FERTILISER ASSOCIATION OF IRELAND

Proceedings

Potassium in Irish Farming Present and Future

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NO. 8

MAY 1972

Fertiliser Association of Ireland

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PRESENT AND FUTURE

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Published by The Fertiliser Association of Ireland,
59, Deerpark Road, Mount Merrion, Co. Dublin.

POTASSIUM IN IRISH FARMING - PRESENT AND FUTURE

(Paper presented at a meeting of the Fertiliser Association of Ireland on 19th May, 1972).

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The use of potassium fertilisers in Ireland was negligible before 1900, although nitrogen and phosphorus were well established by the end of the 19th century. During the first half of this century development was slow, but since 1945 there have been great increases in the use of all three major plant nutrients, and more K is now used than either N or P.

Table 1 : Use of Nitrogen, Phosphorus and Potassium in Ireland since 1953

('000 tons)

	N	P	K
1953/4	12.0	23.7	30.5
1954/5	14.7	23.6	31.5
1955/6	13.6	24.3	32.2
1956/7	15.9	23.9	39.5
1957/8	18.0	27.0	43.5

Table 1 (contd)

	N	P	K
1958/9	20.6	33.0	43.7
1959/60	21.7	36.0	48.0
1960/61	24.6	35.0	55.0
1961/62	29.0	40.0	66.0
1962/63	33.0	48.0	74.0
1963/64	34.2	50.6	75.6
1964/65	29.1	48.8	75.1
1965/66	31.4	43.2	69.0
1966/67	47.0	55.2	91.6
1967/68	53.0	63.6	103.5
1968/69	63.0	68.4	109.8
1969/70	70.7	72.6	115.7
1970/71	84.6	77.8	123.0

However the result of the situation which existed for the first half of this century, when there was relatively large use of N and P but little K, was that in 1954 over 90% of soil samples analysed had less than 38 ppm K (Morgan's extract), and 66% had less than 25 ppm. The improvement since this time is illustrated by the virtual disappearance of samples in the lowest category.

Table 2 : Percent of Advisers' soil samples analysed with 0 - 24 ppm of K

Year :	1954	'57	'58	'59	'61	'62	'65	'68	'70
% :	66	32	20	17	11	11	5	4	2

The situation, again reflected in analyses of soil samples, for 1970 was :

Table 3 : Analyses of advisers' soil samples 1970

ppm K	0-24	25-49	50-74	75-99	100-500
% of samples	2	14	27	21	36

The improvement in the analyses figures only shows that soil fertility is responding to the increased amount of K being used. We have to turn to the Fertiliser Use Survey 1967 for a guide to how K fertilisers are being used, and whether crops are under or over fertilised.

Table 4 : Rates of K used on tillage crops and grassland

Crop	lb. K applied per acre (actual)	Per cent Fertilised	Recommended rate lb/acre*
Wheat	56.1	97.5	30 - 50
Feeding barley	48.9	98.3	
Malting barley	41.5	99.1	
Oats	39.4	86.2	
Potatoes	103.1	93.2	100 - 200
Sugar beet	336.1	100.0	300
Feed roots	85.5	96.2	50 - 150
Hay	29.0	66.1	100
Silage	39.0	87.4	100
Pasture	25.9	35.1	30 - 80
Rough grazing	9.3	2.0	-

* Source : "Fertiliser Manual" An Foras Taluntais 1970.

Table 4 indicates that K use on tillage crops is mainly satisfactory. Parts of the oats, potato and feed roots crops are underfertilised but there are probably economic factors involved. The tillage crops which pay best are generally given enough fertiliser (including K) and often too much.

The satisfactory picture for cereals results from the cereal growers' tendency to use high K compounds such as 10:10:20. These crops tend to be underfertilised with nitrogen.

The most serious examples of under-use of K are on grassland. A high proportion of grazing, hay and silage gets no K at all, and where it is used the rates are inadequate. A hay or silage cut will remove up to 150 lb. of K per acre.

The rates recommended in the "Fertiliser Manual" allow for a soil contribution of about 50 lb/acre. Modern practice makes much greater demands on soil reserves than traditional systems and must result in reduced fertility and productivity where a field is cut for several consecutive seasons. Where more than one cut is taken per year this depletion will occur much more quickly.

There are a number of developments in grassland management whose implications for the use of potassium fertilisers should now be considered.

Increased use of Nitrogen

The use of nitrogen to increase grass yields has been shown to increase K uptake and to deplete soil K. Under experimental cutting conditions, N responses have been greatly reduced where no K was applied and it has been suggested that the rate of K applied should be related to the N rate, e.g. 1 lb. of K per lb. of N, under continuous cutting.

Another factor to be considered is the effect of N on clover. In many cases, clover can be maintained in pastures receiving moderate quantities of N, provided that it is still able to get enough K. Because of the competition between grass and clover for K, pastures where clover is present need to be kept at a higher K status than those where it is absent.

Silage Making

A silage cut of about 10 tons/acre fresh weight, with 20% dry matter containing 2-3% K or higher, will remove 90-150 lb. of potassium per acre from the soil. There is no immediate return of K in urine, as with grazing, and areas cut for silage receive more nitrogen than pasture. (In the Fertiliser Use Survey 1967 the average N rate for silage was 35 lb/acre, and for pasture 12 lb/acre.) The increase in silage making will therefore tend to increase the K requirements for modern dairy farming.

Silage making is to a great extent replacing hay making. A hay cut also makes great demands on soil K, although generally hay receives less nitrogen. The practice of cutting hay with little or no applied K in the past, must have been one of the main causes of low K levels in grassland soils.

Two-Sward Systems

The use of separate swards for grazing and cutting will eliminate the return of K by grazing livestock on one part of the farm and concentrate it on another. Other factors will probably vary between the two areas. The grazed area may get less fertiliser nitrogen and rely to some extent on clover nitrogen fixation.

Two-Sward Systems (contd)

Different seeds mixtures may be used for the two swards. Obviously each sward will require a different K fertiliser regime. This system results in an increase in effective stocking rate on the grazed area, which is discussed under the next heading.

Increased stocking rates and closer grazing control

The increase in livestock units/acre and the more widespread use of paddocks and electric fencing to control grazing should improve the efficiency of the potassium cycle, and keep the K maintenance requirement for grazing to a fairly low level.

Cattle excrete up to 90% or more of the K ingested in herbage but, when voided on the sward, this is concentrated in small urine patches. For this return of K to be valuable a high proportion of the grazing area must be affected within a short period of time. Obviously this cannot happen at low stocking rates, and where cattle are allowed to range over relatively large areas. Increased stocking rates and controlled grazing improve the rate of ground cover by urine, and lead to more even distribution.

Application of slurry to grassland

Since livestock retain relatively little of the potassium they ingest, the return of slurry from winter-housed animals could replace much of the K removed by cutting for conservation. The figure quoted by J. Lee and S. Diamond ('Farm and Food Research' March/April 1972) is 60 lb. of K during a 120 day winter by one cow. Most of the potassium, however, is contained in the urine and unfortunately many systems for the recovery and storage of slurry allow much of the liquid excreta to escape into drains.

Collins (1) has estimated that with the complete collection of slurry, as in slatted floor systems, a 'closed' K system could operate at high stocking rates. If the return of slurry from feeding two silage cuts gives about 135 lb/acre of K, together with soil release of K this could be sufficient for optimum production.

Experimental Data - Grassland

Cutting trials on permanent grass were carried out at 27 sites, distributed over the major soil types, during the years 1967-1970. The effect of applied K on annual dry-matter yield and K-uptake is shown, for some of the soils, in Appendix 2.

Table 5 : The Effect of Applied K on Per Cent Yield

	Year	K Levels			
K applied lb/acre	1	0	110	220	330
	2	0	110	220	330
	3	0	70	140	280
	4	0	70	140	280
		Percent Yield			
Light textured Soils	1	87	98	100	100
	2	71	95	100	99
	3	57	87	100	100
	4	55	88	98	100
Heavy Textured Soils	1	93	98	96	100
	2	87	94	96	100
	3	81	93	100	99
	4	82	97	98	100

Table 5 summarises the effect of applied K on dry-matter yield. The soils have been divided into two groups according to the yield restriction in the zero-K plots in four years' cutting. Those which gave the greatest restriction in yield were the dry tillage (Associations 6,8,9,20,22, General Soil Map) whilst smaller restrictions were shown by the soils with heavier textures (13, 17, 24, 27).

Where no potassium was applied on the dry soils, yield was restricted to 87% of the maximum in the first year and had fallen to 55% in the fourth year. On the heavier texture soils, the corresponding figures are 93% falling to 82%. In view of this difference, it is interesting to note that the quantities of applied K required for maximum yield by the two groups are very similar.

The difference between the two groups when no K is applied is apparently due to the greater quantity of K supplied by the heavier textured soils (Table 5).

Table 6 : Uptake of K where no K was applied (lb/acre)

	Light Textures	Heavy Textures
1967	194	222
1968	96	165
1969	67	132
1970	50	97

The 'Fertiliser Manual' suggests that the soil can be relied on to replenish about 50 lb/acre of the K removed in a silage cut. These figures indicate that even the 'dry' soils should be able to provide this, if there is no more than one cut per year.

