Fertilizers and Pollution

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Abstract

In countries with an intensive agriculture, the effects of society on the environment have been studied increasingly in recent years. But elsewhere in the world, achievement of a higher production level will have priority for some time to come.

A higher N-input can contribute to a higher output of consumable N, but this is accompanied, unfortunately by heavier losses of N, P and K to the environment.

The greatest loss of N, P and K occurs in the form of food consumed by the population, the excrements of which, for reasons of hygiene, are transported directly or indirectly to the ocean.

Where a farm can meet (part of) its own nitrogen requirement through leguminous crops, the loss of P and K will have to be made good in some other way if the soil is not to be exhausted. This can be done by means of fertilizer, organic manure, or concentrated feeds, but these solutions require much fossil energy.

Considering the world food supply situation, it might be important to recycle elements that are valuable to agriculture from urban waste water, which would at the same time achieve a reduction in surface water pollution. On the farm, all technological measures should be taken to restrict losses to the groundwater and the atmosphere as much as possible.

By combining data collected in Western Europe with the WHO-norms for drinking water it was attempted to set limits to mineral-N fertilization on arable land and grassland in intensive agriculture. It was found that, in the case of arable land on sandy soil, it is difficult to comply with the WHO-norm.

An ever growing world population increasingly demands food, thereby also increasingly putting pressure on local agriculture to meet this demand. It was pointed out at the Congress on "Cycling of Mineral Nutrients in Agricultural Ecosystems" held at Amsterdam in 1976 that the consumable N-output (i.e., production of nitrogen in foods and feeds) is positively correlated with the total farm input of nitrogen (Figs. 1 and 2). The total farm input of nitrogen consists of a combination of N-sources such as biologically fixed nitrogen (legumes), chemically fixed nitrogen (fertilizer-N) and nitrogen imported in concentrated livestock feeds, in organic manure and in precipitation and irrigation water.

However, it was also pointed out at the Congress that a higher N-output

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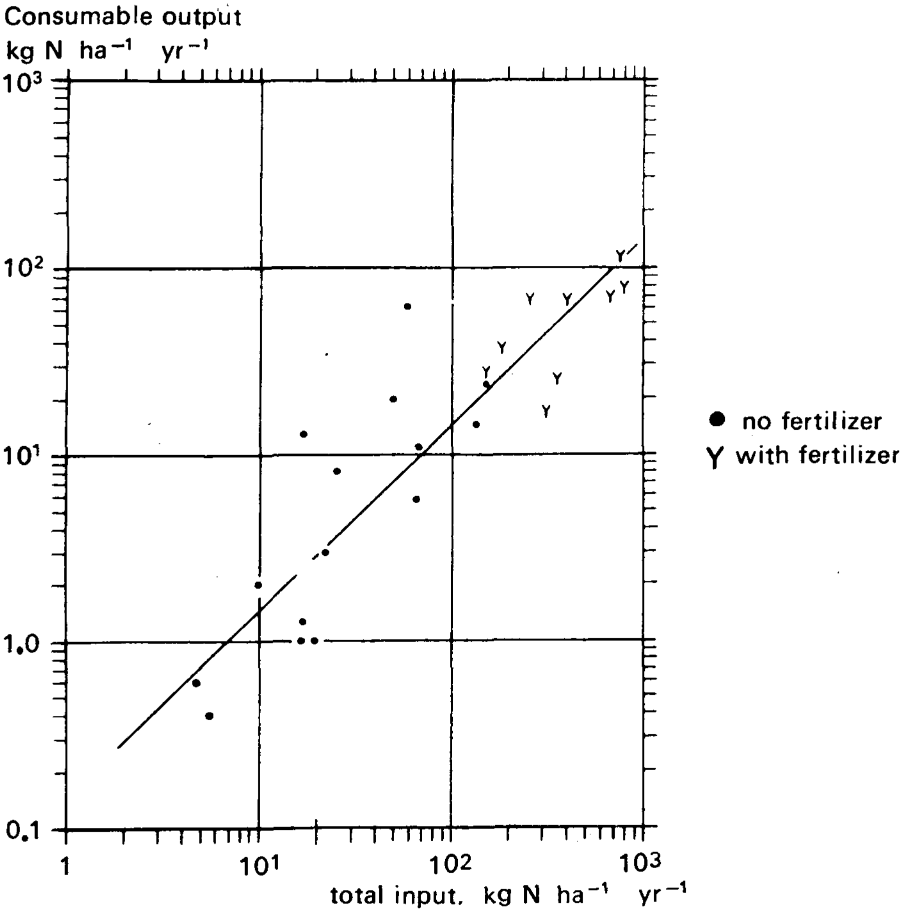


Fig. 1. Relation between input and output of nitrogen in farming systems with only an output of animal products

is accompanied by a proportionally higher farm output of P and K (Fig. 3). The relatively close relation between farm input and output of N indicates a dominating influence of nitrogen, but it is obvious that, to avoid exhaustion by overcropping, higher inputs of other plant nutrients, such as P and K, should also be considered. A mixed farm, for instance, having the proper proportions of arable land and grassland, could meet its own needs by utilizing nitrogen, biologically fixed in the clover-grass pastures, on its arable land via animal manure. However, in terms of other plant nutrients such as P and K, grassland will be impoverished to a certain extent, the consequences of which depend on the nutrient supplying power of the soil. If the supply of these nutrients in the soil is not adequate, they have to be supplied in the form of fertilizer, organic manure, or concentrated feeds.

