceed a maximum of 3 LU/ha, there is still room for other (non-land-dependent) animal species, on a K_2O equivalent basis (rate 0.4 LU). The remaining (non-land-dependent) livestock is assigned to arable land of normal tolerance (on an N equivalent basis) until the limit of 2.0 LU/ha is reached. Finally, the livestock not yet "accommodated" is assigned to arable land with low and very low tolerance, on a P_2O_5 equivalent basis. If any stock then still remains, this means that the stocking intensity in the relevant region exceeds the threshold, so that the area is subject to registration. The above procedure can in principle also be applied on an individual farm basis.

The permissible stocking rate per region (or per farm) can be calculated from points 2, 3 and 4. The difference between the permissible and the actual stocking rate (1) is a measure of the manure surplus.

The copper analysis mentioned under point 5 could be effected periodically on farms with large numbers of fattening pigs and on the land of large buyers of the relevant manure - i.e. farms on which more than 40 tonnes/year of pig manure is applied per hectare of arable land or more than 20 tonnes/year per hectare of grassland.

The soil could be analysed for phosphorus (5) in areas with land of below normal tolerance, due allowance being made for the limitations of soil analysis.

Many other problems may arise in the elaboration of points 1 - 5. For instance, it is necessary to assess whether regional differences must be taken into account in determining the nitrogen requirement of a given crop (a basic parameters for fixing the permissible stocking rate per ha of arable land). The need for simplicity of the system is relevant here. Quite a different kind of problem is to determine who should be responsible for assessing the tolerance of the soil (point 4). The obvious course is to call in specialists on land use development for this purpose; for other problems arising, farm management and fertility experts will probably have to be consulted. The whole matter, of course, also has legal aspects. The authors are unfamiliar with the full range of these problems and are therefore unable to put forward any suggestions for their solution.

Summary

It is proposed that central bodies performing the functions of registration and regulation should be set up only for areas (or farms) where the stocking rate exceeds a certain threshold (below the maximum permissible stocking rate). The threshold is set at 2 livestock units (2 LU) per hectare of arable land of normal tolerance, at 1.5 LU per hectare of arable land with low or very low tolerance, at 3 LU of land-dependent cattle per hectare of grassland, and, at lower stocking rates (cattle), at 0.4 LU K_2O equivalents in the form of pigs, poultry, etc (non-land-dependent). The rate for animals other than cattle must be converted to LU on an N equivalent basis for arable land or normal tolerance, a P_2O_5 equivalent basis for arable land of low and very low tolerance, and a K_2O equivalent basis for grassland. For this purpose the central bodies should have the information and powers mentioned in points 1 - 5 at their disposal and perform a regulatory function with regard to the collection of surplus manure and its removal to areas with a known capacity to accommodate it.

VII. Guidelines for farmers on the responsible use of animal manures

Introduction

Like any human activity, livestock farming impresses its stamp on the environment in which it takes place. The most obvious way of disposing of the waste products of livestock farming is to recycle them via the soil. By studying the potential sources of pollution, using his common sense, and observing certain ground rules, the livestock farmer, even if he cannot entirely prevent the less desirable effects of his activity on the environment, can at least substantially limit them.

However, certain measures may have economic repercussions for the farmer, as a result of which their implementation becomes less attractive. Other measures, on the other hand, will be of direct economic benefit or may improve living and working conditions on the farm. Where the adoption of the most desirable measures appears not to be readily feasible economically in specific situations, the possibility of government support in the general interest should be investigated. The fact that measures to restrain environmental pollution exist or are in preparation in a number of countries with intensive livestock farming reduces the risk of distortion of competition to the disadvantage of the national product by unilateral increases in cost factors. This risk could be still further reduced by international coordination of measures.

1. Choice of manure recovery and storage system

Considering the manure cycle as a whole, the basis for an environmentally acceptable cycle on the farm lies in the choice of the system of manure recovery and storage. For this reason this aspect of farm organization must receive careful attention when a new livestock farm is established or where an existing farm is substantially improved and expanded. In principle, there is a choice between three possibilities :

(i) separate recovery and storage of solid and liquid manure;
(ii) mixed storage in solid form, either in litter or not in litter (poultry manure);
(iii) mixed storage in liquid form.

Some of the criteria determining this choice are as follows :

(i) probable manure production;
(ii) possibilities of utilizing the expected manure production on the farm's own soil;
(iii) situation of fields relative to farm buildings;
(iv) possibilities of disposing of any surplus manure in the immediate vicinity;
v) geological and topographic limitations;
vi) hydrological limitations.

The planned animal complement may well produce a manure surplus relative to the available area of cultivated land, particularly if any other limiting factors are taken into account. The system of separate recovery of solid and liquid manure or that of mixed storage in litter (as in the case of the old-fashioned type of animal housing without a dung channel) then offers the following advantages :

i) practically unlimited storage of solid manure;
ii) economically superior possibilities of transporting solid manure over much longer distances to potential purchasers;
iii) more economic possibilities of drying the manure, as manure drying costs increase substantially with increasing moisture content.

Liquid manure can only be stored for a limited period, as the capacity of a manure pit is, of course, limited in volume. A full pit must be emptied whether the circumstances so allow or not. Under favourable conditions, this may constitute a source of pollution in the farmyard and on the land (runoff of manure); it may lead to unbalanced application of animal manure only on easily accessible and negotiable fields, and may be harmful to the sward if crushed under tractor wheels, etc. when too wet.

Owing to its high moisture content, resulting in a lower manurial value a and higher volume, liquid animal manure is unsuitable for transport over long distances. Its high moisture content makes it unattractive at a raw material for the preparation of dried manure.

Purchasers of liquid manure must have a manure pit themselves if the manure cannot be immediately spread on the land. Purchased solid manure, on the other hand, can always be stored temporarily on the field for which it is intended.

Mixed manure storage is suitable primarily for farms which can use their entire manure production themselves, provided that they have sufficient storage capacity.

2. Location, size and construction of manure storage facilities for solid manure

A watertight shallow manure pit of size depending on the expected manure production of the animal complement should be used to store solid manure.

This pit must be linked to the liquid manure pit for elimination of the manure leachate. Large shallow manure pits could be divided up into separate compartments each having a drain line to the liquid manure pit and fitted with its own individual shutoff valve. To prevent excessive dilution of the liquid manure with rainwater, the drain line to the liquid manure pit can be temporarily closed when there is no manure in a compartment, the rainwater being discharged direct into the surface water.

The manure pit must not be located in the immediate vicinity of trenches, ditches, streamlets and other surface water; it must also not be unfavourably situated with respect to drinking water wells and springs. The direct discharge of manure leachate to the surface water is not allowed.

A location sufficiently distant from surface water should be chosen for temporary storage of manure in a field pending application. The manure leachate must be collected in a trench dug round this manure pit.

3. Size and construction of storage facilities for liquid animal manure

Liquid and solid manure pits, etc. must in general be of watertight construction. Their storage capacity must conform to the expected production of

(i) liquid manure or slurry;
(ii) manure leachate (seepage);
(iii) silage juices;
(iv) washwater from animal housing and milking parlour;
(v) domestic sewage if disposed of in the manure pit.

Capacity must also be sufficient for

(i) the method of storage (open or covered);
(ii) the longest period during the year in which manure is collected but cannot be spread on the land.

Liquid manure or slurry production can best be calculated on the basis of full occupation of the housing facilities with adult animals.

Dilution with washwater and rainwater must be limited as far as possible. In this connection, local precipitation amounts should preferably be taken into consideration when determining the form of the manure pit and whether or not it is to be provided with a simple cover. Every millimetre of rainfall per square metre of manure pit area produces 1 litre of water. In the winter half of the year, in particular, there are hardly any evaporation losses to offset this. With a large-area manure pit, tens of cubic metres of extra water can be added to the manure in this way and must be eliminated later. A considerably larger pit is then required, or the pit must be emptied more frequently. Large quantities of rainwater also substantially reduce the concentration of the manure, thus lowering its manurial value, while storage, transport and spreading costs are increased.