Deapite the fact that the soils varied greatly, physically and chemically, and were subjected to a regime highly demanding of potassium (3-5 cuts per year + 200 lb/acre of N) it appears that their fertiliser K requirement for maximum yield is roughly constant at about 140-200 lb/acre. In practice, and in particular where there is a risk of hyponmagnesaemia, a smaller rate could be used on the wetter soils, with only a slight yield restriction. The wetter soils should also need less K with less demanding systems, such as grazing only and lower nitrogen rates.

Experimental Data - Tillage Crops

At 19 of the grassland experimental sites mentioned above two tillage rotations were carried on over the same period. The rotations and potassium treatments were as follows:

Table 7 : Potassium Rates (lb/K/acre)

Year	Crop	K Levels			
		0	1	2	3
1967	Wheat	0	30	60	90
1968	Barley	0	30	60	90
1969	Swedes	0	60	120	180
1970	Potatoes	0	80	160	240
1967	Swedes	0	84	168	252
1968	Potatoes	0	84	168	252
1969	Wheat	0	20	40	60
1970	Barley	0	20	40	60

Table 8 gives the effect of K treatments on crop yields. Each figure is the average of all sites, except that data from some badly lodged cereal sites were ommited.

Table 8 : Crop Yields (cwt of grain or tons of roots per acre)

Year	Crop	K Levels			
		0	1	2	3
1967	Wheat	33.3	34.1	34.0	32.8
1968	Barley	39.9	40.0	38.1	38.1
1969	Swedes	19.6	21.2	21.5	22.1
1970	Potatoes	7.6	13.3	14.6	15.1
1967	Swedes	17.8	19.8	20.1	20.0
1968	Potatoes	10.7	18.1	20.9	22.7
1969	Wheat	39.4	42.5	43.7	43.1
1970	Barley	31.0	32.5	32.7	31.6

These figures show that generally there is little response to potassium in cereals, whilst potatoes are still very responsive. The crops were grown in rotation (as shown) on the same plots. Consequently the Zero-K plots would have become progressively more depleted during the experiment. In view of this the small K responses in Barley 1970 are surprising. It is also noteworthy that 60 lb K/acre depressed the yield of the cereals slightly when compared with 30 lb K/acre ('67/'68) or 40 lb/K/acre ('69/'70).

Table 9 gives the per cent responses of each crop on particular tillage soils (numbered according to the General Soil Map of Ireland).

$$\text{Per cent response to K} = \frac{\text{Maximum Yield} - \text{Zero-K Yield}}{\text{Maximum Yield}} \times 100$$

Table 9 : Per cent response to K on different soils

	Swedes 1967	Potatoes 1968	Swedes 1969	Potatoes 1970
6	14.7	49.4	16.8	47.4
8	11.3	48.4	16.7	53.4
20	22.3	71.5	18.8	63.0
22	31.9	38.5	14.0	54.0
24 Limerick	12.1	46.9	9.1	36.2
24 Meath	17.9	55.3	11.8	55.6
	Wheat 1967	Barley 1968	Wheat 1969	Barley 1970
6	2.5	1.4	11.2	1.8
8	4.9	3.0	8.7	8.9
20	5.7	3.4	20.5	42.9
22	4.3	2.2	18.7	5.7
24 Limerick	6.8	L	5.3	3.8
24 Meath	8.9	L	22.5	4.9

(L = Lodged)

Although soil 24 was a better source of K for grassland than the dry tillage soils, the figures above show that this soil still gives good responses to K on tillage crops (potatoes in particular). The Meath sites gave better responses than those in Co. Limerick.

The most responsive soil was soil 20 which was the only soil to give a significant response in barley in 1970.

These are coarse-textured limestone gravels found in the Midlands, Co. Carlow and Co. Kildare, and described in detail in "The Soils of Co. Carlow" Soil Survey Bulletin 17, as the Athy complex.

Information on another important tillage crop, sugar beet, is currently being obtained from a separate series of experiments, being carried out in co-operation with C.S.E.T. Particularly good responses to K were obtained in 1971, but since only one year's results are available they must be interpreted with caution. Potassium increased both root yield and sugar content. The resulting effect on sugar yield is summarised in Table 10.

Table 10 : Effect of K on sugar yield (Cwt/acre) according to soil type

lb/K/acre	Soil 7	Soil 8	Soil 9	Soil 20	Soil 21	Soil 23
0	62.9	71.1	62.0	65.1	64.0	58.2
200	65.2	70.8	67.0	70.9	67.0	64.7
400	63.7	75.2	69.8	76.1	71.7	68.2

(N rate 80 lb/acre; P rate 80 lb/acre; Na not used).

The soils chosen for this study were predominant in areas where beet growing is concentrated and high yields are obtained.

It is apparent, therefore, that although K applications on cereals now appear to be mainly necessary as an 'insurance' and to maintain fertility, root crops (particularly potatoes and sugar beet) continue to give good yield responses.

Residual Value of Potassium

Ten of the tillage sites referred to earlier were examined in 1971, to evaluate the residual value of the K treatments applied during the previous four years. The results are summarised in the following table.

Table 11 : Effect of residual and freshly applied K on yield of potatoes - tons/acre

K applied 1967/1970 (lb/acre)	(average of 10 sites) K applied in 1971 (lb/acre) 0	75	150	300
0	6.1	9.0	10.1	11.8
208	8.4	9.8	10.7	11.7
416	10.4	11.2	11.7	12.1
624	11.3	11.9	11.8	12.7

These figures demonstrate the value of high fertility in obtaining maximum yield. They also suggest that a response to freshly-applied K can also be obtained even at high levels of fertility. It is notable that although witholding K for 5 years restricted yield to about 48% of the maximum, residual K from the first four years could provide up to 89% of maximum in the fifth year. In general, both residual and freshly-applied K were required for maximum yield.

Conclusions

The authors believe that the use of potassium fertilisers in Ireland must continue to increase in the immediate future for the following reasons :

1. Grass, which is by far the most important and most extensive crop, is generally inadequately fertilised with K at present.
2. Grassland productivity will need to be increased if we are to take full advantage of our membership of E.E.C.
3. Silage making is likely to continue increasing in popularity for some time, since there is still considerable room for expansion in this area.

There are also a number of developments which can be expected to slow down this increase eventually. Of these, the setting up of more efficient systems for collecting dung and urine during overwintering of cattle seems to be particularly important.

Increases in stocking rates will tend to keep the K requirements of grazed areas down to relatively low 'maintenance' levels.

Despite increases in fertility, root crops still give good responses to K and 'maintenance' dressings are still recommended for cereal crops. No change is foreseen here at present. However, in response to economic pressures and bearing in mind the absence of fertiliser subsidies in E.E.C., there may have to be some re-thinking on the subjects of 'maintenance' levels, residual values and rationalising K applications to make better use of soil K reserves while avoiding depletion. With regard to the rationalisation of K-use on grassland, this paper has already indicated that soil properties other than K status can affect the requirements of different soils. In considering what has been said about "heavy" and "light" soils, it must be remembered that the former generally will support a lower stocking rate and require a longer overwintering period. These are obstacles to the efficient cycling of potassium under grazing on these soils which may tend to offset the advantages which they have as suppliers of K.

A great deal of future research is now needed so that the factors which influence potassium requirements can be quantified. For instance, we have suggested that there are differences between soils which are of practical importance. It is essential that studies of the K requirements of grassland should take into account potassium cycling under different soils, management systems and stocking rates. Such studies will have to be extended to marginal land if this continues to grow in importance under economic pressures.

It is concluded that potassium will continue to be an important factor in agricultural production, and will deserve a good deal of attention from the farmer, the adviser and research scientist.

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Appendix I - Soil Description

Soil Association*	Series	Parent Material
6	Borris	Granitic glacial drift.
6	Screen	Morainic sand.
8	Clonroche	Ordovician or Silurian Shale glacial drift.
9	Not yet named	Old red sandstone glacial drift.
13	Abbeyfeale	Upper Carboniferous Shale glacial till.
17	Not yet named	Carboniferous/Ordovician Sandstone/Shale glacial till. (Wet Drumlin).
20	Athy Complex	Carboniferous limestone morainic gravel.
22	Not yet named	Carboniferous limestone glacial drift.
23	Not yet named	Carboniferous limestone rock and glacial drift.
24	Elton	Carboniferous limestone glacial till.
27	Macamore	Dense calcareous glacial mud of marine origin.

* See General Soil Map of Ireland.

Appendix II

Effect of K* on Grass D.M. Yield and K Uptake

Soil	Year	Yield lb/acre D.M.				Uptake lb/acre K			
		K_0	K_1	K_2	K_3	K_0	K_1	K_2	K_3
6 Borris	1	8120	9420	9500	9280	247	365	442	479
	2	6910	10290	10960	11180	73	205	322	380
	3	6240	9750	10770	11210	70	126	250	352
	4	4400	7520	9380	9080	35	95	230	329
8	1	8320	8950	9530	9510	223	317	422	465
	2	7320	9580	10020	9940	91	212	308	391
	3	6070	10080	12050	11970	65	164	255	396
	4	5270	8680	10190	10550	60	116	215	343
20	1	7910	8960	9230	9410	196	302	368	398
	2	6810	9280	9920	10010	104	204	294	352
	3	5100	7930	8990	9460	67	123	201	338
	4	5850	7500	8350	9220	65	116	207	302
22	1	6760	8240	8340	8750	131	246	354	410
	2	6220	8640	9130	9350	95	172	267	321
	3	5080	8230	9760	9390	52	143	249	322
	4	4050	7930	8580	8770	33	108	214	328
13	1	7260	8080	7720	8230	224	283	315	348
	2	9310	10450	10520	10230	189	280	378	401
	3	8390	9390	10840	10270	155	212	310	343
	4	7090	7380	8120	8370	118	168	259	322

contd ...