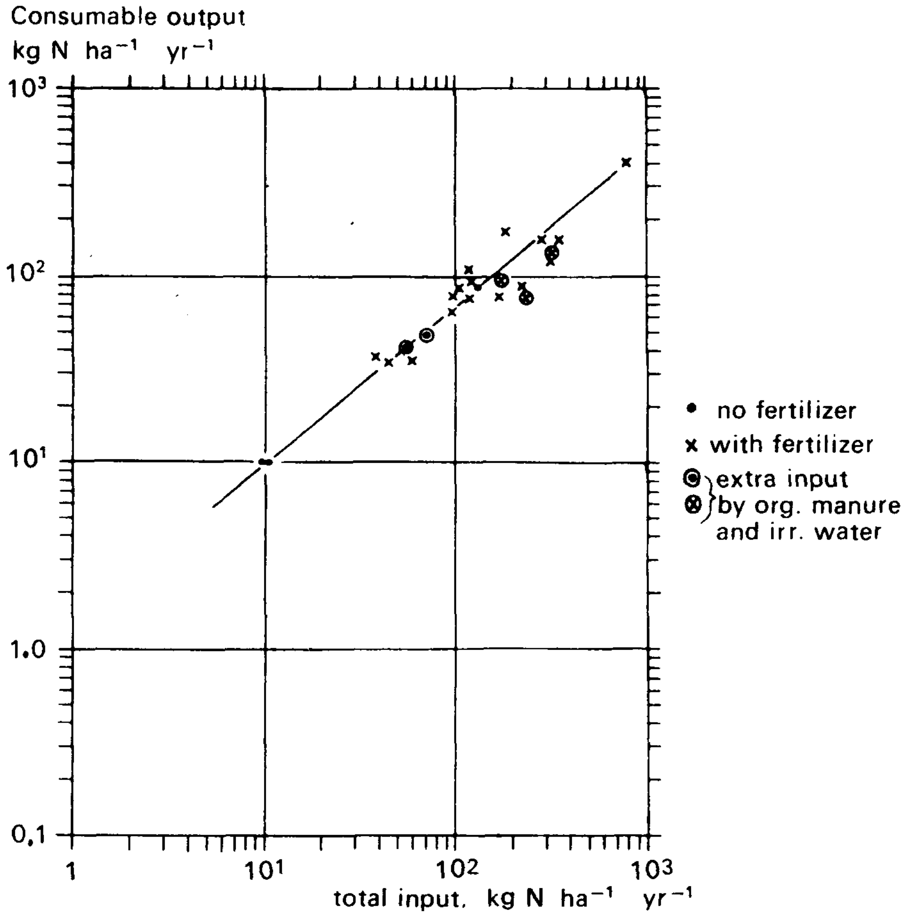


Fig. 2. Relation between input and output of nitrogen in arable farming systems

Taking into consideration the additional factors, such as the need of replenishing P and K (Figs. 1 and 2), the farmer, by freedom of choice of N-input, can cause a great variation in N-output, and can hope for economic result. In industrialized countries, this freedom of choice has been used to good advantage during the last 25-50 years, because of the availability and economic pricing of fertilizers. In these countries questions are now being asked about the secondary effects of these larger inputs, especially on their environmental consequences. In the following sections these consequences will be analyzed to consider as to what extent the increased inputs are acceptable from the viewpoint of protection of the environment.

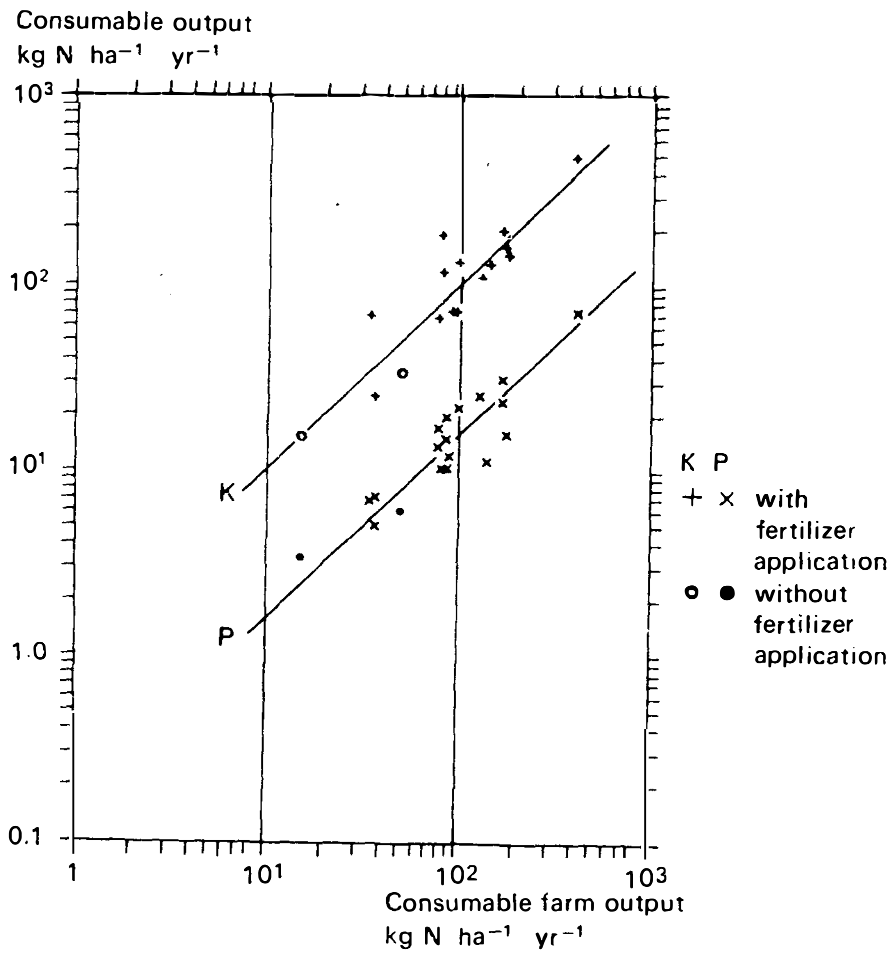


Fig. 3. Relationship between consumable farm output of nitrogen, phosphorus and potassium

Effects on the Environment

Fig. 4 gives a schematic representation of the input and output of nutrients of an arable farm. It is apparent that there are three "leaks" in the cycle: (1) export of food from the farm to the population (N, P, K), (2) leaching to the groundwater (N, P, K), and (3) volatilization to the atmosphere (N).

The relation of these "leaks" to total N-input is shown in Table 1. The data are based on Figs. 2, 3 and 5, which were derived from the same information on balance sheets that was presented at the Amsterdam Congress mentioned earlier. This information was collected in different, agriculturally diverse, areas in the world.

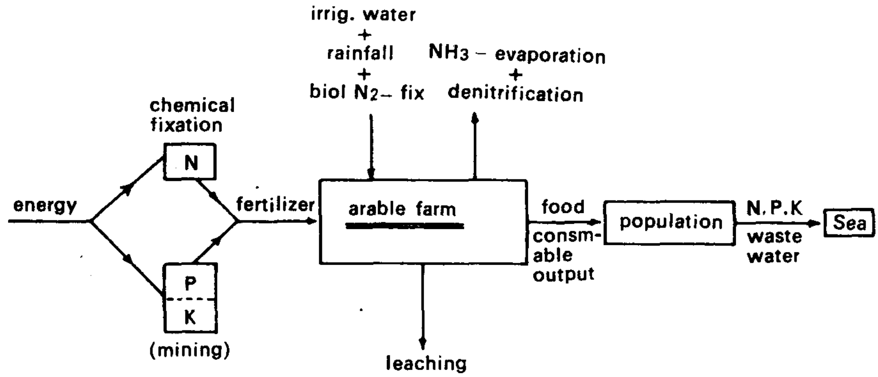


Fig. 4. The nutrient cycle of an arable farm

Table 1. Average output of nitrogen, phosphorus and potassium as a function of total N-input