It is very important for a satisfactory manuring policy, grassland management and maintenance of soil structure to have a manure pit of amply sufficient capacity. If manure has to be spread under adverse conditions, there is not only the chance of direct detriment to the farmer (damage to the grass surface, deterioration of structure, unbalanced manuring, etc.), but also of unnecessary environmental pollution. Again, the manure pit must be empty at the beginning of the winter season. With small pits, it is important not to wait until the last minute, but to empty the pit at intervals at reasonably favourable times.

Slurry storage is expensive. For this reason cheaper forms of slurry storage have been sought, which the farmer can possibly construct himself. These include, for example, unsealed pits (in or above ground) and silos with unsealed bottoms. There is no objection to these forms of storage provided that the following conditions are satisfied :

(i) the manure must be stored out of reach of the highest groundwater level and sufficiently far from any drains;
(ii) the soil layer above parent rock must be sufficiently thick;
(iii) the soil must not allow seepage through cracks, rock, etc.;
(iv) the pits must be sufficiently far from trenches, ditches, streams, other surface waters, springs and drinking water wells.

In other words, the hydrological conditions of the land must be favourable for the construction of these facilities.

4. Manure dosage

On extensive and normal cattle farms, the entire manure production can generally be utilized without problems on the farm itself. Indeed, in most cases additional application of chemical fertilizer will be appropriate. The only precaution that must be taken is to distribute the manure as well as possible over the area of the farm as a whole in accordance with the crop requirements.

On intensive livestock farms, especially with large numbers of non-land-dependent animals (pigs, poultry, etc.), surpluses are more likely to arise. On these farms, it is first necessary to examine what quantities and types of manure are available and to what extent the farm can supply its own needs or even has a surplus. Important criteria to establish this are :

(i) available quantity and types of manure;
(ii) composition and nutrient efficiency of this manure;
(iii) available area of cultivated land;
(iv) arable land/grassland ratio;
(v) choice of crops for arable land;
(vi) timing of manure application;
(vii) topographic, geological and hydrological limitations on the use and dosage of organic manure.

Overdosage of manures and fertilizers is in general undesirable. Although not necessarily always disadvantageous from the agricultural point of view, overdosage must be minimized for environmental reasons. On arable land, manure application must not be allowed to exceed the crops' requirements of available nitrogen. Usually, additional application of chemical fertilizers is then no longer necessary. Aerated manure, part of whose available nitrogen has been lost, must not, however, be applied on this basis, as this would result in undesirable overdoses of other elements. In this case, the dose should be determined on the basis of non-aerated manure and the nitrogen loss (about 50%) should be offset in the form of chemical fertilizer.

Manure dosage on grassland should be determined on the basis of the potash requirement. The nitrogen supplied in the form of animal manure can then be supplemented with chemical fertilizer.

Surplus manure must be removed from the farm. The manure requirement and hence the amount of manure that can be used on the farm's own soil can be increased by modifying the choice of crops and increasing the arable land/grassland ratio.

The quantities of manure which may be spread in a single application must be matched to the permeability and water holding capacity of the soil. The lower the permeability and water holding capacity, the more it will be necessary to split the total quantity of manure into a number of applications.

Great care must be exercised with manure dosage in water extraction areas. It is not known whether frequent overdosage will eventually pollute the deep groundwater and to what extent. If pollution does occur, it will be noticeable first on light soils.

5. Distribution of manure over the farm

Manure must not only be applied in the correct dose but also distributed evenly over the farm. Unbalanced application of animal manure to only a few fields is most likely to occur if the layout of the fields is unfavourable and/or if trafficability is restricted under wet conditions. Such restrictions will be less harmful the higher the storage capacity for liquid manure.

Unbalanced distribution means that nearby fields receive excessive applications of animal manure whilst the more remote parcels are given chemical fertilizer; as a result, the total quantity of manure and fertilizers exceeds the requirements of the farm.

Sufficient storage capacity must be provided for the manure that will be produced. If the layout of the fields is unfavourable, the unfavourably located fields must be disregarded in calculation of the amount of manure that can be utilized on the farm, or, if possible, another form of manure recovery and storage must be used (see Section 1).

To sum up, in order to avoid undesirable accumulations in the soil, accompanied by an increased probability of adverse effects on livestock (hypomagnesemia, copper intoxication and nitrate poisoning), crops (reductions in quality) and the environment (increased risk of runoff and leaching), the manure must as far as possible be distributed over the entire farm in proportion to crop requirements, as well as the use of other waste products such as sewage sludge. The copper content and other parameters should be regularly checked by soil analysis.

6. Timing of manure application

From the point of view of the environment, the best time for spreading manure is the spring; for grassland, the entire growing period is satisfactory.

If applied at these times, optimum manure efficiency is achieved, nitrogen losses are minimized, and overdoses of other substances (if manure only is used) are contained within reasonable limits.

In some cases - e.g., arable land with heavy soil - spring manuring is liable to impair soil structure, so that the manure must then be applied in Autumn.

It is important to avoid spreading manure at inappropriate times, e.g. when the soil has an impermeable frozen layer or is saturated with moisture. Even on flat land, possible pollution of the surface water with manure particles entrained by runoff can thus be avoided. Here again, adequate storage capacity for liquid manures is important.

7. Measures to prevent odour nuisance when manuring

Although odour nuisance has not been dealt with earlier in this report, it is considered that some attention must be devoted to it here.

Certain types of manure - in particular, slurries stored under anaerobic conditions - may give rise to an unpleasant, penetrating odour when applied to the land. This odour nuisance can be reduced or eliminated by:

(i) taking account of wind force and direction with respect to sensitive points (residential areas, holiday resorts, swimming pools, etc.) when manuring;

(ii) applying the manure preferably in calm and cool weather;

(iii) on arable land, as quickly as possible turning the manure in with a harrow or cultivator, ploughing it under, or injecting it direct into the soil;

(iv) on grassland, preferably spreading manure during light rain (but not on saturated soil).

In very sensitive areas, there are two possibilities. The first is to aerate the slurry in an aerator. However, half the nitrogen is thereby lost. It is then inadvisable to determine the dose on the basis of available nitrogen owing to the risk of overdosage with other elements in the manure. The alternative on arable land is to inject the manure to a depth at which it is just covered by soil. This method has not yet proved feasible on grassland.

8. Measures during manure spreading

In the operation of manure spreading equipment, allowance must be made for wind direction and force and sufficient distance must be maintained from field edges bounded by watercourses and other surface water, to ensure that manure particles are not blown into the water and on to the banks.

Steeply sloping land should not be completely covered with manure. One recommendation is to leave a few strips unmanured perpendicular to the slope, to absorb dissolved manure constituents in the runoff water from manured parts at higher levels. Also, a ditch closed at both ends could be dug at the bottom of the slope for the same purpose.

With adverse topography and hydrology, large doses of manure should not be applied at once, as the likelihood of runoff losses is thereby substantially increased. Manure should also not be applied to sloping fallow land in winter, or to unsuitable land such as road verges and embankments.

On slopes and relatively impermeable soil, vegetation cover (grass) can greatly contribute to limiting unavoidable losses. Intercropping on arable land can also help to limit runoff and leaching losses.

For the sake of livestock health, it is inadvisable to spread manure on grazing land once the grass length exceeds 10 cm, to avoid the spread of diseases as well as copper intoxication (in sheep where copper-enriched manure from fattening pigs is used). It is even more sensible not to graze any sheep on grassland to which copper-rich manure has just been applied or which is regularly dressed with such manure.

9. Differential use of types of manure

On farms with a very substantial production, it is best, where possible, to spread potash-rich cattle manure on arable land and other types of manure on grassland.

Phosphorus-rich poultry manure should as far as possible be alternated with varieties containing less phosphorus, or used on phosphorus-fixing soils if these are present on the farm.