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* See Table 5 for potassium treatment levels.

Appendix II

Soil	Year	Yield lb/acre D.M.				Uptake lb/acre K			
		K_0	K_1	K_2	K_3	K_0	K_1	K_2	K_3
17	1	6690	6110	6260	6290	163	197	215	230
	2	6810	6800	7130	8000	108	193	233	278
	3	7640	9350	10030	9320	143	274	289	358
	4	6600	8655	7770	7740	66	171	245	260
24 Limerick	1	7710	8320	8120	8270	232	325	397	421
	2	8470	9840	10390	10750	122	222	343	395
	3	8430	9890	10400	10160	102	172	277	372
	4	7970	9480	9620	9710	92	161	262	405
24 Meath	1	9560	9940	9850	10130	336	433	499	549
	2	9490	9880	10590	11290	226	314	366	464
	3	8720	10050	10780	11540	150	822	283	384
	4	8550	9710	10620	11240	87	137	250	315
6 Screen	1	7148	8133	8461	7387	122	229	321	338
	2	5458	7607	8468	7327	64	153	245	288
	3	5260	8786	9402	8777	49	107	186	297
	4	4640	7502	7256	6187	39	116	172	235
9	1	7731	7921	7702	8164	242	311	344	386
	2	9100	10406	10534	10762	146	235	334	401
	3	8346	10536	12164	12578	98	170	285	411
	4	5925	8925	9888	10870	66	141	234	353
27	1	7727	8652	8372	8925	156	269	323	359
	2	8284	8971	8430	8664	182	252	255	267
	3	7573	8382	8402	8469	109	149	185	261
	4	7778	9899	9374	9335	123	191	232	304

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Proceedings

Fertilisers, Farming Practice, Water Quality

Dr. G. KOLENDBRANDER

NO. 9

November 1972

Fertiliser Association of Ireland

FERTILISERS, FARMING PRACTICE and WATER QUALITY

by

Dr. G.J. KOLENBRANDER

Paper presented at a meeting of the Fertiliser Association of Ireland on 17th November 1972

Reproduced by courtesy of the Fertiliser Society, London

Published by The Fertiliser Association of Ireland,
59, Deerpark Road, Mount Merrion, Co. Dublin.

CONTENTS

Page

FERTILISERS, FARMING PRACTICE AND WATER QUALITY

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I. INTRODUCTION

In the last years, from all points of the compass, publications of limnologists and biologists have reached us, in which it has been pointed out that agriculture, besides population and industry, is causing serious pollution of ground and surface waters.

In this connection the ever increasing use of fertiliser is mentioned as a source of increasing losses of nitrogen and phosphorus to the natural waters(1, 2).

Sometimes a combination of organic manuring and biological control of plant diseases, without any use of fertilisers and pesticides, is proposed as an alternative method.

In view of the important economic and social consequences it is quite understandable that discussions on this subject are mostly very emotional. However, it is also clear that agriculture has to check these theses and has to make inquiries into possible corrections by means of other and more useful methods. Of course we have to start from the responsibility of agriculture to produce enough "wholesome" food for mankind, a responsibility which weighs the more heavily as the world population grows at an increasing rate.

The possibility of reclaiming new soils for food production diminishes very fast. In some regions marginal soils are taken out of production. The consequence of all this is that maximum yields are needed and that optimum use of the remaining acreage must be made. However, these results automatically in a more intensive fertilisation practice and an increase in fertiliser use per unit of area.

This development in food production brings along with it the risk of increasing losses of plant nutrients which may cause an increasing enrichment or eutrophication of the natural ground and surface waters with plant nutrients.

This, in turn, will result in a serious disturbance of the balance in aquatic life of the surface water, by a unilateral stimulation of algae growth.

If such an excessive population of algae dies in autumn, the organic matter built up by the algae will cause a very serious organic pollution of the surface water, which results in a lack of oxygen in

the water. As a consequence, fish will die. H_2S and NH_3 are formed, giving a bad odour and a poor taste to the water. In this way the surface water becomes unfit for use for many of the purposes it has in our community.

In the following paragraphs we shall enter into the problem of enrichment or eutrophication of ground and surface waters by nitrogen and phosphorus originating from agriculture.

In general emphasis is put on both these elements, if stimulation of algae growth is the point in question. Nevertheless, Legge and Dingeldein(3) pointed out that also carbon may be a limiting factor. Woldendorp(4), however, concluded in a review concerning effects of N, P and C on algae growth, that under the prevailing conditions in the Netherlands it is not clear, which element will be the limiting factor in algae growth.

It is also possible that eutrophication already has reached the stage in which a factor such as "light penetration capacity" of the surface water has become the limiting factor.

We shall not dwell upon this question of limiting factors. This is a problem of limnologists and needs more fundamental research.

Where ground and surface water is used for drinking water the phosphorus content of the water in itself is of little interest, in contrast with the nitrate content. High nitrate concentrations in drinking water (but also in food) may cause infant methemoglobinemia (or "blue-baby disease"). This disease, only found in infants younger than six months of age, is thought to be due to reduction of nitrate (NO_3) to nitrite (NO_2) in the stomach. This type of poisoning is also found in cattle, mostly after consumption of feed high in nitrate. Viets and Hageman(5), however, have concluded that a high nitrate content of water and food (e.g. spinach) is toxic to infants only in isolated cases. In many of these cases the toxicity resulted from contamination with microbes which converted nitrate to nitrite.

Recently, attention has been drawn to another human health aspect of high nitrate levels, viz. the possible formation of nitroso-compounds within the intestinal tract. According to Archer et al.(6) a number of these are carcinogenic to animals. However, Wolff and Wasserman(7) conclude: "The extent of real danger is not yet known, but the available information would suggest that the hazard is not sufficiently great to cause alarm".

The following standards for nitrate-nitrogen in drinking water are used:

World Health Organisation		U.S. Drinking Water Standard	
recommended	up to 11·3 ppm	desirable	: virtually absent
acceptable	up to 22·6 ppm	permissible	: 10 ppm
ommended	over 22·6 ppm		

II. ORIGIN OF LOSSES

In agriculture, nitrogen and phosphorus losses to the ground and surface waters arise from:

(1) leaching

(2) run-off

(3) erosion by water and wind

(4) direct applications or discharge of plant nutritions and animal waste to the surface water.

The contribution by way of the first three modes depends strongly on the geographic conditions as climate, type of soil, topography, and plant cover of the region. These factors cannot easily be influenced by the farmer. But he certainly can reduce bad effects caused by them as water and wind erosion by applying correct measures. Also the contribution due to point 4 can be reduced to nearly zero by the farmer himself.

The losses by leaching are determined by rainfall, evaporation, soil type, and crop. When a water surplus exists in flat regions, effects of leaching will dominate, but in uneven terrain run-off will become more important. If also intensity of rainstorms (> 25 mm/h) and their frequency are increased, run-off will be changed into water erosion. But also under dry conditions there is a risk of erosion, viz. by wind. High amounts of top soil can be carried away from sandy and peat soils, containing considerable quantities of total nitrogen, total phosphorus and other plant nutrients(5, 9).

Table 1, taken from an O.E.C.D. report of the Working Group on Fertilisers and Agricultural Waste Products(10) gives an impression of the contribution of agriculture by the different processes under average West-European conditions of 700mm rainfall and about 250mm of drainage water.

From Table 1 it is clear that especially water erosion and direct discharge of animal waste contribute important quantities of total nitrogen and total phosphorus to the surface water.

The contribution of direct discharges of animal waste could be reduced easily by suitable technical measures which would increase the storage capacity for animal waste. This is, however, an expensive and uneconomical affair for the farmer, so support by slate funds will be necessary. Losses by soil erosion are generally no serious problem in Western Europe. These losses can be effectively reduced by 75% or more by wise erosion control measures(11).

TABLE 1. Estimates of agricultural contributions to ground and surface waters.

Mechanism of loss	Element	Origin of loss				
		Soil and fertiliser			Animal waste	
		Minimum	Average	Maximum	Conventional farming, average	Industrial farming, average
1 Leaching* grassland	P	—	0·22	—	—	—
	N	—	4	—	—	—
Leaching* tilled mineral soils	N	—	23	—	—	—
	P	0	0·22	—	—	—
Peat soils	P	—	2·0	—	—	—
2 Run-off + leaching from cultivated land	P	0·06	0·40	0·80	—	—
	N	2	12	24	—	—
Run-off + leaching from forests	P	0·01	0·05	0·13	—	—
	N	0	2	6	—	—
3 Water erosion	P	0·5	3	5	—	—
	N	5	35	50	—	—
4 Direct discharge to surface water	P	na	na	na	0·2	3
	N	na	na	na	5	50

*100 kg. N.ha^{-1}.y^{-1} as fertiliser.

average = 250mm drainage water per year
maximum = 500mm drainage water per year
na = not applicable, included in 2.