N-input	Type of output	Output (kg ha^{-1} yr^{-1})			
(kg N ha^{-1} yr^{-1})		N	%	K	P
100	Consumable	70	(70)*	70	11
100	Leached	10	(10)	13	trace
100	Denitrif. + NH_3	20	(20)	—	—
200	Consumable	130	(65)	130	20
200	Leached	30	(15)	29	trace
200	Denitrif. + NH_3	43	(21)	—	—
300	Consumable	180	(60)	180	28
300	Leached	66	(22)	43	trace
300	Denitrif. + NH_3	51	(17)	—	—

Trace = 0-2.0 kg P ha^{-1}yr^{-1}; *Figures in parentheses indicate percentages of N-output

Food, Man and Environment

Table 1 shows that a higher N-input results in a higher consumable output of N, P and K. On arable farms, consumable N-output varies from about 70% at an input of 100 kg N/ha to 60% at an input of 300 kg N/ha. This is a considerably higher percentage than that for livestock farms (Fig. 1), where N-output averages 15%. The cause lies in the poor utilization of the nitrogen in the animal feed: much of this nitrogen is excreted and "recycled" to the land, thus constituting no farm-output. Also the minerals in the food consumed by the population will be excreted almost entirely. In this case, however, often no recycling to agriculture takes place as in the case with a livestock farm; the excrements are transported directly or indirectly with the waste water to the ocean.

This "leak" not only causes severe pollution of surface waters, but it also permanently removes elements that are indispensable to food production. If no soil exhaustion is to occur, these elements will have to be replaced one way

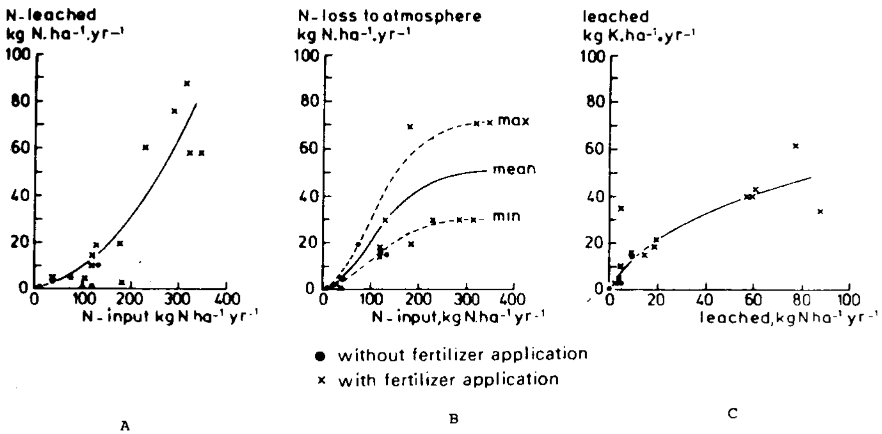


Fig. 5. Nitrogen losses by leaching and to the atmosphere by denitrification and ammonia evaporation as a function of total nitrogen input and the relationship between nitrogen and potassium leached on arable farms

or another. This can be done by collecting and recycling the excrements separately. If this is impossible for reasons of hygiene, then the only alternative is to purify the waste waters, or to import the elements in the form of fertilizer insofar as P and K are concerned. The nitrogen requirement, after all, can be more or less met by biological fixation of N_2.

Losses to the Groundwater

Losses to the groundwater occur through leaching. This process can be controlled by the farmer only to a limited extent, because it is largely determined by climatic conditions and soil properties. A control of these losses can lead to a larger output without an increase in input. In other words, the efficiency of the inputs is improved. Aside from being a direct economic disadvantage to the farmer, leaching constitutes a direct threat to the quality of our ground- and surface-waters used for drinking and also contributes to eutrophication of surface waters.

Phosphorus. It is an important limiting factor in the growth of algae in surface waters. Fig. 6 shows how P-concentration of the soil solution increases with increasing P-status of the soil (Pw value). However, because the concentration in the soil solution and the drainage water is low, leaching of phosphorus is, from an agricultural point of view, of very little importance — variation in sandy soils and clay soils 0-0.5 kg P ha^{-1} yr^{-1}; peats 2 kg P ha^{-1} yr^{-1}; (Kolenbrander 1973a, b).

Nitrogen. It plays an important role in the quality of drinking water in connection with the occurrence of nitrite poisoning or methemoglobinemia in

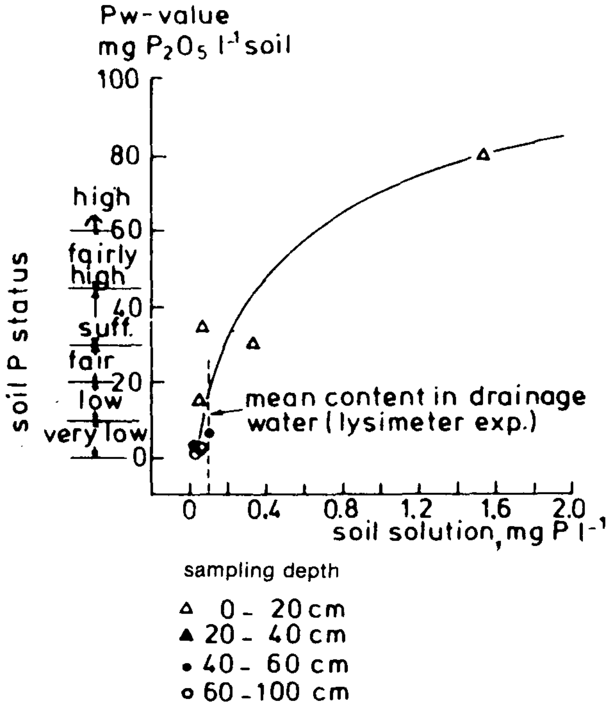


Fig. 6. Relationship between Pw-value and P-concentration in soil solution (sandy soil NGe-84 Ruurlo)

babies, and of cancer in older persons due to the formation of nitrosamines in the digestive tract. The WHO has therefore introduced certain limits to the nitrate content of drinking water. The recommended safe level is <11.3 mg NO_3-N l^{-1} and the unsafe level is >22.6 mg NO_3-N l^{-1}.

Fig. 7 (Kolenbrander 1969) shows that leaching losses decrease in heavier soil. This is due to the fact that the volume of macropores is smaller in a heavy soil and, therefore, water movement in the profile is slowed down.