10. Choice of location for new farms

In the establishment of new livestock farms with little or no land, location in areas of predominantly arable farming provides better opportunities for disposal of the manure arising than in grassland regions, where the possibilities are already very limited.

VIII Hierarchic classification of agricultural regions according to the presence or absence of manure surpluses

To facilitate identification of areas with manure surpluses, a diagram for the classification of agricultural regions is given in this Chapter. The diagram is based on the approach adopted by the Forschungsanstalt für die Landwirtschaft (FAL), Braunschweig, in the study on characterization of the different agricultural regions of the EEC.

Although the following pages always refer to "regions", the diagram can also be applied to farms. The thresholds used are those set out in Chapter VI. The first level (x_0) of the dendrogram (figure 9) represents regions having a maximum stocking rate of 1.5 cattle equivalents (phosphorus) per hectare of cultivated land (1.5 CE-P).

In these regions the stocking rate is so low that neither the crops nor the environment are liable to be harmed by the animal manure supplied to the land: neither the threshold for grassland (maximum of 3.4 cattle equivalents (potash)) nor the threshold for arable land (2 cattle equivalents (nitrogen)) is exceeded in this case (see figure 10). No problems are likely even on arable land with very low tolerance. Of course, the manure must be distributed homogeneously over all the cultivated land. For all regions not included in this level, note that the threshold of 1.5 CE-P can be exceeded for arable land of low tolerance.

At the second level (x_l), the remaining regions (more than 1.5 CE-P per hectare of cultivated land) are divided into three groups on the basis of the land-dependent stocking rate per hectare of grassland (i.e. cattle excluding fattening calves, horses, sheep and goats). If the land-dependent stocking rate does not exceed 3 CE-K per hectare of grassland, no problems are likely to arise as regards this sector of livestock farming. It may even be possible to accommodate a certain amount of manure from the non-land-dependent stock. This amount is here taken as 0.4 CE-K; in sandy regions with a low stocking rate, even more can be accommodated. If the land-dependent stocking rate is greater than 3 but does not exceed 3.4 CE-K per hectare of grassland, this sector of livestock farming still conforms to the relevant standards. It may even be possible to increase the stocking rate per hectare of grassland up to a maximum of 3.4 CE-K. If the land-dependent stocking rate exceeds 3.4 CE-K per hectare of grassland, part of the manure must be disposed of (e.g. to the arable land).

Of the two groups of regions with land-dependent stocking rates of not more than 3 CE-K and 3.4 CE-K per hectare of grassland respectively, those in which the non-land-dependent stocking rate (comprising pigs, hens, fattening calves, etc.) does not exceed 2 CE-N per hectare of arable land are included in the third level (x_2) of the dendrogram.

Manure surpluses need not arise in these regions, because the manure from the entire animal complement can be applied to the land without unacceptable effects on crops or the environment. Problems may, however, arise with phosphorus on arable land of low tolerance.

Of the regions with land-dependent stocking rates not exceeding 3 CE-K per hectare of grassland not eliminated in the third level, some can be included in the fourth level (x_3), the part of the non-land-dependent livestock complement that exceeds the threshold for arable land (2 CE-N per hectare of arable land) being transferred to grassland on a potash equivalent basis.

Regions in which the quantity to be transferred does not exceed 0.4 CE-K per hectare of grassland may also be disregarded from now on.

Of the groups of regions with a land-dependent stocking rate greater than 3 but not exceeding 3.4 CE-K per hectare of grassland, a further number are included in the fifth level (x_4) of the diagram. In this case, as in the fourth level, the part of the non-land-dependent complement which exceeds the threshold for arable land is transferred to grassland on a potash equivalent basis. If the sum of the land-dependent stocking rate and the part of the non-land-dependent stocking rate to be transferred does not exceed 3.4 CE-K per hectare of grassland, no surplus exists in such a region according to the standards adopted.

On the sixth level (x_5), of the group of regions with a land-dependent stocking rate exceeding 3.4 CE-K per hectare of grassland, the part of the land-dependent stocking rate exceeding 3.4 CE-K per hectare of grassland is transferred to the arable land. The figures are converted on a nitrogen equivalent basis. The amount to be transferred is added to the non-land-dependent stocking rate per hectare of arable land. If this total does not exceed 2 CE-N, such a region conforms to the standards adopted.

Figure 9 Diagram for hierarchical classification of agricultural regions and/or farms

$x_0 = \frac{\text{CE-P}}{\text{ha cultivated land}}$

$x_1 = \frac{\text{LD CE-K}}{\text{ha grassland}}$[1]

$x_2 = \frac{\text{NLD CE-N}}{\text{ha arable land}}$[2]

$x_3 = (x_2 - 2) \cdot \frac{\text{NLD CE-K}}{\text{NLX CE-N}} \cdot \frac{\text{arable land}}{\text{grassland}}$

$x_4 = x_3 + x_1$

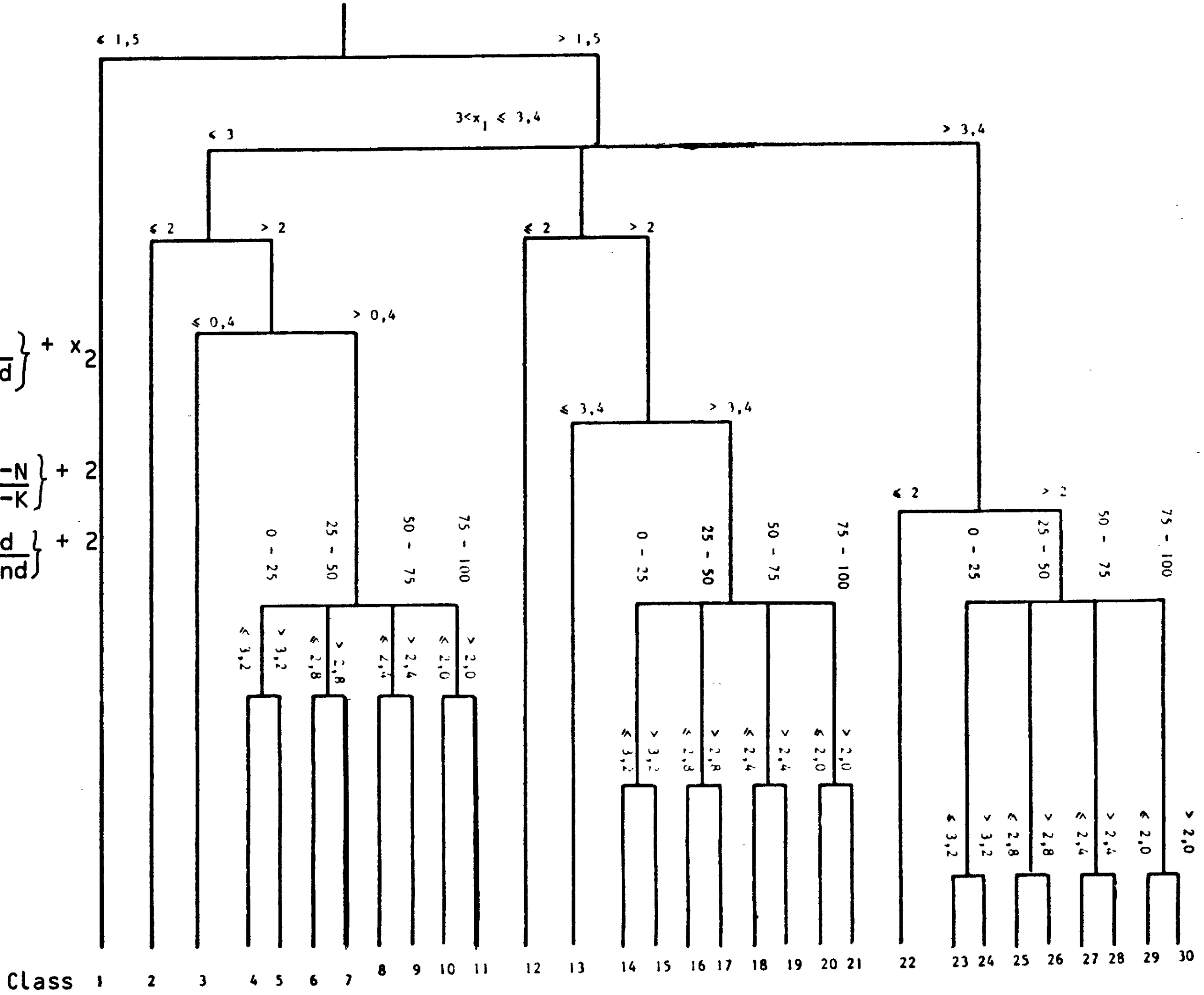
$x_5 = \left\{(x_1 - 3.4) \cdot \frac{\text{LD CE-N}}{\text{LD CE-K}} \cdot \frac{\text{grassland}}{\text{arable land}}\right\} + x_2$