It will be much more difficult to reduce losses by run-off, because run-off is more important in sloping terrain. It can take place also on flat soils in winter when snow melts on frozen ground. Nutrient ions are carried away with dead and decomposed organic material, with clay particles, or dissolved in the melting snow.

In regions with a water surplus (in our humid climate mostly in autumn and winter) the production of drainage water can hardly be prevented. The rate of leaching, therefore, will depend on the amount of drainage water annually formed and on the concentration of water-soluble salts in the profile.

In areas with a lack of water, irrigation will be used in crop production. But to reduce capillary rise of salts from the subsoil, the soil has to be over-irrigated, which will give leaching losses in summer during crop growth.

III. EFFECT OF LAND USE

A comparison in Table 1 of total contribution from land under cultivation and under forest shows that the former has the highest losses of N and P. Furthermore that the leaching loss, especially of nitrogen, on tilled land is much higher than on grassland. Although it is not shown in Table 1, this is also the case with soil erosion.

The ever increasing demand for food in the past centuries has caused that more and more waste land, forest and prairies are reclaimed for cultivation. The data in Table 1 make it likely that this change in soil use will have also stimulated eutrophication of surface waters.

Now the question arises to what extent the already existing eutrophication has been increased by the intensive use of fertiliser and organic manure.

IV. TYPE OF RESEARCH

To study eutrophication in relation to fertilisation it would be necessary to have catchment areas of the same type but with and without use of fertiliser or organic manure. In addition, the results should not be disturbed by discharges from population or industry.

However, it is very difficult to find these catchment areas, so we have looked for artificial objects. In this respect lysimeter experiments are very valuable. Although run-off mostly is excluded from these experiments, the loss by leaching is determined directly and quantitatively.

V. N LOSSES BY LEACHING

A. Tilled Land

1. N loss from fertiliser

Table 2 shows the increase in nitrogen loss by leaching, from fertiliser only, on cropped tilled lysimeters, without leguminous plants in crop rotation. The profile depth of the lysimeters was about 1m. These results were taken from Kolenbrander(12).

From Table 2 it is clear that losses by leaching increase with increasing amounts of fertiliser. But the rise is not linear but exponential.

TABLE 2. Fertiliser-N losses by leaching in kg. N.ha^{-1}.y^{-1} at different heaviness of soil, and rate of fertiliser application on cropped land at 250mm drainage water.

N-fertiliser applied, kg N.ha^{-1}.y^{-1}	Percentage particles <16μm			
	0–10	10–20	20–30	30–40
0	0	0	0	0
30	1·0	0·5	0	0
40	2·0	1·0	0·5	0
50	3·0	1·5	0·5	0
60	4·0	2·5	0·5	0
70	6·0	3·5	1·0	0
80	8·0	4·5	1·5	0
90	11·0	6·5	2·5	0·4
100	14·0	8·5	3·5	0·5
110	19·0	12·0	5·0	0·8
120	24·0	16·0	7·0	1·2

At a level of 100 kg.ha^{-1}.y^{-1} of applied nitrogen fertiliser, an increase of 20 kg N.ha^{-1}.y^{-1} will cause that on heavy clay soils about 3·5% and on light sandy soils about 50% of the additional 20 kg N is lost by leaching.

A similar relationship was found by Commoner(1) as shown in Fig. 1. This figure shows the relationship between the annual *change* in nitrogen fertiliser use in Nebraska (U.S.A.) and the annual *change* in nitrate load of the Missouri River *during the following year* (not mentioned is the average nitrate level in kg.ha^{-1}.y^{-1}). Assuming that the change in nitrate load of the river is due to leaching of nitrate the year before, it can be calculated that of 75,000 tons of extra nitrogen fertiliser about 20% is lost to the river. On the average this loss would be 13% at 38,000 tons of extra nitrogen fertiliser. This is a loss, compared with those calculated from lysimeter experiments, that may be found in an area where loamy soils and clay soils predominate.

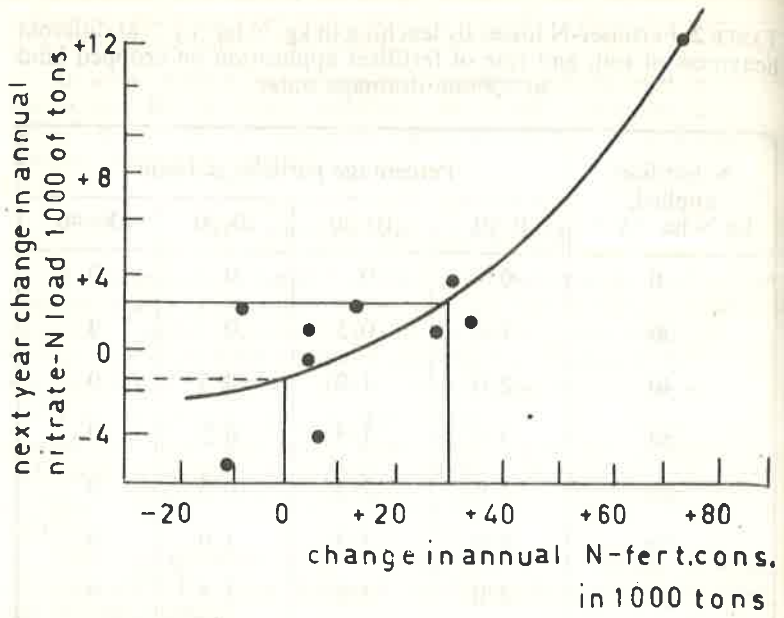

Fig. 1. *Relation between the change in annual nitrogen fertiliser consumption in Nebraska and the change in nitrate load in the River Missouri next year*[1].

From Table 2 it is also apparent that the N-leaching loss decreases as the soil becomes heavier. We may suspect that if the nitrogen is not leached from loamy soils the N-recovery by plants would be higher. But Fig. 2 does not show a better recovery on heavy soils than on light ones. So if N-recovery by plant is not raised and the nitrogen is not leached out (not even with a great time interval) this is an indication that losses occur by denitrification. A possible N-fixation in the clay minerals will be of small importance in these old tilled soils.

As the soil becomes heavier the percentage of small pores will increase considerably. Therefore after a rain shower the water/air ratio will increase much more on heavy soils than in light ones. This will cause, temporarily, partial anaerobic conditions in the small pores and denitrification will start. So it will be clear that in Fig. 2 the clay content of the profile is used as a single value for the pore size distribution in the soil.

2. N loss from organic manure

a. *Organic matter as a source of soil fertility.* In agriculture, soil organic matter (S.O.M.) has an important role, because of its large

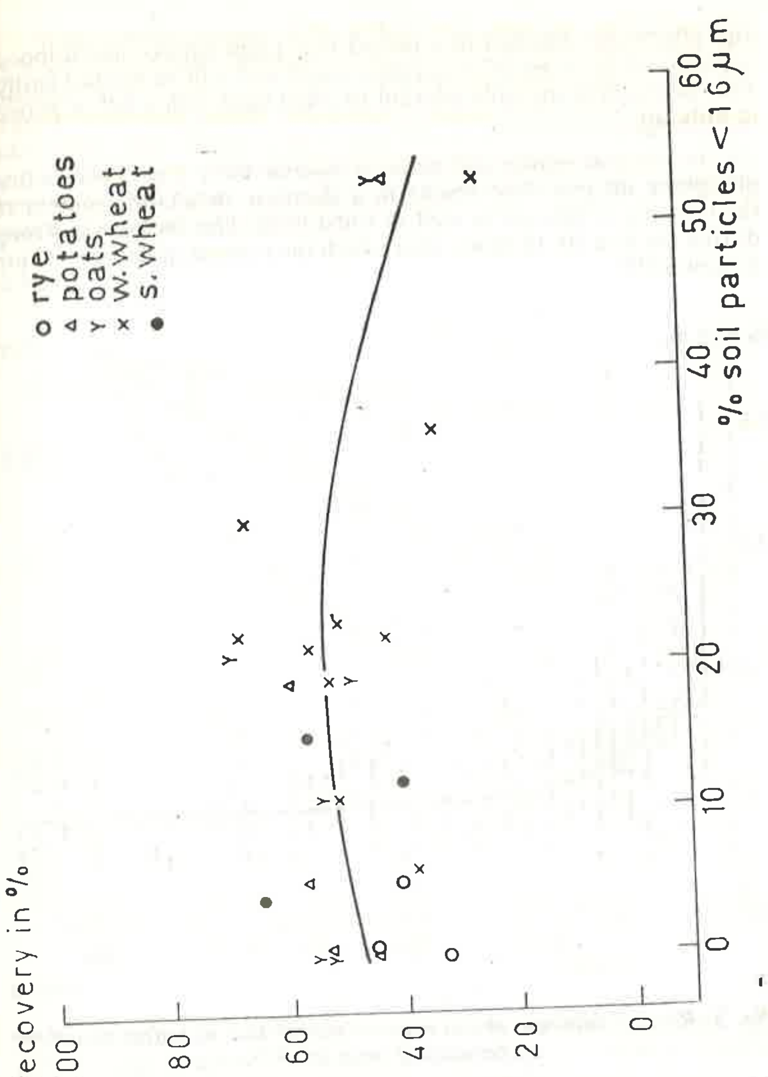

Fig. 2. *Relation between N-recovery and clay plus silt content of soil.*

adsorption complex for water and mineral plant nutrients. Besides, S.O.M. is also a big storehouse of nitrogen and phosphorus in a water-insoluble form and therefore protected against leaching.