Fig. 8 shows the effect of quantity of drainage water and type of crop on losses of N due to leaching. The results have been taken from a lysimeter investigation by Maschhaupt (1941). It is clear that up to 500-600 mm drainage water per year for this soil (25% particles <16 μm), a linear relation exists between quantity of N leached out and quantity of drainage water.

The amounts of drainage water being equal, leaching losses from grassland are found to be smaller than those from arable land. This is due to the fact that there is no fallow period on grassland.

Fig. 8 further shows that leaching losses of N from arable land are greater following a leguminous crop than in the absence of such a crop in the rotation. A crop like winter wheat following peas will reduce this leaching loss

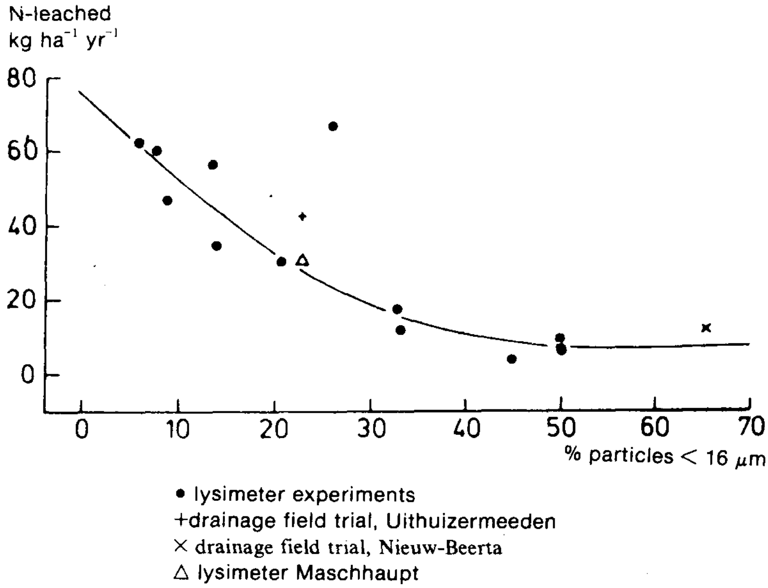


Fig. 7. Relation between heaviness of soil and nitrogen leached from cropped arable lysimeters with 2% organic matter in the soil and without nitrogen fertilization (drainage water production 350 mm per year)

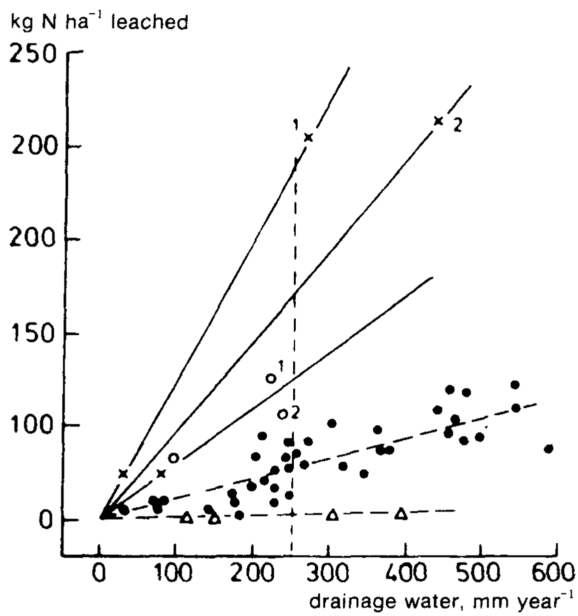


Fig. 8. Leaching losses of nitrogen with and without legumes (Maschhaupt 1941)

somewhat, but it remains greater. The phenomenon of heavier leaching losses after a legume has also been observed by other workers (Karraker *et al.* 1950; Bolton *et al.* 1970; Low 1973; Wiklander 1977).

The problem is that an increase in farm input through legumes for the purpose of obtaining a higher consumable output will be accompanied by extra N-losses compared with those from fertilizer nitrogen, resulting in a heavier load in ground- and surface-waters.

In Western Europe, with its highly intensive agriculture and relatively high population density, considerable research has been done in the recent past on leaching of plant nutrients and their role in water pollution. With these data from different West-European countries I have tried to assess the magnitude of losses due to leaching. I have assumed that, for this climatic region, the relation between amounts of drainage water and N-loss is linear; this makes it possible to reduce all results to 300 mm drainage water per year.

Fig. 9 shows the relation between input of mineral nitrogen and the amount of nitrogen from a sandy soil and a clay soil used as arable land and as grassland. The groundwater level, which also plays a role here (Van Dijk 1980; Rijtema 1980), was more than 1 m below the surface in these experiments.

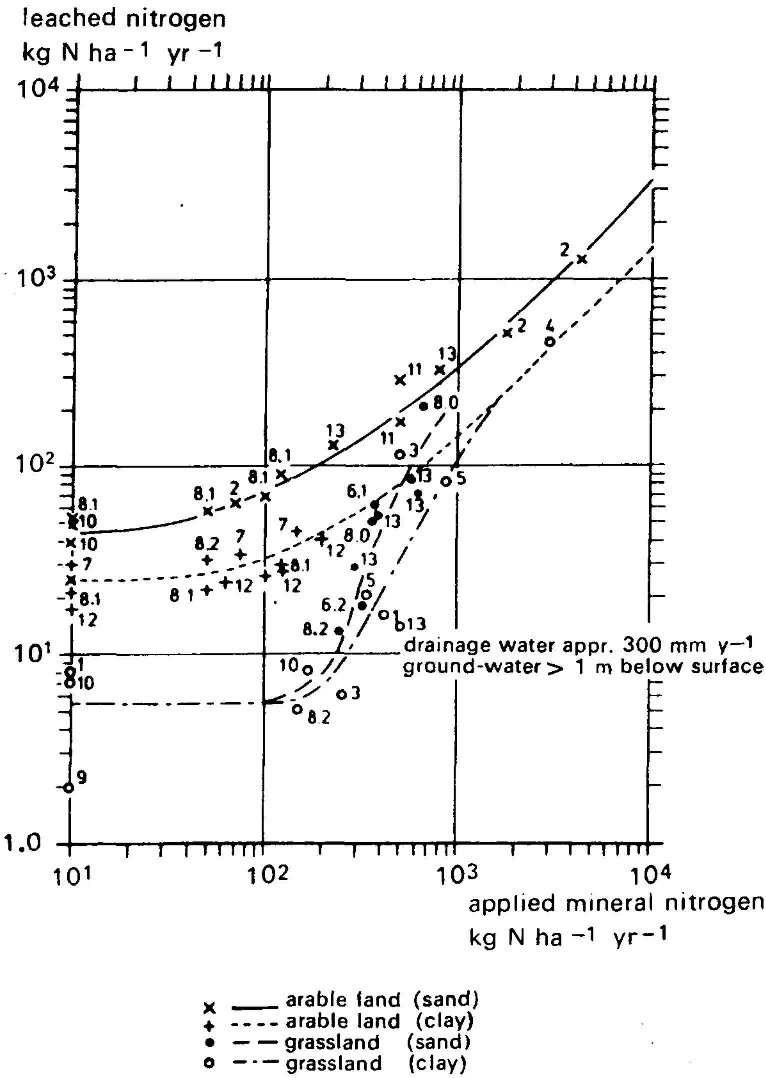
The extremely high N applications concern trials in which animal manure was dumped. In these cases, only the amount of mineral N contained in the manure (Sluijsmans and Kolenbrander 1977) was counted on the abscissa.