$x_6 = \%$ cereals on arable land

$x_7 = \left\{(x_3 - 0.4) \cdot \frac{\text{grassland}}{\text{arable land}} \cdot \frac{\text{NLD CE-N}}{\text{NLD CE-K}}\right\} + 2$

$x_8 = \left\{(x_4 - 3.4) \cdot \frac{\text{NLD CE-N}}{\text{NLD CE-K}} \cdot \frac{\text{grassland}}{\text{arable land}}\right\} + 2$

$x_9 = x_5$



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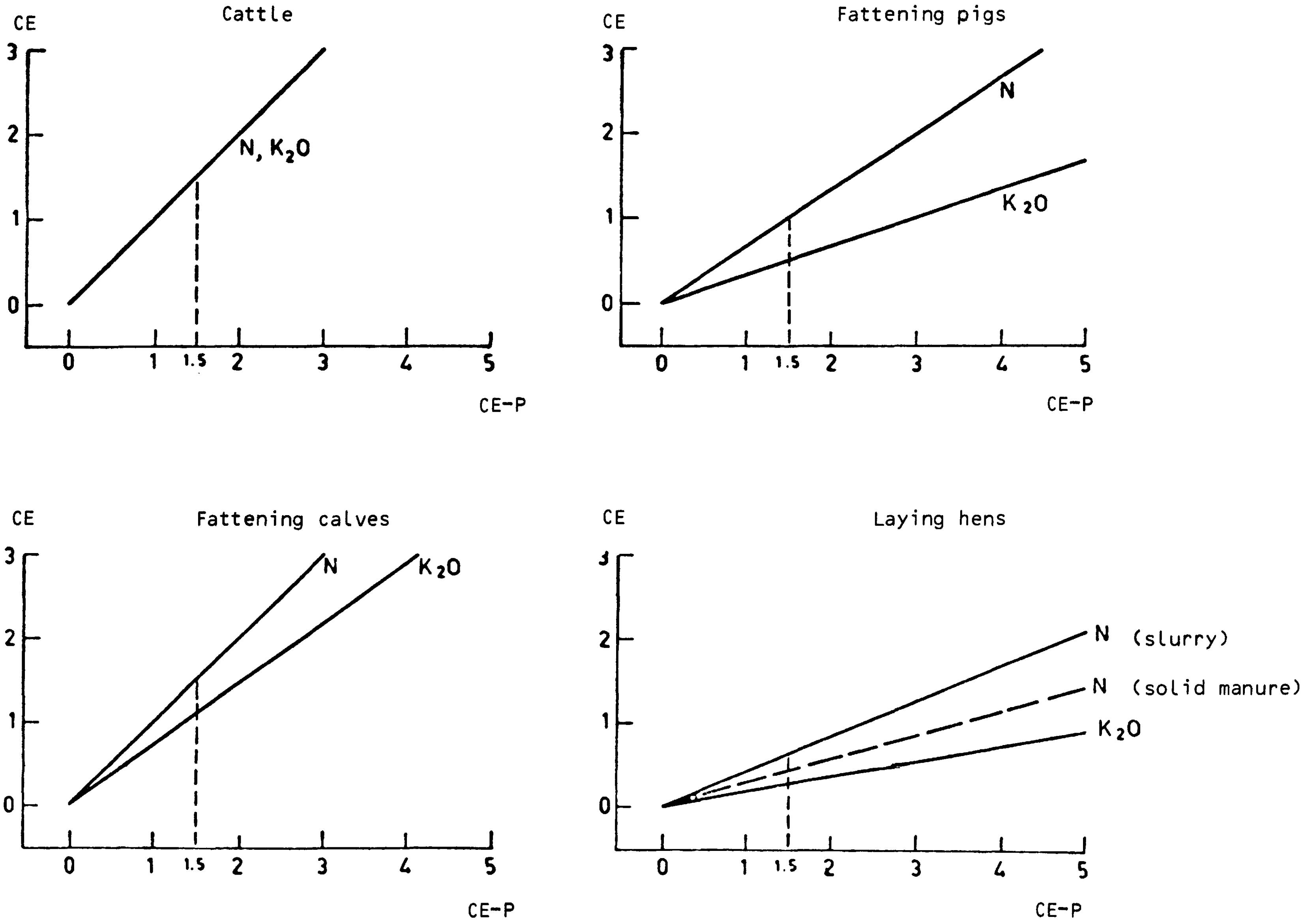
[1] LD = Land-dependent

[2] NLD = non-Land-dependent

Fig. 10 Relationship between CE(P and CE-N or CE-K for different animal species



The three remaining groups of regions are each divided, on the seventh level (x_6) of the dendrogram, into four groups on the basis of the percentage of cereals on arable land. This is because crops other than cereals - e.g. potatoes, beets and maize - have a considerably higher nitrogen requirement than 100 kg nitrogen per hectare per year. For this reason, the standard of 2 CE-N per hectare of arable land can be increased for a number of regions (see figure 11).

The eighth, ninth and tenth levels (x_7, x_8 and x_9) include regions with cropping systems permitting higher manuring and with stocking rates (expressed in CE-N per hectare of arable land) below the standard figures that are then applicable.

The standard rate is 3.2 CE-N per hectare for 0-25% cereals.
The standard rate is 2.8 CE-N per hectare for 25-50% cereals.
The standard rate is 2.4 CE-N per hectare for 50-75% cereals.
The standard rate is 2.0 CE-N per hectare for 75-100% cereals.

The regions then remaining have higher stocking rates than the tolerance limits adopted. These regions thus have manure surpluses, and regulatory measures could be contemplated for them. The surpluses can be calculated easily, because the load is always expressed in CE-N per hectare of arable land on the last three levels of the dendrogram. If the tolerance limit for the cropping system is subtracted from this, the remainder is the surplus expressed in CE-N per hectare of arable land. The surplus in tonnes of manure can be calculated by multiplying by 90 (1 CE-N = 90 kg nitrogen) and dividing by the nitrogen production in the manure per animal species per year (see Chapter 11, Table 2).