The organic compounds of N and P in S.O.M. have to be "mineralised" into a water-soluble form by the activity of micro-organisms. However, this process, like all biological processes, depends strongly on temperature and is therefore difficult to control by the farmer. This results in the fact that nitrogen, ammonified and afterwards nitrified in a period that plant uptake has stopped, is produced in excess of crop requirement and will be leached easily. This situation is specially relevant to tilled land with a fallow period in autumn.

b. *Organic matter and nitrogen balance sheet.* Fig. 3 shows that ploughing up grassland results in a decrease in S.O.M. content of the top soil, if this soil is used as tilled land. The decrease is strong during the first 10–15 years, after which the process of decomposition is slower.(13)

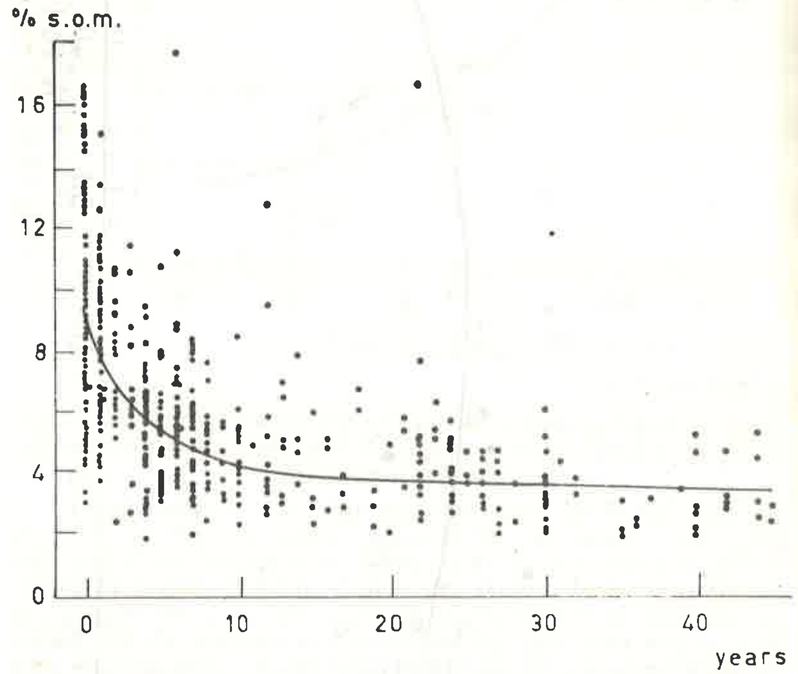

Fig. 3. Rate of decrease of soil organic matter (s.o.m.) after ploughing up permanent grassland(13).

The reason for this decrease is, at first, a mixing of the organic matter in the sod (0–5cm) with the soil layer (5–20cm) below the sod, which is relatively low in S.O.M. content. Furthermore the organic matter production on tilled land is much smaller than on grassland. The input is too small in relation to the rate of decomposition of the organic matter of the sod. An equilibrium will therefore be reached only at a lower level of S.O.M.

A negative organic matter balance sheet will result generally also in a negative nitrogen balance sheet, as is shown in Fig. 4. These results are taken from Stevenson(14).

With a monoculture of corn there was after 50 years a loss of 43% of the original amount of nitrogen. The N-balance was influenced in a favourable way by a different crop rotation and by organic manuring which raised the nitrogen input considerably. It takes many years before a new equilibrium in nitrogen level will be be reached. Bartholomew and Kirkham(16) estimated a period of time of 50–100 years depending on crop rotation and manuring system. This is also suggested by Fig. 4.

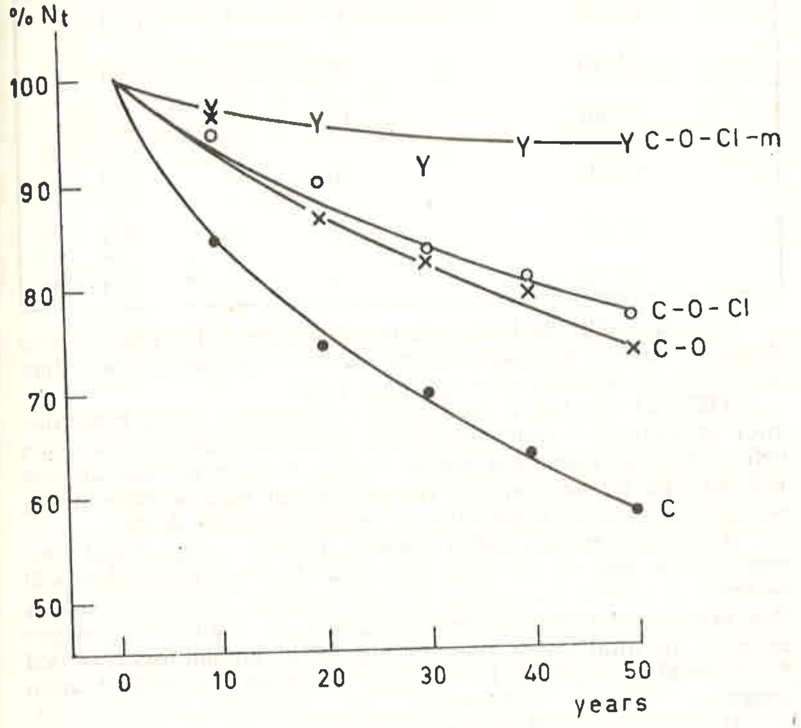

Fig. 4. Decline of soil nitrogen content on the Morrow Plots with different crop rotations and manuring systems(14). *C = corn; O = oats; Cl = clover; m = manure.*

c. *Soil organic matter and N leaching.* Table 3 shows the nitrogen losses on cropped lysimeter experiments. These results have also been taken from Kolenbrander(12).

Table 3 shows that a soil, also without any fertiliser or organic manure application, can lose considerable amounts of nitrogen. These N-losses are high on sandy soils which results in nitrate concentrations in the drainage water above the U.S. Drinking Water Standards (10mg $N_{NO_3}.l^{-1}$).

TABLE 3. Nitrogen leaching losses from soil organic matter on cropped land at 250mm drainage water and without any N fertiliser application.

Heaviness of soil, % particles $<16\mu m$	N loss, $kg.ha^{-1}.y^{-1}$	N conc., $mg. l^{-1}$
0–10	45	17·9
10–20	30	12·1
20–30	18	7·1
30–40	10	4·0
40–50	6	2·3
50–60	5	2·1
60–70	5	2·1

On clay soils the losses are much smaller. This effect is also shown in Table 2 in relation to the losses of applied fertiliser, Here also losses by denitrification will play a part.

This nitrogen loss from S.O.M. is partly due to the mineralisation of residues of roots and organic manures applied in the years before the experiment was started. It may be expected that the loss will decrease in the course of the experiment because without any nitrogen application (input) the soil will be depleted slowly.

d. *Organic manure and N leaching.* Based on Figs. 3 and 4 we may assume that on old tilled land now about an equilibrium will be reached on the humus and nitrogen balance sheet. This means that every year there will be mineralised an amount of nitrogen equal to the total annual nitrogen input. The annual loss is caused by removal of nitrogen in the crop, leaching and denitrification losses.

If in practice a soil has a low level of nitrogen mineralisation, as will be found in soils of low soil fertility, a regular input of organic manure can increase this level.

With a high application it will be possible to get yields, which are equal to those obtained with fertiliser. This is illustrated by results of Roorda van Eysinga(16) collected from glasshouses in which vegetables received annually 100 tons of farmyard manure (F.Y.M.). From Fig. 5 it is clear that as the glasshouse was older and had received more farmyard manure, the recovery of a fertiliser application became smaller and smaller, and was zero after 20 years. That means that after 20 years the nitrogen mineralised from the F.Y.M. (20 × 100 $ton.ha^{-1}$) was already so high that the maximum possible yield was obtained and additional fertiliser application did not have any effect on the yield.

An amount of 100 ton F.Y.M. per ha annually represents about 500 kg $N.ha^{-1}.y^{-1}$. But also other salts are available in high amounts. So it becomes clear that in horticulture the soil has to be "washed out" regularly by over-irrigation in order to decrease the salt content of the soil. This, however, will result in high losses of plant nutrients and eutrophication of surface waters.

In agriculture a part of the nitrogen is mineralised outside the growth season, specially on tilled land and will be lost by leaching. This nitrogen loss will increase proportionally with the amount of nitrogen applied in excess of crop uptake.