The results in Fig. 9 demonstrate not only the effect of soil texture (sand vs. clay) on leaching losses of N from the root zone, but also of the type of crop (arable land and grassland). Further, it is clear that any increase in N-input on arable land and grassland in excess of 100 and 200 kg N_{min} ha^{-1} yr^{-1}, respectively, will result in a relatively strong increase in leaching losses of N which will in turn constitute an additional mineral load in ground- and surface-waters.

Losses to the Atmosphere

Denitrification. By the process of denitrification, nitrogen is recycled in the form of gas to the original source, the atmosphere, from where it was removed by biological or chemical fixation. Denitrification is accompanied by formation of nitrogen oxides, which may attack the ozone layer surrounding the earth (White-Stevens 1977). This layer protects man and animals from excessive radiation of short wavelengths.

To the farmer, there is an extra, economic, disadvantage: the process of denitrification decreases the available input of nitrogen and therefore also the consumable N-output. Fig. 5B shows that losses increase with increasing inputs of nitrogen. While denitrification has a negative effect on consumable N-output and on the ozone layer in the atmosphere, it has a favourable effect on the nitrate content of ground- and surface-waters. Fig. 10, derived from data from Van Dijk (1980) and Steenvoorden and Oosterom (1972), shows



1	Dowdell and Webster	(1974) lys	8.0	Kolenbrander	(1974) lys
2	Foerster	(1973) field	8.1	Kolenbrander	(1973a, b) lys
3	Garwood and Tyson	(1972) lys	8.2	Kolenbrander	(1969) lys
4	Geneygen	(1973) field	9	Low	(1973) lys
5	Hood	(1976) field	10	Pfaff	(1950) lys
6.1	Hupselsebeek	(1972) catchm	11	Vetter and Klasink	(1972) field
7	Jung and Juirgens-Gschwind	(1974) lys	12	Kjellerup and Dam Kofoed	(1979) field
			13	Steenvoorden and Oosterom	(1972) field

Fig. 9. Leaching of nitrogen from arable land and grassland

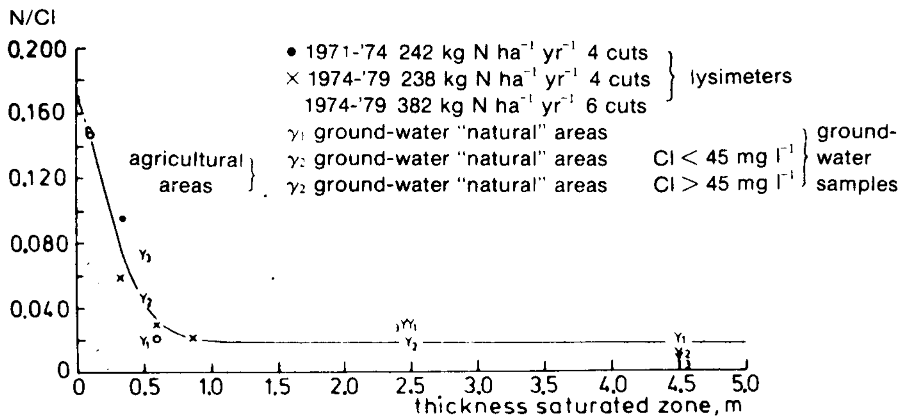


Fig. 10 N/Cl ratio in drainage- and ground-water as a function of the thickness of the saturated zone passed by the ions at sampling (Steenvoorden and Oosterom 1972 and Van Dijk 1980)

that the ratio of N and Cl concentrations in drainage water and groundwater is lower as the saturated soil layer through which the water passes is thicker. After passing through a layer of 50 cm (10 cm → 60 cm), about 80% of the nitrogen disappeared. Because the ratio N/Cl is used, dilution does not play a role. It may, therefore, be assumed that the nitrogen disappeared through denitrification.

Fig. 10 also indicates that this effect is limited to the first 60-70 cm of groundwater, and becomes very small beyond this depth. This would mean that in soils with a relatively high water table a considerable higher concentration of nitrate in the drainage water leaving the root zone would be permissible than the norm set by the WHO for drinking water.

Considerable amounts of nitrogen have been found to disappear also from surface water through denitrification. Vollenweider (1970) studied the N-balance sheet of six large lakes in Switzerland and found that about 60% of the net N-load had disappeared, presumably due to denitrification. This value is in good agreement with measurements of Van Kessel (1976), who found a N-loss due to denitrification of 56% after a residence time of only 1.7 days in a canal over a distance of 800 m.

NH_3-volatilization. The ammonia content of the soil is generally very low, so that losses due to volatilization and leaching are not significant. However, organic wastes, especially those of human and animal origin, often contain considerable amounts.

Fig. 11 shows ammonia loss as a percentage of the total amount of ammonia-nitrogen present in organic waste and in fertilizer. It is clear that after 14 days, 90% of the NH_3-N present at the time of application is already lost if such organic wastes are not immediately ploughed down.