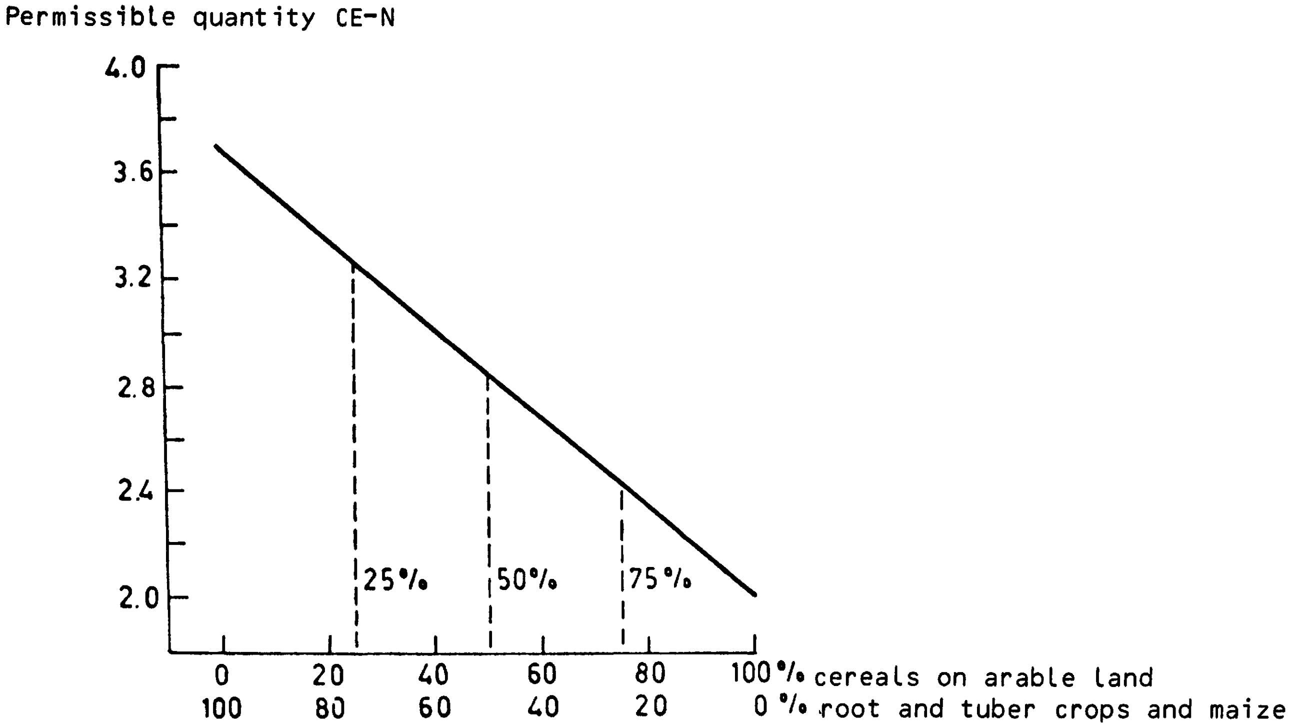


Figure 11. Permissible application of nitrogen in CE-N per ha of arable land for different cropping systems.

Summary

A diagram for the hierarchical classification of agricultural regions and/or farms has been drawn up. The thresholds established in previous Chapters of this report are used. Tolerance limits which may exceed the threshold are applied only with respect to the cropping system. These tolerances are based on the average nitrogen requirement of the crops in the cropping system.

The size of manure surpluses can also be calculated relatively simply from this diagram.

IX. Summary and recommendations

1. Social, economic and technological developments in the last few decades have led to greatly increased animal stocking rates per hectare of cultivated land. Areas of concentration of non-land-dependent sectors of intensive livestock farming (pigs, poultry, etc.), liable to cause various forms of nuisances, have arisen.

> It is recommended that governments within the EEC pursue policies designed to encourage livestock farmers to have regard for the quality of the environment. In addition to intensive information and education, the imposition of certain regulations on the use of animal manure may be contemplated.

2. The report deals with the problems of manure surpluses. Where there is a surplus, the animal manure produced on farms contains larger quantities of minerals than are required on the farm's land.

> To avoid pollution of soil, groundwater and surface water and adverse effects on crops and animals, this report suggests that no more manure may be applied to the land than is necessary to obtain maximum crop production coupled with acceptable quality. If even this amount of manure is liable to cause unacceptable soil or water pollution, the upper limit must be set at a lower level. Manure surpluses must be removed. These principles should be incorporated in information to farmers and possible official regulations.

3. The amount of manure required for maximum production coupled with acceptable quality for arable crops depends primarily on its nitrogen content; the potash content is the relevant factor for grassland. The effects of nitrogen include lodging of cereals, reduction of sugar content and juice purity in beets, and reduction of yields; excess potash on grassland, especially at very high doses, promotes the incidence of grass tetany in cattle.

> It is recommended that the maximum amount of manure to be applied from the point of view of crop production be based on the nitrogen requirement in the case of arable crops and on the potash requirement for grassland.

4. The nitrogen requirements of the various arable crops are in general known and are usually expressed in kg of chemical fertilizer N per ha applied in spring. This quantity can be converted into kg N in animal manure. The report indicates that with regular application of manure to a given plot of land, assuming uniform distribution over autumn, winter and spring, the effect of 100 kg N in animal manure corresponds to that of about 60 kg of chemical fertilizer N. Most arable crops will have a requirement of between 100 and 200 kg chemical fertilizer N per ha, which thus amounts to 166 to 333 kg N in animal manure.

> It is recommended that the maximum dose of manure for arable land be determined from the average chemical fertilizer N requirement of the crops featuring in the rotation by multiplying this requirement by a factor of 1.66 (= 100 - 60).

The report also states the potash requirement of grassland. If it is assumed that all the manure of the land-dependent livestock is applied to grassland, clay soil can accommodate additional manure only if measures to prevent grass tetany are taken. The extra capacity then amounts to about 40 kg K_2O per ha. Somewhat more manure can be accommodated on light soil: an additional dose corresponding to 70, 55 and 40 kg K_2O per ha (figures rounded) at stocking rates of 1, 2 and 3 livestock units (LU) per ha respectively, again provided that measures to prevent grass tetany are taken. At stocking rates of more than 3 adult cattle per hectare of grassland, there is no capacity for additional manure on either clay or sandy soil.

> In determining the maximum additional dose of manure for grassland, it is recommended that the cattle stocking rate on the farm and of the type of soil be taken into account. This dose will be about 40 kg K_2O per ha on clay soil, unless the stocking rate is higher than 3 LU/ha, in which case there is no capacity for any more manure than that of the farm's own herd. This also applies to sandy soil, although in this case maximum additional doses equivalent to 70, 55 and 40 kg K_2O per hectare are suggested for stocking rates of 1, 2 and 3 LU/ha respectively (assuming 100% efficiency for the potash in the manure).

5. It is not easy for the livestock farmer to determine how much nitrogen and potash he is applying with the manure. If manure applications were

officially regulated it would be equally difficult to verify the amounts of nitrogen and potash applied in the manure by way of inspection. This difficulty is avoided in the report by converting quantities of manure into standardized livestock units (Tables 2 and 3). A crop requirement of 100 kg chemical fertilizer N, corresponding, as shown in item 4 above, to 166 kg N in animal manure, is met by, for example, the manure produced by 1.9 adult cattle (Table 2) or 7.9 . 1.9 = 15 pig places (Table 3). Capacity for an additional manure dose of, for instance, 55 kg K_2O per ha of grassland amounts, according to Table 2, to the manure of 9 pig places or 153 laying hens (Tables 2 and 3). Using the figures in Tables 2 and 3, the farmer or controlling agency can calculate the N and K production of the animals and determine the size of the manure surplus relative to the maximum levels mentioned in item 4 above.

> It is recommended that the permissible dose of manure and the size of any surplus should be expressed not in kg but as "the manure of x standardized animal units". Tables 2 and 3 in this report can be used to convert numbers of animals into quantities of N and K in manure and vice versa. If required, the figures can be adapted to accord with local conditions.

Table 2 gives figures for the production and composition of the manure per animal (or animal place) per year. Table 3 allows conversions as between the different species of animals on the basis of equal production of N or K or other manure components. One LU represents the slurry production of an adult cow (annual basis), containing 89 kg N (assuming an efficiency index of 0.6), 40 kg P_2O_5 and 100 kg K_2O[1].

6. The maximum quantities mentioned under item 2 above do not present a soil pollution hazard, as the productivity of the soil is not impaired seriously, for a long period and irreversibly; on the contrary, productivity is generally increased rather than reduced. An exception is where copper-enriched pig manure is regularly used, owing to the toxicity of the copper. However, even with a cropping system with a substantial N requirement (e.g. 170 kg chemical fertilizer N per ha), which is entirely covered by such pig manure (about 40 tonnes/ha) it would still take about 75 years before the copper content of the soil would become toxic for some crops. The same period

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[1] See also Appendix III

applies to grassland where 20 tonnes of manure, in addition to that of the cattle present, is applied per annum. At doses of this order, however, a critical situation for grazing sheep will arise much earlier.