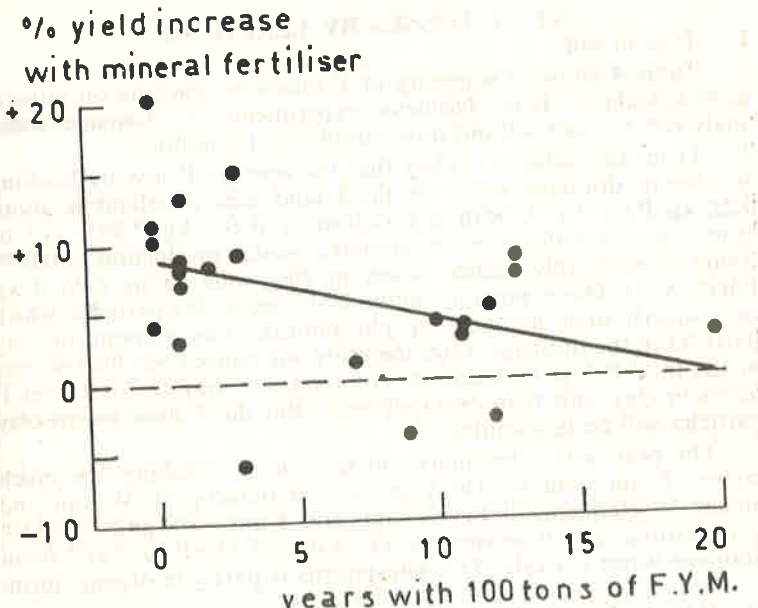

Fig. 5. Effect of annual applications of farmyard manure on the relative yield of glasshouse vegetables (optimum application of mineral fertilisers = 100%)(16).

Such a situation in agriculture is not hypothetical, especially in regions with high cattle densities, due to the presence of feed lots and industrial farming. Here slurry is produced far in excess of crop requirements.

B. Grassland

Permanent and temporary grassland differ from tilled land in the following respects:

(1) high growth rate of grasses,
(2) the excess of carbon produced in the root system by which nitrogen is fixed easily,
(3) the absence of fallowing, and
(4) the total amount of nitrogen applied is given in 4–5 split applications.

These factors are the reason why nitrogen losses by leaching on grassland are much smaller than on tilled land. From lysimeter experiments(12, 17, 18, 19) the leaching loss from the S.O.M. in the sod was estimated at about 3 kg N.ha^{-1}.y^{-1} at a rainfall of 700mm. The contribution of fertiliser nitrogen was about 1–2% of the amount applied.

The surprising thing is that in spite of considerably higher applications on grassland (in the Netherlands about 225 kg N.ha^{-1}.y^{-1}), the nitrogen losses by leaching are far smaller than on tilled land at a fertiliser rate of 100 kg N.ha^{-1}.y^{-1}).

VI. P LOSSES BY LEACHING

1. Type of soil

Table 4 shows a summary of P losses by leaching on mineral soils calculated from lysimeter experiments(20), drainage water analysis(8, 21), and soil moisture samples at 1m depth(22).

From this table it is clear that the average P loss by leaching at 250mm drainage water on tilled land and grassland is about 0·22 kg P.ha^{-1}.y^{-1}, with a variation of 0–0·5 kg P.ha^{-1}.y^{-1} or more due to differences in drainage water production. Pfaff(23) found considerably higher values in clay soils (from 2 to 4 kg P.ha^{-1}.y^{-1}). This is possibly caused by losses of clay particles, which can adsorb high amounts of phosphorus. The amount of clay particles in the drainage water therefore will cause great fluctuations in the total-P loss by leaching. The tendency may be for higher P losses in clay soils than on sandy soils. But the P fixed by the clay particles will be less soluble.

On peat soils phosphorus losses due to leaching are much higher. From data by De Vries and Hetterschij(24), Wilson and Staker,(25) Henkens,(21) Eggelsmann and Kuntze(16), and Munk(22) it was estimated that an annual average loss of 2 kg P.ha^{-1} at 250mm drainage water is likely. This phosphorus is partly in organic form.

2. P losses from fertiliser

In contrast with nitrogen, in general little relation has been found between the amount of P-fertiliser applied and the loss of P by leaching in lysimeters with a profile depth of 1m. In view of the low phosphorus concentration in the drainage water (about 0·08 mg P.l^{-1}) due to a strong adsorption in the profile(8), such a leaching effect may hardly be expected, and specially not in experiments in which the application of phosphorus is in good agreement with phosphorus removal in the crop.

This picture, however, changes in experiments in which phosphorus is applied far in excess of crop requirement.

So Miller and Nap(27) mentioned a field experiment at Harrow (Ontario) on a light sandy soil, in which the phosphorus had penetrated to a depth of 1m after 11 years during which annually 60 kg P.ha^{-1} superphosphate (= 140 kg P_2O_5.ha^{-1}) was applied. Obvious this sandy soil had a small adsorption capacity for phosphorus.

TABLE 4. Leaching losses of phosphorus in cropped soil profiles of 1m depth (lysimeter experiments and drainage water analyses).

	Tilled land		Grassland	
	Loss, kg P.ha^{-1}.y^{-1}	Drainage, mm.y^{-1}	Loss, kg P.ha^{-1}.y^{-1}	Drainage, mm.y^{-1}
Bolton et al.(19)	0·72 0·48	250 250	0·30 —	250 —
Coppenet(44) Quimper Versailles	0·13 0·28	250 250	— —	— —
Cooke and Williams(8)	0·13	?	0·20	250
Holtan(45)	0·07	?	—	—
Kolenbrander(20)	0·06	250	0·2—	250
Low and Armitage(18)	—	—	(1·23)	250
Minderman and Leeflang(46)	0·05	250	—	—
Henkens(21)	0·07	250	—	—
Munk(22)	0·11	250	—	—
Average	0·21	250	0·23	250
Average concentration, mg. l^{-1}	0·084	—	0·092	—

Fig. 6, taken from Prummel(28), shows in what way the total-P content of the topsoil (0–20cm) decreases if no P is applied. With a superphosphate application of 30 kg P.ha^{-1}.y^{-1} (= 70 kg P_2O_5.ha^{-1}.y^{-1}), in agreement with P-removal by crop, this P content of the topsoil remains constant during the next 35 years. But with an application of 60 kg P.ha^{-1}.y^{-1} (= 140 kg P_2O_5.ha^{-1}.y^{-1}) there is a rise in total-P content, this increase levels off after 20–25 years. This means that, at the same level of P removal by the crop of

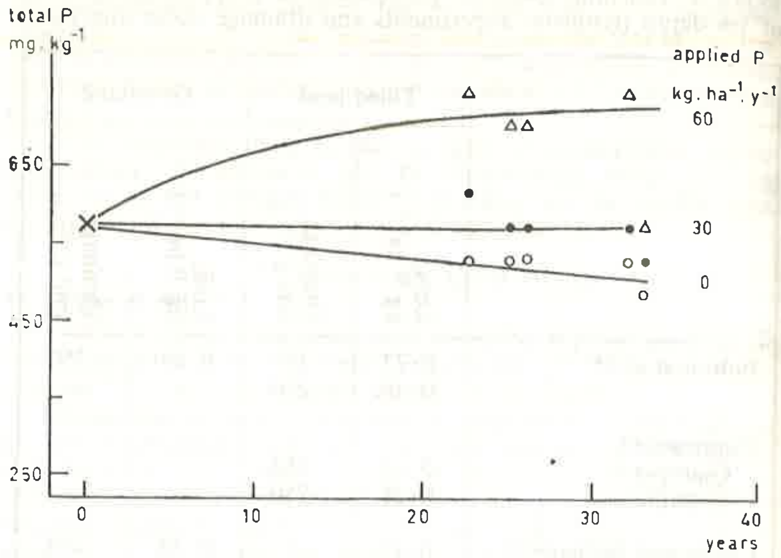

Fig. 6. Effect of an annual application of superphosphate on the total P content in the top layer of a sandy soil⁽²⁸⁾.

30 kg P.ha^{-1}.y^{-1}, there will be an additional maximum loss of 30 kg P.ha^{-1}.y^{-1} from the topsoil, which loss can be caused only by leaching to the subsoil.

These results raise the suspicion that on the long run, due to continuous fertilisation with inorganic phosphorus in excess of crop requirement, the P-adsorption capacity of the topsoil will be used up by the excess of phosphorus. This will result in an increased solubility of the phosphorus in the soil moisture, which might be a favourable effect from the agricultural point of view. But if this point is reached, an application of phosphorus in excess of crop uptake will stimulate the movement of P into the subsoil.

3. P losses from organic manure

Results of Vetter and Klasink⁽²⁹⁾ with high amounts of slurry show a 2–3 fold increase in phosphorus content in the subsoil (60–90 cm) after 20 years.

De la Lande Cremer⁽³⁰⁾ found an increase in total-P at 1m depth even within a year after eight applications of 30 tons of slurry on a sandy soil in a few weeks.

After potato waste water applications, Dietz⁽³¹⁾ found a content of 9 mg P.1^{-1} in the drainage water at a depth of 40cm. Van Geneijgen and Scheltinga⁽³²⁾ found 2.6 mg P.1^{-1} at 60cm after application of waste water from the dairy industry. De Haan⁽³³⁾ reports a content of about 1·20 mg P.1^{-1} in the ground-water at a depth of about 150cm, a month after irrigation with 420mm of potato waste water. This is 17 times as much as the original concentration of 0·07 mg P.1^{-1} before irrigation. Finally, Koelliker and Miner⁽³⁴⁾ mentioned a content of 0·5 mg P.1^{-1} at 122cm after irrigation with livestock waste.