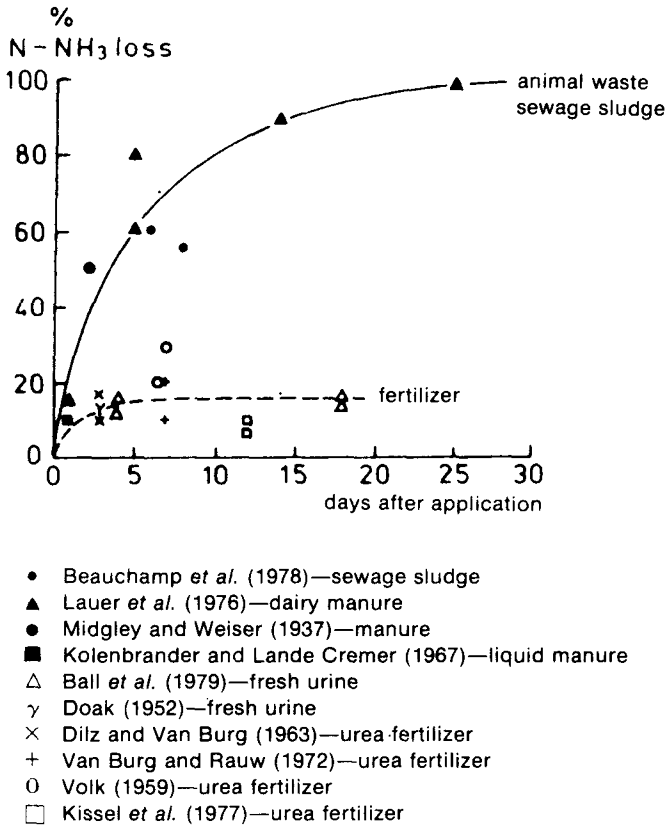


Fig. 11. Relation between N_{NH_3}-loss, as a percentage of the amount of ammonia applied, and time after application of animal waste, sewage sludge, fresh urine and fertilizer urea

It may be argued that this is an advantage in view of possible movement of N to the groundwater following oxidation of the ammonia in the soil. But the ammonia that volatilizes will be spread by the wind and will return to the earth in precipitation. Part of it will end up in surface waters (lakes and rivers), thus creating an extra N-load, however in a very diluted form.

Correct methods of storage, transportation and especially of application of organic wastes can limit pollution of the environment and may increase consumable output through the improved efficiency thus obtained.

Are There Limits to the Inputs of Plant Nutrients?

In view of the deleterious effects which high inputs of some plant nutrients may have on the environment, the question may be raised to what extent an increased input is acceptable from the viewpoint of protective demands on the environment. It is obvious that this depends entirely on the kind of demands made. For instance, a demand on an ecological basis will be much heavier, because of the wide range of aspects involved, than a demand that concerns only one factor, e.g., the nitrate content of drinking water or the P-load in eutrophication of surface water. In view of the complexity of the problem we will confine ourselves, for the time being, to the more "simple" cases.

Nitrogen

In regions with intensive agriculture and a temperate climate a maximum rate of N application could possibly be established on the basis of Fig. 9, in combination with the norms set by WHO for drinking water. Under conditions of 300 mm drainage water per year (the basis of Fig. 9) and accepting the WHO-norm of 11 mg NO_3-N l^{-1}, a leaching loss from the root zone of, an average, 33 kg N ha^{-1} (Level A) would be permissible. In Fig. 9 a number of quantities of mineral nitrogen may be read off which would constitute the maximum permissible amounts on sandy soils and clay soils used as arable land and grassland. The same can be done for the highest WHO-limit of 22 mg NO_3-N l^{-1}; the average maximum leaching loss would then be about 66 kg N ha^{-1} yr^{-1} (level B).

It is questionable to what extent losses due to denitrification in the upper layers of the groundwater should be taken into account, because the results in Fig. 9 were obtained in the presence of a groundwater table generally below 1 m below the surface, so that such losses at least in part, may already have been incorporated into the leaching data. If we, in spite of this risk, wish to introduce the possibility of taking denitrification into account, we could accept Rijtema's figures, who estimates that at least 50% of the nitrogen in the groundwater may disappear through denitrification. This means that for the norm of 11 mg NO_3-N l^{-1} also level B may be considered, but that leaching losses for the maximum level could be raised by a factor of 2, i.e., 132 kg N ha^{-1} yr^{-1} (level C).

Table 2 presents the maximum permissible doses of N, calculated in this way. They comprise not only fertilizer-N, but also the mineral N contained in organic manure and compost. Thus, in a temperate climate (300 mm drainage water per year) on a sandy arable soil the WHO-norm cannot be met at level A (no denitrification). Also at level B (with or without denitrification) there

Table 2. Maximum permissible applications of mineral N, kg N ha^{-1} yr^{-1}

Max. leaching loss at 300 mm drainage water, kg N ha^{-1} yr^{-1}		WHO-norm mg NO_3-N l^{-1} 50% denitrif.		Arable land		Grassland	
		−	+	Sandy soils	Clay soils	Sandy soils	Clay soils
A	33	11	—	0 kg N ha	100 kg N ha	320 kg N ha	500 kg N ha
B	66	22	11	70 kg N ha	360 kg N ha	450 kg N ha	725 kg N ha
C	132	—	22	260 kg N ha	900 kg N ha	650 kg N ha	1100 kg N ha

are no possibilities for intensive arable cropping on sandy soils, because in this situation an input of more than 100 kg N ha^{-1} yr^{-1} in the form of fertilizer is needed (Kolenbrander 1973a). Only level C offers possibilities to arable cropping on sandy soils.

The situation for arable cropping on clay soils is much more favourable than on sandy soils, due to smaller losses through leaching (see also Fig. 7); but in this case also, level A offers insufficient possibilities for intensive arable cropping, which requires a high N-input. Levels B and C present no restrictions to arable cropping on clays.

On grassland it should be reckoned with that, in addition to fertilizer, mineral N in animal manure is available that must be recycled. The formula on which the abscissa of Fig. 9 is based is as follows:

$$N_{min} = N_f + xL$$

or

$$N_f = N_{min} - xL$$

where

N_{min} = maximum amount of mineral N applied, kg N ha^{-1} yr^{-1}
L = number of livestock units (LU) per ha
x = mineral N applied in animal manure, kg N LU^{-1} yr^{-1}
N_f = fertilizer N, kg ha^{-1} yr^{-1}

Under West-European conditions, factor x for dairy cattle is about 45 kg N_{min} LU^{-1} yr^{-1}. At a stocking rate of 3 LU ha^{-1} the following maximum values for N_f are obtained for grassland on sandy soils:

level A 185 kg N ha^{-1} yr^{-1}
level B 315 kg N ha^{-1} yr^{-1}

For grassland on clays, these "ecological" maxima are again considerably higher and will give no problems from a productivity point of view at level A, but definitely not at level B.

Phosphorus

As mentioned before, loss of phosphorus due to leaching varies from 0 to 2 kg P ha^{-1} yr^{-1}. However, even these small amounts cannot be entirely disregarded in view of their importance to water management.

The relationship between annual discharge per hectare of catchment area D_c and the load per unit water surface S_l of an open water basin (e.g., lakes, water reservoirs, canals etc.) receiving all the discharges of the area can be expressed as:

$D_c = 10\ S_L\ A_L\ A_C$ with D_c as: kg P_t ha^{-1} yr^{-1} and $-S_L$ as: g P_t m^{-2} yr^{-1}

A_L/A_c represents the ratio between the area of the basin (A_L) and the area of the watershed (A_c). For small basins in large watersheds, D_c will be small for a specific value of S_L.