> It is recommended that the addition of copper to pig feeds be limited to the minimum required. Also, arable farms applying more than 40 tonnes of pig manure per ha and grassland farms applying at least 20 tonnes of pig manure per ha should be subjected to periodic soil analysis (e.g. every five years). If the copper content (soluble in dilute HNO_3) in arable land exceeds 50 ppm in the 0-25 cm layer (100 ppm on grassland in the 0-5 cm layer), further use of copper-containing manure should be discouraged or prohibited. As an emergency measure, the copper-rich top layer can be ploughed down. On grassland used for grazing sheep, the use of copper-containing manure should preferably be avoided entirely.

7. Like chemical fertilizer, animal manure applied to the land is liable to increase the nitrate content of the groundwater. Such an increase is deemed in this report to be harmful if the concentration rises above the EEC standard level for drinking water of 11.3 mg/l nitrogen as nitrate. If the quantities of manure mentioned in item 2 above are used, the drainage water passing through the rhizosphere (arable land, spring application) contains less nitrogen than the EEC standard level in the case of heavy soil, but more if the soil is light. The EEC standard is exceeded in both cases with autumn application. It is also exceeded on light soil if no animal manure but only chemical fertilizer is applied in the optimum quantity for the crop. Drainage water from grassland is likely to exceed the EEC standard concentration only at high cattle stocking rates (over 2.5 LU/ha).

In intensively farmed grassland regions and areas of arable land with light soil, the shallow groundwater is thus liable to be polluted with nitrate. The risk is smaller for the deep groundwater because part of the leached nitrogen can volatilize during its descent and because the nitrate concentration of the groundwater can increase only slowly since its volume is large relative to that of the drainage water penetrating into it.

> Because, on the one hand, the deep groundwater is still of good quality, and there is little risk of its becoming seriously polluted in the short term, and because, on the other hand, the consumer can take technological measures (e.g. the use of ion

> exchangers) to purify nitrate-polluted groundwater used for drinking water; it is recommended that the aspect of groundwater pollution should feature in the information provided to farmers but should not yet be included in compulsory regulations.

8. The most important component of manure as regards surface water is phosphorus. The water is liable to be polluted not so much through leaching (except where the top layer of the soil is thin or excessively permeable and the subsoil is impermeable) as through the occurrence of surface runoff containing particles of manure and soil or phosphorus already dissolved in the soil moisture. The extent of runoff depends on the phosphorus status and tolerance of the soil; the latter in turn depends on the permeability and water-holding capacity of the soil, its slope and vegetation cover, precipitation amounts and intensity, and the timing of manuring. There are no universally applicable norms for determining tolerance.

> It is proposed that a study be undertaken to establish generally valid standards for classification of soils as to tolerance (in relation to runoff); pending this classification, tolerance should be determined locally by land use development experts, soils being classified in, say, three classes: normal, low and nil. In the low tolerance category, the permissible quantity could then be reduced to half the level mentioned in item 2 above. This reduction only becomes urgent once the phosphorus content has risen to a high level. The phosphorus status should be evaluated locally by soil fertility experts. If no information on tolerance is available, the "normal" class should be taken as the basis.

9. The size of the manure surplus can in principle be determined per farm and per region. The surplus is the amount produced over and above the standard level mentioned in item 2. The following parameters are required for calculation:

(i) numbers and species of animals present;
(ii) area of cultivated land and ratio of arable land to grassland;
(iii) relative areas of the different arable crops;
(iv) relative areas of land of normal, low or no tolerance;
(v) any limitations due to excessive copper or phosphorus content (the latter for low-tolerance soils).

The first point to be considered is the land-dependent cattle stocking rate of grassland. If this does not exceed 3 LU, there is a margin for manure of other animals on a K equivalent basis (see item 4). The remaining manure of the other animals is intended for the arable land of normal tolerance, provided that the nitrogen requirement of the overall cropping system so allows. Part of any surplus still remaining can be accommodated on any areas of low-tolerance land, up to a maximum of 60 kg P_2O_5 (1.5 LU) per ha, i.e., a dose corresponding to the amount of phosphorus removed every year with the crop.

> It is recommended that livestock farmers be taught how to calculate the manure surplus of their farms and be encouraged to dispose of this surplus off the farm. The same calculation procedure can be followed when existing farms are enlarged or new ones established. The result constitutes an indication for the authorities as to the desirability of limitations on farm enlargement or the establishment of new farms.

10. Technical means such as soil analysis cannot be used to verify whether surpluses are in fact disposed of. An administrative procedure would be more appropriate. The report mentions the possibility of obliging farmers to dispose of surpluses through an independent central registering body.

> In livestock concentration regions, it is recommended that farmers initially be given an opportunity to offer their surpluses voluntarily to an independent central administrative body, which will also keep records of the disposal of these surpluses. If the total amount offered is found to fall short of the surplus calculated for the region, more stringent measures would have to be considered, e.g., compulsory disposal on an individual farm basis, again with registration by a central body. A rough check by the central body on the destination of the surplus manure (via transport documentation) appears to be sufficient in the first instance. A transport subsidy would increase the possibilities of effective inspection (see also Appendix II). The transport of solid manure, which has a higher manurial value and is easier to store, is less eligible for subsidization than that of slurry.

11. Where non-land-dependent livestock holdings are scattered over an arable farming or horticultural region, the surplus manure can readily be disposed of in the area. Problems arise where such holdings are concentrated, especially in grassland areas where little additional manure from animal species other

than the cattle already present can be accommodated.

> In this connection it is recommended that more opportunities should be provided for non-land-dependent livestock farming in arable and horticultural regions than in grassland areas. The establishment of administrative bodies (item 10) is less urgent in the former types of regions. It is proposed that registration be limited to regions (possibly farms in these regions) where manure surpluses are expected.

This will be the case if the non-land-dependent animal complement - after deduction of 0.4 LU on a K20 equivalent basis for each hectare of grassland (or 0 LU if the cattle stocking rate exceeds 3 LU/ha grassland) - is greater than 2 LU per ha of arable land on a nitrogen equivalent basis. If the region (or farm) comprises a large area of land of low tolerance, the figure 2 must be reduced to 1.5. In this case, the conversion to numbers of other animal species must be based on P_2O_5 equivalents.

The deduction of 0.4 LU relates to the 40 kg of K_2O which constitutes the minimum additional quantity that can be accommodated on grassland if the cattle stocking rate does not exceed 3 LU/ha (item 4). The norm of 2 LU stated for arable land is based on the nitrogen production of these animals, which is about 180 kg and corresponds in its effect to 100 kg of chemical fertilizer N. Such a quantity will be a reasonable minimum on virtually all arable land. Finally, the level of 1.5 LU applies to low-tolerance land which will not tolerate more than 60 kg P_2O_5 per ha (the production of 1.5 LU) owing to the danger of runoff.

12. The timing of manure application and distribution over the various fields within a holding depend on a number of factors, some of them complex, which do not readily lend themselves to official inspection.

> It is recommended that the timing of manure application and its distribution within the farm should not be regulated but should be optimized by extending information.

13. Farmers are often compelled to spread manure at inappropriate times owing to insufficient storage capacity. The construction of storage facilities calls for heavy capital investment.

> It is recommended that the authorities promote the establishment of storage facilities for liquid manure both on the farm and centrally in problem regions, in particular to cover periods unfavourable for manuring. In the establishment of storage facilities, the construction of further processing (drying, purification) plants could also be considered.

14. Responsible use of mixed feeds is also relevant to the solution of manure problems. Government information here should therefore also extend to the mixed feeds industry, the aim being to limit additions of inorganic constituents to livestock feeds over and above the requirements of the animals. In manure surplus areas, promotion of the use of no longer wanted nutrients in the form of chemical fertilizer, sewage sludge, town refuse compost, etc., should be avoided.