The fact that also after chemical treatment of sewage water with iron and aluminium compounds the P content did not decrease below 0·5 mg P.1^{-1}⁽³⁵⁾, may be an indication that this phosphorus is in organic form, and has to be mineralised first by bacterial activity before it will be adsorbed.

In contrast with nitrogen the P losses from agriculture are small. However, in the O.E.C.D. Report of the Working Group on Fertilisers and Agricultural Waste Products⁽¹⁰⁾ it was pointed out that, based on results of Vollenweider,⁽³⁶⁾ a discharge equal to an average leaching loss of 0·22 kg P.ha^{-1}.y^{-1} is permissible for only 35% of the lakes. It is already dangerous to another 35% of the lakes, which are the smaller and shallower ones. Therefore a small increase in P leaching loss may be harmful to a great number of lakes.

The problem of phosphorus leaching is a form of a very slowly increasing soil "pollution". It can be accelerated unnoticed when the P-adsorption capacity becomes saturated. Though only small amounts are at stake it must be realised that polluted soil profiles cannot readily be cleaned up.

VII. FARMING PRACTICE

In the foregoing the remark was made that factors as climate, soil type and topography, causing eutrophication of surface waters, can hardly be influenced by the farmer in a favourable way. This, however, is not the case with the factor fertilisation which is determined by the farmer himself. In the process of fertilisation the following points are important:

(1) time of application,
(2) type of fertiliser,
(3) amount of plant nutrients.

1. Time of application

The time and frequency of application are important factors in the control of leaching and run-off. In our climate with a water surplus in autumn and winter, nitrogen applied during this period is subjected much more to leaching and run-off than nitrogen applied in spring and early summer, when there is a negative water balance sheet.

Even on flat land run-off can take place when soils are frozen and snow is melting. In spring and summer run-off will occur incidentally after a heavy rainstorm.

Kolenbrander(12) found in the case of grassland on a sandy soil that nearly 40% of the fertiliser nitrogen applied in the beginning of November was lost, while there was no loss at all in spring. The effect of an autumn application of farmyard manure (F.Y.M.) is also about 50% of that applied in spring(37).

However, much nitrogen is applied in autumn and winter as farmyard manure and slurry because:

(1) storage capacity is too small, as costs of construction are very high,
(2) frozen soils have a better bearing power,
(3) this period is attractive in relation to spreading of labour.

The use of fertiliser in autumn is restricted to phosphorus and potassium. Also here spreading of labour and limitation of soil structure deterioration in spring are important factors. In relation to the culture of potatoes, the favourable effect of leaching of Cl ions in autumn and winter can be mentioned.

A part of the plant nutrients in fertiliser and organic manure applied in autumn and winter may be transported over the frozen soil to the surface waters by melting water of snow.

It is clear that from the point of view of eutrophication, fertilisation in autumn and winter is a bad practice. The risks of spring application are much smaller. Leaching is reduced strongly also during March and April because after a downward movement of nitrogen there will be a capillary rise in the next period(38). Split application can have a good effect in reducing the nitrate concentration in spring.

However, we have to realize that the farmer is using autumn and winter applications only because it is favourable from an economic point of view. Each measure in this respect to reduce eutrophication will result in extra labour costs and will cause a serious rise in price of agricultural products.

2. Type of fertiliser

The farmer can choose between organic manures (green manure, F.Y.M., compost etc.) and fertilisers. Fertilisers can be split up into two groups, viz. fast- and slow-acting types.

It was already mentioned that organic manure is very important in maintaining S.O.M. content and soil structure of tilled land, but also that intensive use of organic manure may increase the nitrogen and phosphorus losses by leaching.

In this respect the use of conventional fertilisers may be preferable to organic manures because they can be applied in such a way that no surplus is left at the end of the growing season when udtake by the crop has ceased.

A disadvantage of conventional fertilisers is that when they are applied at once the nitrate concentration increases very strongly, with all consequences in relation to losses by denitrification and leaching. Here split application may favourably influence particularly the losses by denitrification but costs of application are increased.

The use of ammonia fertilisers may be preferable in periods with low temperatures because oxidation to nitrate is retarded. Van Burg(39) found that the use of ammonium sulphate on grassland in an early stage of growth under wet spring conditions gives less occasion to leaching losses than the use of ammonium nitrate and even considerably less than the use of calcium nitrate.

On the other hand, the use of ammonium sulphate causes a serious decrease of pH of the soil, while under frosty conditions the risk of sward damage may be important.

The use of slow-release fertilisers can remove the drawbacks of high nitrate levels in spring and increased cost of application. But as Cooke(40) stated: "Some (slow-release fertilisers) decompose or dissolve so quickly they are just as liable to be leached as are soluble inorganic fertilisers: others remain in the soil longer but fail to provide N quickly enough at critical periods in crop growth". Also Winsor(41) remarked: "Once a *heavy* application of slow-release fertilisers has been given, the grower is no longer in control of the nutritional situation".

It is clear that it will be very difficult for the farmer to determine the proper degree of solubility which is required in preventing losses by leaching of residual slow-release fertiliser after the growing season. It is also clear that this objection is much more important under the conditions of tilled land than under those of grassland, where fallowing is absent.

The coated conventional fertilisers offer in this respect perhaps the best outlook, but the problem of run-off is not solved in this way, because the residual nitrogen will dissolve slowly in the run-off water or afterwards in the surface water.

Therefore we should not have very high expectations concerning the contribution of slow-release fertilisers to reduce the problem of eutrophicaten with nitrogen.

3. Amount of plant nutrients

a. *Fertiliser*. The amount of fertiliser the farmer has to apply to get maximum yields depends, besides on the type of crop, on:

(1) the amount of plant nutrients available in the soil in spring;
(2) the amount mineralised during the growing season from S.O.M. and organic manure; and
(3) the losses due to weather effects.

Although both nitrogen and phosphorus are mineralised from S.O.M., the rate at which they become available to the crop is much more determined by physico-chemical processes than is the case with nitrogen. The lack of such a system for nitrogen makes its availability much more sensitive to temperature and moisture content, and therefore sensitive also to weather conditions, than is the case with P and K.

The difficulty of an exact application in practice is illustrated by Fig. 7. This figure shows, for one field experiment (Pr Lov 6) the relation between the annual maximum yield of sugar and potatoes over a period of 13–18 years and the annual fertiliser nitrogen necessary to produce this yield without any additional organic manure.

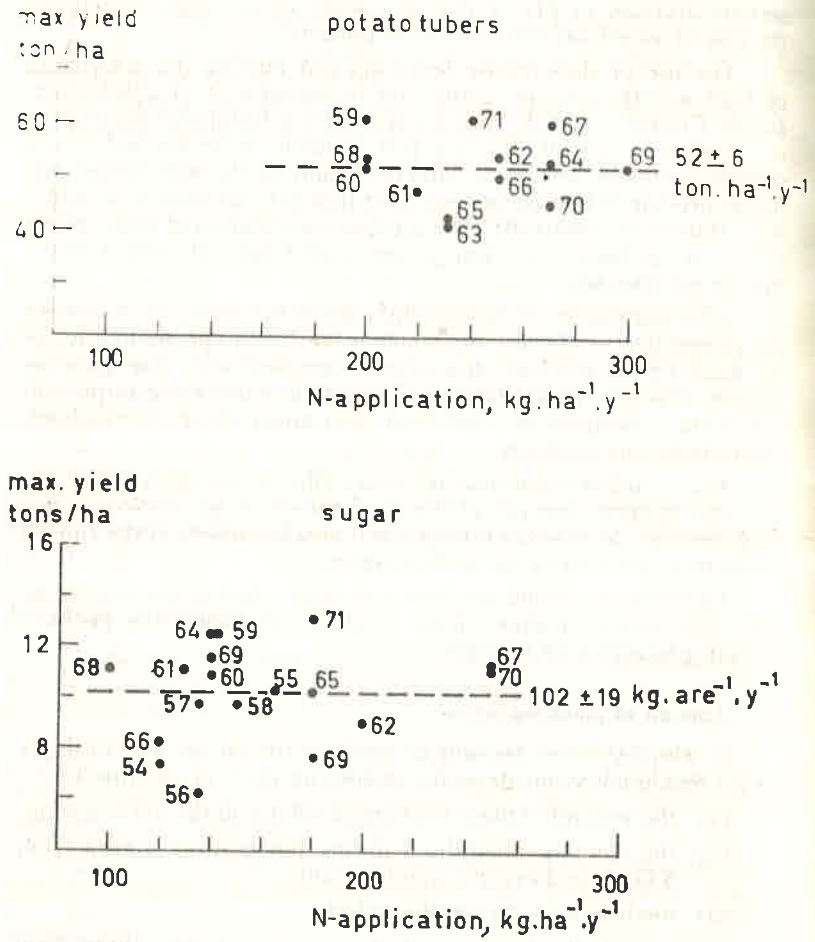

Fig. 7. The nitrogen fertiliser application required to get the maximum yield in different years.

From Fig. 7 it is obvious that the nitrogen applied for the sugar yield ranges from 100–250 kg $N.ha^{-1}.y^{-1}$, and those for potatoes from 200–300 kg $N.ha^{-1}.y^{-1}$.