The value of S_L (specific surface load) is related to the trophic status of the basin. For each basin there will be a distinct value of S_L below which the trophic status remains oligotrophic (biological activity is low). But there will be also a value of S_L above which the basin becomes eutrophic or hypertrophic (biological activity high and very high, respectively).

This "dangerous load" for deep lakes in Europe was calculated to be 0.1 g P m^{-2} yr^{-1} (Vollenweider 1970), for shallow lakes in the USA 0.5 g P m^{-2} yr^{-1} (Brezonik 1972), and for strongly polluted rivers in The Netherlands 6 g P m^{-2} yr^{-1} (Peelen 1973). For "clean" water the norms of Vollenweider (1970) and Brezonik (1972) are probably more acceptable than those of Peelen (1973), but an important difference in the maximum P-load between deep and shallow waters remains. This may be explained by the fact that the large lakes, because of their greater depth, have a hypolimnion (lowest part of the lake volume with anaerobic conditions) and therefore a higher "P solubility factor" than the more "aerobic" shallow lakes, in which a greater part of the phosphorus load is fixed to the bottom sludge.

The "permissible load" has been set at 50% of the "dangerous load." The danger of leaching of P of agricultural origin, causing eutrophication of surface waters, however small that may be, is actually present only in sparsely populated areas. In those regions it could be necessary to weigh the advantages of increased P-fertilization with a view to increase food production against the disadvantages of a higher P-load in the surface waters, especially when conditions are such that surface runoff and soil erosion are liable to occur.

In densely populated areas the P-load of surface waters will be determined mainly by the waste water produced by the population. The P-load of surface water in about 1970 in The Netherlands, a densely populated country with an intensive agriculture, may serve as an example (Kolenbrander 1974). The internal contribution from sources within the country to the P-load (thus excluding imports of P via rivers from abroad and excluding contributions from detergents) was then about 8.2 million kg P per year and was distributed as follows:

Excrements from population	49%
Industrial waste water	21%
Agriculture	18%
Natural load	12%

It is clear that the contribution from agriculture was about 50% higher than that from natural sources; the population, however, contributed about three times as much. This fact must be taken into consideration when an answer is to be given to the question: "more food and/or cleaner water?"

For Dutch conditions, a Dutch working group recommended an average maximum P-load of 1 g P m^{-2} yr^{-1}, a considerably lower value than the value actually found in 1970 of about 6 g P m^{-2} yr^{-1} (Golterman 1976).

Potassium

The element potassium is not important as a factor in soil and water pollution. From an agricultural point of view, however, an excess is objectionable, because the composition of grass from grassland with high levels of potassium, combined with high applications of nitrogen, may lead to grass tetany (hypomagnesemia) in cattle. But this situation does not really constitute pollution of the soil, because high levels of potassium can be quickly reduced to normal proportions by omitting fertilizer and/or manure.

Henkens (1978) reported the limits to stocking rates (dairy cows) per hectare grassland in different West-European countries (Table 3), whereby often a balanced K-fertilization regime was used as the criterion.

Table 3. Maximum numbers of dairy cows per ha of grassland (Henkens

Country	Conditions	Max. no. of dairy cows per ha grassland
West Germany	Pasture	1-2
The Netherlands	Grassland on clay soils	2-2.25
Belgium		2.5
The Netherlands	Grassland on sandy soils	2.75-3.00
Switzerland		3.0-3.5
West Germany	Hay fields	3.9-4
Sweden		2.9-5

Taking variations into consideration, an average maximum value of three heads of dairy cattle per hectare grassland is obtained. At this stocking rate, potassium and phosphorus levels can be maintained in the soil that cannot be considered excessive (Commission European Communities 1978).

This threshold value of 3 LU ha^{-1} is also an indication of where the concept "feedlot" begins. Feedlots are enterprises where a much higher stocking rate is maintained, which is made possible by purchasing roughage and concentrates from outside sources. Because of the relatively small consumable output (see Fig. 1), such an enterprise produces a large surplus of animal manure which is "dumped" on the available farmland. This creates a risk to the quality of ground- and surface-waters.

Nature of Future Research

In the industrialized nations, which often have an intensive type of agriculture, the effects of society on the environment have been studied increasingly in recent years. But elsewhere in the world, a higher production will have priority for some time to come. Yet it is desirable to involve environmental effects in future production-oriented research from its inception, and to set limits on fertilizer use appropriate for local conditions. Obviously the data presented here cannot be applied to strongly different climatic areas and/or to a more extensive type of agriculture. However, it would be wise to take advantage of the insights gained, and so to conduct research more purposefully and effectively.

The foregoing shows that an increase in food production (i.e., consumable output) through an increase in input of N, P and K can be expected to result in a heavier load on our environment, i.e. ground- and surface-water and, may be, also the ozone layer around the earth. To lighten this load as much as possible, attention will have to be given especially to efficient utilization of the available plant nutrients. For nitrogen, this does not only apply to fertilizer nitrogen, but also to nitrogen biologically fixed by legumes. A more efficient utilization will, at the same input level, increase consumable output and lessen environmental pollution. Such an increase in efficiency is possible by using different technological means, such as:

1. Development of appropriate crop rotations that not only increase inputs but also better utilize biologically fixed nitrogen.

2. Improvement of methods of storage and application of animal manure and compost to restrict losses due to leaching and volatilization as much as possible.

3. When methods 1 and 2 do not offer possibilities and other growth factors as water, pH, phosphorus, potassium and trace elements are not limiting, N-fertilizer can be resorted to as a supplement. To optimize the efficiency of the inputs by restricting losses as much as possible, various techniques and materials can be used, e.g., split application, band application, slow-release N-fertilizers, and nitrification inhibitors.

In the regions with an intensive agriculture and a high fertilizer consumption, research should be concentrated on reaching a compromise between the demands made by agriculture to obtain maximum yields on the one hand and the limitation necessary to prevent pollution of soil and of surface waters on the other.

For feedlots, which produce manure surpluses because of their high stocking rates, measures could be considered that will lead to a better distribution of the manure or slurry over the available area of cultivated land. Thus, serious pollution with nitrogen of the deeper groundwater, a source of drinking water, can be avoided (Commission European Communities 1978).

Finally, it is clear from Fig. 4 and Table 1 that export from the farm of minerals contained in food products constitutes the most serious "leak" in the mineral-supply cycle in agriculture.