15. To improve the scientific basis of future regulations, more information must be obtained about certain processes of soil and water pollution.

For this reason it is recommended that research should be encouraged on the following:

a. contribution of runoff to eutrophication of surface water with phosphorus, in both hilly and level terrain;
b. the time needed for phosphorus equilibria to become established in different soils, and the level at which this occurs;
c. possibilities of chemical denitrification in hydrologically important soil layers.

Financial, legal and administrative aspects have been almost entirely ignored in the considerations on which the above proposals and recommendations are based. The authors do not wish to minimize the importance of these aspects, but consider that these do not fall within their sphere of competence.

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Appendix I

Balance sheet for the mineral nitrogen in the soil

The report mentions nitrogen losses without going into details of the relevant factors in the nitrogen supply of cultivated land. For this reason, the components of the mineral nitrogen balance sheet of the soil are calculated below.

The nitrogen balance sheet of the soil consists of the following inputs and outputs :

Input

1. Seedbed
2. Rainfall
3. Manures and fertilizers
    a. Inorganic
    b. Organic
4. Nitrogen fixation from air
    a. Symbiotic N fixation
    b. Asymbiotic N fixation (Azotobacter, etc.)
5. N mineralized from the soil's reserve of organic matter (net mineralization)

Output

1. Nitrogen uptake (entire plant)
2. Leaching (net)
3. Volatilization
    a. Denitrification (N_2 and N_2O)
    b. Volatilization (NH_3)

Together with the nitrogen mineralized from the soil's reserve of organic matter (the "soil fertility level"), the application of inorganic or organic manures and fertilizers can increase the *input* to a level sufficient to satisfy the nitrogen requirement of the plant, including its root system (output side).

Leaching will generally be slight if supplementary nitrogen is applied in spring at the correct dose, since plant growth begins shortly after application. In this case the leaching loss will primarily consist of soil nitrogen mineralized outside the growing season. The extent of this leaching in turn depends on the length of the growing season, which increases for the following crops in the orders : cereals, potatoes, beets and grass. This means that even if dosage is correct, nitrogen leaching losses on arable land will in general be greater than on grassland.

A surplus arises if much more mineral nitrogen is supplied on the input side than the crop requires. Most of this surplus will leach out in autumn and winter with the soil nitrogen mineralized outside the growing season.

Leaching can occur because rainfall exceeds evaporation in autumn and winter under western European climatic conditions; this gives rise to surplus precipitation averaging 250 mm per year.

The process of denitrification is important with regard to the availability of mineral nitrogen for the plant and the degree of leaching of mineral nitrogen. The process involves the reduction of nitrate by micro-organisms under anaerobic conditions to N_2 or nitrogen oxides. The lower the air content of the soil, the more likely such anaerobic conditions are to occur, particularly as the soil becomes heavier (i.e., with increasing content of finer particles). Owing to the high pH and the large quantities of NH_3 nitrogen generally contained in organic manures, losses due to NH_3 volatilization will occur in particular if these manures are not quickly turned under. Such losses may also occur on alkaline soils with inorganic fertilizers containing urea or NH_3, in which case a nitrate fertilizer should preferably be used.

The heavier the soil, the lower nitrogen leaching losses will be. This is due primarily to the lower mobility of water in heavier soils, and secondarily to the occurrence of denitrification. Lysimeter tests on various soils with vegetation cover but which had not been manured or fertilized for a number of years gave the following results (Kolenbrander, 1969).

Table 1. Nitrogen leaching losses with 250 mm drainage water on arable land with vegetation cover, unmanured

Type of soil	% particles $< 16\ \mu m$	Nitrogen loss kg ha^{-1} $year^{-1}$
Sand	0-10	45
Light sandy clay	10-20	30
Heavy sandy clay	20-30	18
Light clay	30-40	10
Heavy clay	>40	$\leqslant 6$

The following percentages of an additional application of 100 kg N per ha (mineral nitrogen) were lost by leaching :

Sandy soil	0-10%	<16 μm	14%
Light sandy clay	10-20%	"	8%
Heavy sandy clay	20-30%	"	3%
Light clay	30-40%	"	<3

Denitrification is likely to be significant mainly in the part of the growing season when supplementary manure or fertilizer has already been applied but the uptake capacity of the plant is still low and leaching is not yet appreciable as evaporation already exceeds rainfall. The nitrogen concentration will be high during this period, and denitrification losses may also be high if anaerobic conditions arise.

Lysimeter tests without legumes are very suitable for nitrogen balance sheet measurements, as all components of the balance sheet other than denitrification losses and the contribution of asymbiotic nitrogen fixation (which is small) can be determined direct. Denitrification losses are then "measures" as a "deficit on the balance sheet".

Table 2 is derived from tests of this kind (Kolenbrander, 1975); it shows that the nitrogen taken up by the plant (as a percentage of input) declines with increasing doses of inorganis nitrogen. The comparison was made at different leaching levels, also expressed as percentages of input. The "deficit on the balance sheet" can now be calculated by subtracting the sum of leaching and plant uptake from 100%.

Table 2 shows that as the nitrogen dose increases, so does the "deficit o on the balance sheet", but that this increase is lower the higher the leaching level. This was presumably due to coarser soil texture. The "deficit on the balance sheet", considered as a loss predominantly due to denitrification, is found to vary, at 0 kg N/ha, from 2 to 18% of input, the range being 22 to 50% at 250 kg N : ha^{-1}.

Table 2. Nitrogen uptake by plant at different leaching levels as percentages of input (arable land)

Nitrogen dose	Leaching level	30%	20%	10%	Average
0 kg	N.ha^{-1}	68%	72%	72%	71%
50 kg	"	66%	70%	70%	69%
100 kg	"	62%	64%	64%	63%
150 kg	"	56%	56%	55%	56%
200 kg	"	51%	48%	46%	48%
250 kg	"	48%	44%	40%	44%

Appendix II

Manure banks

1. Aim

Manure banks have been set up in the Netherlands in three provinces having concentrations of intensive livestock farming. These banks should be regarded as advisory and executive bodies which develop and guide private initiative ar support it over a number of years by subsidizing the cost of transporting liquid organic manure over long distances. They endeavour to achieve this aim by :

(i) acting as an intermediary between farms with manure surpluses and ones with a shortage of organic manure;
(ii) promoting responsible use of animal manure by both producers and potential buyers.

The main task is to serve as an intermediary. Producers and purchasers are put in contact with each other, the aim being to obtain permanent relationships based on good agreements. The producer can then be assured of a regular channel of disposal and the purchaser of receiving supplies at the desired time. Also, the origin of the manure is known, which may be beneficial to quality.

2. Organization

Manure transport is not arranged and performed by the manure banks themselves but through normal channels by the farmer or a custom worker.

The disposal of solid manure to areas with ample capacity for utilization generally creates no problems. This manure is more valuable than slurry and can be transported on more favourable terms. For this reason, surpluses of solid manure are largely disposed of through commercial channels; they are not eligible for transport subsidies. Hence the manure banks are practically not concerned with these.

Disposal of slurry, on the other hand, is more problematical, because its manurial value per unit of volume is appreciably lower. To promote disposal of this manure over relatively long distances, the Agricultural Development and Rehabilitation Fund (Ontwikkelings- en Saneringsfonds voor de Landbouw) in the Netherlands instituted a subsidization system for manure banks in 1973. A 90% subsidy on the wages of one bank official and bank facilities is paid, as well as a transport subsidy averaging 3.00 guilders per tonne of slurry conveyed to users at least 8 km from the producing farm. To qualify for these subsidies, the manure bank must arrange transport for 5,000 tonnes of slurry in the first year, 10,000 tonnes in the second and third years, and 20,000 tonnes in the fourth year. The maximum contribution to transport costs is 200,000 guilders per year.