To be always sure of maximum yields, the farmer would have to apply annually 250 and 300 kg $N.ha^{-1}.y^{-1}$, respectively. However, this system would result in a great squander of fertiliser nitrogen in those years that maximum yields would be gained at much lower nitrogen fertiliser levels. Even the risk is considerable that as a result of the excessive N-application a yield depression would be produced. Both constitute a serious loss in profits to the farmer.

From the standpoint of eutrophication the lowest application rate would be attractive, but also this means to the farmer a serious loss because the yield in a great number of years is too low. The farmer has found a compromise in an "average" application which ensures the best profits in relation to yield and price of fertiliser. Cooke(40) comes to a similar conclusion for P and K.

A main application and a small additional gift afterwards depending on the crop development and weather conditions might be a technical solution, but it is unattractive to the farmer from the point of view of labour cost(40).

From Fig. 7 it is clear that the maximum yield differs from year to year. Here weather conditions and plant diseases will play an important role.

In general for each plant nutrient element we can say that the *total input* in organic manure and fertiliser *may never exceed* the *output* in a maximum crop yield taking into account possible losses to the environment (e.g. nitrogen) and the rate of fixation in the soil (e.g. phosphorus). Under these conditions the farmer will produce the "maximum" yield, necessary for feeding mankind, with the smallest possible losses to the environment.

b. *Organic manure.* In Fig. 8 the experiment with potatoes gives some support to the conclusion made in a previous chapter, that with organic manure alone the same maximum yield can be produced as with fertiliser. Fig. 8 demonstrates also that on tilled land, starting from a more conventional application rate of 20 tons F.Y.M. $ha^{-1}.y^{-1}$ containing about 100 kg total nitrogen, the increase in dry matter production in the year of application is only 0·3 times that of 100 kg N as fertiliser. This means that, in terms of fertiliser nitrogen, the relative activity coefficient of the nitrogen in F.Y.M. in the first year is at best 30%.

This is clear because not all nitrogen from F.Y.M. can be used the first year as only 40% of the organic matter is decomposed. However, we may expect a residual effect in the next years after application.

In a situation in which equilibrium in soil organic matter content is reached with 20 tons F.Y.M. $ha^{-1}.y^{-1}$ an equivalent of 100 kg N in F.Y.M. will be mineralised annually, partly outside

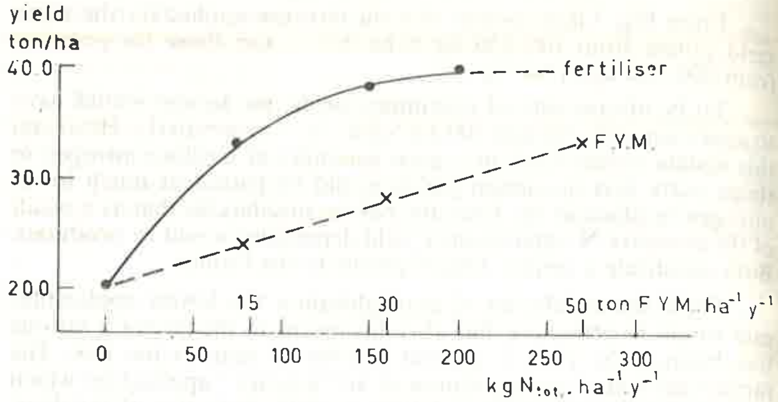

Fig. 8. Effect of nitrogen from fertiliser and farmyard manure on the yield of potato tubers.

the growing season, however. So we can make a comparison between 100 kg fertiliser nitrogen applied in spring and 100 kg nitrogen in F.Y.M. applied in autumn.

In the section on "time of application" it was already mentioned that the effect of autumn applied nitrogen in fertiliser and farmyard manure was about 40–50% of that applied in spring. So we may expect that the effect the nitrogen in F.Y.M. will be no more than 50% of that applied as fertiliser.

This means that to get results equal to that of fertiliser, double the amount of nitrogen in F.Y.M. has to be applied. But also the loss to the environment will be doubled under these conditions. If we want to restrict these losses the system of only organic manure will result in a lower yield level. Regardless of whether or not this system can be introduced on a large scale, it would result in a lower dry matter production, less food and higher prices, which may rise, according to Viets(42) by more than 100%.

Moreover, it is not inconceivable that developing countries have to pay the "score" by a decreasing food export from developed countries(43).

An additional circumstance is that in organic manures the ratio between the different plant nutrient elements is not in agreement with those needed by the plant. This leads very easily to a lack or to a surplus of plant nutrients, which can have consequences in plant production and environmental pollution.

However, in spite of all the drawbacks mentioned, a basic application of organic manure will be indispensable in farming practice in maintaining soil organic matter content, soil structure and soil fertility level, and in reducing the fluctuations in yield due to annual changes in weather conditions.

VIII. FUTURE

The investigations of the "Club of Rome" into the possibilities of life on our planet have made it clear that the time factor is a very important one. Here "time" has to be interpreted not in years but at least in decennia if not in centuries.

Although thinking in terms of such long periods is very difficult for man, it means that processes going on very slowly in time, e.g. the leaching of phosphorus into the profile or of other compounds strongly adsorbed on low insolubility (e.g. heavy metals), may not be disregarded any longer.

It is a transport problem which cannot be solved in a few years with field experiments. Research on a short term basis has to produce more fundamental velocity equations, which can be integrated over time by computers, to get information about permissible and harmful levels under a large number of different conditions, as was done by the "Club of Rome" itself.

Especially biologists and limnologists have recently directed our attention to the quality of ground and surface water as a source of drinking water and for recreation. But in agriculture traditionally this water is considered as drinking water for man and animal. The only "standard" was that the salt content should be at a "reasonable" level.

Now, however, the quality of water is considered from other points of view, and the quality standards raised and extended. The consequence is that the farmer's freedom of action is suddenly restricted because a great part of the rain water will always reach the ground and surface water via his soils.

This will increase his social responsibility and his job considerably in fixing enough "energy" in a useful form for mankind in an economical way, but from now he also has to do this with a *minimum load to the environment.*

It is clear that this will be an expensive process for the farmer, but also that the consumer will have to pay his share in the price of his food.

IX. CONCLUSIONS AND THESES

1. Application of a plant nutrient to cultivated land, seen on a long term basis, has to be attuned to maximum removal by crops, the state of soil fertility and a minimum eutrophication of ground and surface water.
2. The mineral stock of plant nutrients in the soil should not be increased more than is necessary for "food" crop production in order to minimize the losses by run-off and leaching as much as possible.

3. Even a slow process as phosphorus leaching may be in the long run a potential danger in eutrophication of surface waters, if applied far in excess of crop removal, especially on light soils with a low P-adsorption capacity.
4. The possibilities of using organic manure in maintaining or increasing S.O.M. level are restricted by its content of plant nutrients, which may not be applied in excess of plant need in relation to soil type and soil fertility level.
5. The increase in dry matter production at 100 kg total nitrogen in farmyard manure (including residual effects) was estimated at about 50% of that gained by fertiliser nitrogen.
6. Complete substitution of fertilisers by organic manure will therefore result in the long run in either lower yields or in higher losses of plant nutrient to the environment.
7. Surpluses of organic manure which cannot be recycled in agriculture have to be immobilized on "controlled" dumping grounds, managed by the government, or treated in such a way by industry that plant nutrients can be exported as fertiliser.
8. Reduction of the contribution to eutrophication by agriculture will increase labour cost to the farm significantly, which will result in higher food prices for the consumer.

X. SUMMARY

A comparison was made of the effect of N and P in fertiliser and in organic manure used in agriculture, on eutrophication of ground and surface waters.

It was shown that losses from soil organic matter and organic manures often are higher than from fertiliser. This is for nitrogen mainly due to mineralization of organic matter by bacterial activity outside the growing season, especially on tilled land. Thus for tilled land the effect on dry matter production of an annual application of 100 kg total $N.ha^{-1}$ in farmyard manure was estimated to be about 50% of the effect of 100 kg N applied as fertiliser in spring. This difference is mainly caused by higher leaching losses of nitrate in autumn and winter and evaporation of ammonia.

The P-losses in agriculture are small and will range from 0–0·5 kg $P.ha^{-1}.y^{-1}$ if soil erosion is absent. However, an average leaching loss of 0·22 kg $P.ha^{-1}.y^{-1}$ was found to be dangerous to 35% of the lakes and permissible to only another 35%. Although movement of inorganic phosphorus into the soil profile is a very slow process, these results indicate that in the long run this penetration process may yet be a dangerous one, especially on light soils.

In organic manure, however, P-compounds are found, which are not easily adsorbed by the soil profile and therefore will move downwards much faster than the inorganic compounds from fertiliser.

Another drawback of organic manure in general is that the ratio of plant nutrients in the manure is not in agreement with crop requirements. This easily leads to a lack or surplus in plant nutrients and in the latter case to increased losses to the environment.

In spite of these drawbacks organic manure will be indispensable in farming practice in controlling soil fertility, and maintaining or increasing soil organic matter content and soil structure.

The conclusion is that an improvement of water quality might be possible to a certain extent by better fertilisation practices. This, however, will result in much extra costs for the farmer and therefore in higher food prices for the consumer.

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