In regions with an intensive agriculture these losses of N, P and K are compensated by fertilizers. But this is possible only through the use of large amounts of fossil energy needed to manufacture the nutrient elements in a form that is suitable for agricultural purposes. The demand for fossil energy will increase strongly if low-input regions go over to intensification. Intensification can never be carried out with biologically fixed nitrogen alone, because this nitrogen will result in a higher output of P and K which will also have to be compensated for. This can be done practically only with fertilizers.

Zwerman and De Haan (1973) and Gravitz (1977) point out that greater attention should be given to recycling of urban waste waters to agriculture. Utilization of waste waters from which P has been removed will not only place a curb on pollution of our waters with P, but will also give a positive contribution to the maintenance of the nutrient cycle, e.g., of N and K, in agriculture to the benefit of food production.

For these developments, so important to future generations, we have the necessary technological know-how. However, it is feared that energy problems, coupled with economic, social and hygienic factors, will be a serious drag on progress into the direction indicated above.

References

Ball, R., Keeney, D.R., Theobald, P.W. and Nes, D. (1979) *Agron. J.* **71**, 309.

Beauchamps, E.G., Kidd, G.E. and Thurtell, G. (1978) *J. Environ. Qual.* 7, 141.

Bolton, E.F., Aylesworth, J.W. and Hore, F.R. (1970) *Can. J. Soil Sci.* **50**, 275.

Brezonik, P.L. (1972) In *Nutrients in Natural Waters* (H.E. Allen and J.R. Kramer Eds.). Wiley-Interscience, New York, pp. 1-50.

Burg, P.F.J. van and Rauw, G.J.G. (1972) *Stikstof* **6** no. 71, 466.

Commission European Communities. (1978) Report 47, 154 pp.

Dijk, T.A. van. (1980) In *Proc. Int. Symp. Eur. Grassland Fe. Pudoc*, Wageningen, 170 pp.

Dilz, K. and Burg, P.F.J. van. (1963) *Stikstof* **4** no. 38, 60.

Doak, B.W. (1952) *J. Agric. Sci.* **42**, 162.

Dowdell, R.L. and Webster, C.P. (1974) Rep. A.R.C. Letcombe Laboratory (1974), pp. 55-57. Source: I.C.I. rep. "Nitrogen leaching from fertilizers: Lysimeters trials: published results from Europe and USA." Central file no. A 128.607, 24 May 1976.

Foerster, P. (1973) *Z.Acker- Pflanzenbau* **137**, 270.

Frissel, J.M. ed. (1977) Special issue: *Agro. Ecosystems* **4**, 354 pp.

Garwood, E.A. and Tyson, K.C. (1973) *J. Agric. Sci. Camb.* **80**, 303.

Geneygen, J. van (1973) Verregening van rundveemest als system van afvoer en opslag. Contactbijeenkomst van onderzoekers over mest-, gier- en stankproblemen 14 (1-4).

Golterman, H.L. (1976) Fosfaten in het Nederlandse oppervlaktewater. Rapp. Stuurgroep fosfaten. Sigma Chemie, 133 pp.

Gravitz, M. (1977) In *Food, Fertilizer and Agric. Residues* (R.C. Loehr Ed.) Proc. Cornell Agric. Waste Management. Conf. 1977. pp. 29-37.

Henkens, Ch.H. (1978) Seventh Gen. Meeting Europ. Grassl. Fed. Gent. 1978, p. 10.2.

Hood, A.E.M. (1976) *Stikstof* **7**, no. 83-84, 395.

Jung, J. and Jurgens-Gschwind, S. (1974) *Landwirtsch. Forsch. Sonderh.* 30; 11, 57.

Karraker, P.E., Bornter, C.E. and Fergus, E.N. (1950) *Kentucky Agr. Exp. Sta. Bull.* 557.

Kessel, J.T. van (1976) Thesis. Pudoc-Wageningen. 104 pp.

Kissel, D.E., Brewer, H.L. and Atkin, G.F. (1977) *Soil Sci. Soc. Am. J.* **41**, 1133.

Kellerup, V. and Dam Kofoed. A. (1979) *Tidssk. Planteavl.* **83**, 330 (Eng. summary).

Kolenbrander, G.J. (1969) *Neth. J. Agric. Sci.* **17**, 246.
Kolenbrander, G.J. (1973a) O.E.C.D. Rep., Paris, September 1973. 72 pp.
Kolenbrander, G.J. (1973b) *Fert. Soc. Proc.* **135**, 36 pp.
Kolenbrander, G.J. (1974) Sem. étud. agric. environ. 1974 — Bull. rech. agron. Gembloux, Hors série 113-126.
Kolenbrander, G.J. and Lande Cremer, L.C.N. de la (1967) Stalmest en gier. H. Veenman en Zonen N.V., Wageningen. 188 pp.
Lauer, D.A., Bouldin, D.R. and Klausner, S.D. (1976) *J. Environ. Qual.* **5**, 134.
Low, A.J. (1973) *J. Sci. Food Agric.* **24**, 1489.
Maschhaupt, J.G. (1941) *Versl. Landbouwk. Onderz.* **47** (4)A, 165.
Midgley, A.R. and Weiser, V.L. (1937) *Vermont Agric. Exp. Sta. Bull.* **419**, 23 pp.
Peelen, R. (1973) Delta Inst. Hydrol. Onderz., Yerseke, Rapp. Versl. 1973: pp. 10-15.
Pfaff, C. (1950) *Z. Pflanzenernähr. Düng. Bodenkd.* **48**, 93.
Rijtema, P.E. (1980) *Proc. Int. Symp. Eur. Grassland Fed. Pudoc.* Wageningen, pp. 137-147.
Sluijsmans, C.M.J. and Kolenbrander, G.J. (1977) *Proc. Int. Semin. Soil Environ. and Fert. Management in Intensive Agric.*, Tokyo, Japan, pp. 403-411.
Steenvoorden, J.H.A.M. and Oosterom, H.P. (1972) *Cultuurtechnisch Tijdschrift* **12**, 231.
Vetter, H. and Klasink, A. (1972) *Landwirtsch. Forsch. Sonderh.* **27**(1), 122.
Volk, G.M. (1959) *Agron. J.* **51**, 746.
Vollenweider, R.A. (1970) O.E.C.D. Rep., Paris, 30th September 1970, 166 pp.
White-Stevens, R. (1977) In *Food, Fertilizer and Agric. Residues.* (R.C. Loehr Ed.) Proc. Cornell Agric. Waste Management Conf., pp. 5-26.
Wiklander, L. (1977) *Acta Agric. Scand.* **27**, 175.
Zwerman, P.J. and Haan, F.A.M. de. (1973) Agron. Paper No. 1009. Dep. Agron. Cornell Univ., Ithaca, NY 14850 USA.