3. Application of the system of transport subsidization

Three parties are involved in the manure transportation :

(i) the manure producer;
(ii) the manure transporter (e.g. jobbing firm);
(iii) the manure utilizer.

To ensure correct use of the manure, the transport subsidy must be paid to the manure utilizer, who must himself apply for it before the manure has been transported. The user is also responsible for paying transport etc. costs and must make sure that a good-quality product is supplied and that it is spread efficiently.

A transaction can be handled administratively as follows :

The manure utilizer informs the manure bank by telephone when transport has been arranged for a consignment of manure. The bank then sends him the necessary subsidy application forms, on which are entered the name and address of the manure utilizer (i.e. the applicant) and of the manure producer respectively, the quantity of manure to be transported, and the date or dates of transport. A month later, delivery forms are sent to the applicant who declares on these that he has received on a certain date or dates from producer A a specified number of tonnes of slurry of a specified kind (type of animal), transported over a given distance. This form must be returned to the manure bank after it has been countersigned by the manure supplier. A copy of the transport firm's invoice is also required. The subsidy, which varies according to distance (one way), is then paid. The scale of payments for different distances depends on the local organization of the manure bank. In some cases the subsidy may be differentiated as between poultry slurry, which is of higher quality, and other types of slurry. Here is an example taken from the Stichting Brabantse Mestbank for 1975 :

Distance	Subsidy per m^3	
Single journey	Poultry slurry	Other slurries
8 - 15 km	0.75 guilders	1.50 guilders
15 - 20 km	1.00 "	1.85 "
20 - 25 km	1.25 "	2.20 "
25 - 30 km	1.50 "	2.55 "
30 - 35 km	1.75 "	2.90 "
35 - 40 km	2.00 "	3.25 "
40 - 45 km	2.25 "	3.60 "
45 - 50 km	2.50 "	4.05 "
50 - 55 km	2.75 "	4.45 "
55 - 60 km	3.00 "	4.90 "
60 - 65 km	3.25 "	5.40 "
65 - 70 km	3.50 "	5.90 "

These subsidies are thus derived from the average contribution of 3.00 Fl per m^3 of manure after deducting the 10% non-subsidizable costs for the manure bank official's wages and facilities.

The manure supplier receives no payment for his manure. In difficult situations, he may even be called upon to contribute 1 to 2 guilders per m^3 towards the transport costs. What is important to him is whether he can satisfy a demand immediately or whether he is forced to have the manure produced by his animals removed because of insufficient storage capacity.

4. Bottlenecks

The manure producer and purchaser respectively must obviously make agreements as to removal of the manure from the former's farm and its use on the latters. Good contacts must also be forged and maintained with the manure carrier.

Manure storage facilities of adequate capacity are important for producer and purchaser alike - for the former, to tide him over critical periods when manure cannot be spread, and for the latter to enable him to use the manure immediately when the opportunity presents itself. This point is also important for farms which are relatively distant from the manure supplying farms. Carriers will then tend to switch to faster trucks with larger manure carrying capacities (up to 45 m^3 and even more). These trucks must have easy access to the producer's manure pit and be able to load and unload quickly. Facilities for temporary storage must be provided at the receiving farm because the heavy trucks are unsuitable for spreading the manure on the land. Government can make a valuable contribution here by promoting the construction and equipment of manure storage facilities of adequate capacity.

Appendix III

Glossary

Animal place - A concept introduced to indicate the relationship between the number of animals for fattening and slaughter (pigs, broilers, calves, etc.) delivered annually and the animal complement present at a given time, allowance being made for any vacancies and for losses. For instance, a farm with fattening pigs, assuming no vacancies, could supply 2.5 pigs per place annually; in practice, the figure is 2.2. The annual manure production of a farm is based on the number of animal places.

BOD_5 - Biochemical oxygen demand. An indirect measure of the quantity of biodegradable matter in water. It is the amount of oxygen, in mg/l consumed by aerobic microorganisms over a period of five days at 20° C.

CE - Cattle equivalent. See LU.

"Commercial" crops - Crops such as poppyseed, beet seed, canary seed, grass seed, colza, linseed, red and white clover, caraway, etc. (Handboek voor de Akkerbouw, deel 1. Proefstation voor de Akkerbouw, Lelystad, 1973).

Cutting frequency - Number of times per year that the grassland of a farm is cut to provide roughage. If the entire available area of grassland is cut once a year, the cutting frequency is 1. A cutting frequency of 1.2 means that 2 out of every 10 ha is cut twice.

Deep groundwater - Groundwater at a depth of 25 to 125 m.

Denitrification - Reduction of nitrates and nitrites to free gaseous nitrogen (N_2).

Ecological optimum - The maximum quantity of manure or fertilizer that can be used on agricultural land without causing soil and/or water pollution.

Economic optimum - The quantity of manure or fertilizer on agricultural land which gives the highest economic yield, i.e. the quality at which the difference between the financial return from the crops and the cost of the manure is greatest.

Hypomagnesemia - Reduction of the magnesium content of the blood of cattle, which may cause grass tetany, often quickly causing death. This condition is more likely to occur when animals receive feeds rich in crude protein (nitrogen) and potash, and occurs principally in productive adult cows. Possible preventive measures are the administration of additional magnesium (magnesium cake), supplementary feeding of hay and magnesium fertilization of grassland.

Intensive livestock farm - Farms (with pigs, poultry or fattening calves) on which feed requirements are not limited by the available area of fodder crops. The stock is then non-land-dependent.

Ley - Temporary grassland of relatively short (1-2 years) or long (3-4 years) duration included in the crop rotation for soil improvement and/or roughage.

LU (livestock unit) - Slurry production of one adult cow of 550 kg live weight with an annual milk production of 4,000 litres (4% fat). One LU supplies the following nutrients annually in the slurry (feces and urine) : 89 kg N (efficiency index 60%), 40 kg P_2O_5 and 100 K_2O (each with an efficiency index of 100%).

Methemoglobinemia - Presence of methemoglobin in the blood. This is formed by oxidation of hemoglobin, from which it differs in that it contains ferric instead of ferrous iron, so that it cannot reversibly bind molecular oxygen. This gives rise to cyanotic symptoms (blue discoloration of skin and membranes) due to lack of oxygen, possibly resulting in death.

Methemoglobin may be formed by oxidizing poisons such as nitrites. These may in turn arise by reduction of nitrates by enterobacteria, which can only develop at relatively high pH levels. In young babies the pH of the gastric juices may under certain conditions increase to 4.6-6.5, enabling nitrate-reducing organisms to become established in the upper gastro-intestinal tract, causing nitrite poisoning.

Mineralization - Decomposition of organic matter in the soil, whereby inorganic (mineral) constituents are liberated.

Physiological optimum - Quantity of manure or fertilizer required for maximum crop production.

Shallow groundwater - Groundwater at a depth of 6 to 25 m.

Slurry - Mixture of feces and urine with some washwater.

Zero grazing - Management system in which animals are housed throughout the summer. In this case grassland is always cut and never grazed.

European Communities — Commission

The spreading of animal excrement on utilized agricultural areas of the Community
I. Scientific bases for the limitation of quantities
and criteria for rules thereon

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This study ist the first part of a broader-based survey of the possible environmental effects of spreading animal excrement on utilized agricultural areas in the various regions of the Community.

The first section analyses the present state of knowledge about the nutrient content of the various kinds of animal excrement and how they may be put to good use in the cultivation of plants. By reference to the optimum quantities of manure and to soil and water quality standards, threshold values for the spreading of dung and slurry are then calculated and graded according to the various requirementys for arable and grassland farming. The study discusses possible rules and in this connection the threshold values established are converted into coefficients of livestock density; it also lays down guidelines for the proper storage and spreading of excrement.

Other parts of the survey are being published in the same series. They deal with the characteristics of those regions of the Community where intensive stockfarming is practised and attempt to identify the areas in which the spreading of animal excrement on utilized agricultural areas raises problems or could do so in the event of further intensification.

This study is published in Dutch, English and French.

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