SOILS BULLETIN 16

EFFECTS OF INTENSIVE FERTILIZER USE ON THE HUMAN ENVIRONMENT

SWEDISH INTERNATIONAL DEVELOPMENT AUTHORITY
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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INTRODUCTION

During the last two decades fertilizers have become indispensable for supplying the necessary food for increasing populations. Between 1950 and 1970 world fertilizer consumption has increased fourfold and it is expected that this upward trend will continue.

The increasing use of agro-chemicals has not passed unnoticed by the general public who have voiced concern about the possible side effects of intensive fertilizer use on the human environment. Considering the importance of applied plant nutrients in stepping up agricultural production it is imperative that any conclusions on the relationships between intensive fertilizer use and the quality of the environment be drawn on the basis of fact. Thus it was with a view to obtaining first hand information on the results of research and experimentation that FAO convened a consultation on this subject in Rome to which a group of experts working in this specific field were invited.

The consultation was held in FAO's Rome Headquarters from 25 to 28 January 1972 and was made possible by financial support received from the Swedish International Development Authority. This generous assistance is most gratefully acknowledged.

Expert advice was sought from countries where fertilizer consumption is relatively high since it is certain that any ill-effects will first appear in areas where fertilizers are intensively applied. Information was also obtained from research carried out by the nitrogen, phosphate and potassium fertilizer industries.

The present report records the findings of the consultation. These indicate that the effects of intensive fertilizer use on the environment are mainly positive. It became apparent that when fertilizers are applied correctly their contribution to the nutrient content of surface waters is small in proportion to nutrients derived from other sources. Where detrimental effects were observed, they were mostly due to improper use of fertilizer which could be corrected by rational soil management practices. In this respect it was noted that the amounts of fertilizers used at present in developing countries are still very low and that local excesses in some of the industrialized countries should in no way prejudice the intensification of agricultural production in the developing world.

FAO will use the material assembled here in the development of its fertilizer use programme. The contacts established with research organizations will be maintained so that the most up-to-date information on effects of fertilizer use on the environment can be made to serve agricultural development.

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SUMMARY OF TECHNICAL DISCUSSIONS

prepared by

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A number of countries in Europe and North America have been using fertilizers heavily for a number of years and particularly since 1945. This high level of fertilizer applications is essential to supply the necessary food for increasing populations and to meet higher demands for animal and plant products. Effects of fertilizer use on the environment should show up first in countries where fertilizers have been used intensively for some time and where consumption is steadily rising. It is the experience gained in such countries which is being discussed below with a view to assessing the impact of fertilizers on the human environment, including the development of methods for recognizing and minimizing any undesirable consequences which may be produced. It should be realized that high densities of human population combined with intensive crop and livestock production have led to the production of organic wastes at a rate too high for natural processes to convert it in ecologically safe compounds. Therefore both direct and indirect effects of intensive fertilizer use have been reviewed.

Side effects of an increased food supply

The greatly increased production of food from farms in Europe and North America has involved both the introduction of crop varieties capable of giving greatly increased yields under conditions of high soil fertility, and also the upgrading of livestock to give either higher yields of milk or eggs, or much faster growth rates under conditions of high nutritive fodders. Thus the extensive use of fertilizers has had the direct effect, in many farm areas, of greatly expanded numbers of animals fed on diets of much higher nutritive value than in the past. Both crops and animals leave residues behind, but whilst a large proportion of crop residues that are not consumed by animals tend to be low in nitrogen and to have most of their mineral elements present in relatively insoluble forms, those from animals tend to be high in urea and decomposable organic nitrogen compounds, and much of the mineral elements are present in a relatively soluble form.

Further, the typical animal fodder crops are grass, grass-legume or pure stands of pasture legumes which tend to build up the humus content of the soil whilst arable cropping tends to lower it.

A greatly increased animal population on farms can have undesirable effects on the environment unless very strict precautions are taken. A dairy cow produces about 15 times as much dung as a human being, so quite a small dairy herd will produce as much as a moderate sized village. Further the herd is usually kept in a yard for part of the year, or part of the day, so that there will be a large concentration of dung and urine in a relatively small area of land. As long as the animal population per hectare on the farm is low, good management in the farmyard allows most of the animal excretion to be returned to the land at a relatively low rate of return per hectare, and the losses from the farm need not be very large. But the problem of disposing of the manure becomes very much more difficult once the number of animals per hectare exceeds a certain threshold value, and it can become very difficult to prevent soluble inorganic and organic constituents getting washed into either the groundwater or the ditches and streams draining the area.

The intensive use of fertilizers can benefit the environment indirectly in that, by increasing considerably the yields of foodstuffs per hectare, it allows withdrawing from cultivation land of low inherent quality, such as steep land, land with shallow soils, and land very susceptible to erosion, without reducing the total food production of the region appreciably. The correct use of fertilizers eases the problem of erosion control on erosion-sensitive land because a strongly-growing well-manured crop, properly managed, gives much better protection to the surface soil than a half-starved crop. Soil wash can be a very serious source of pollution of rivers and lakes, not merely because of the silting up of water ways it causes, but because the soil particles most easily washed off the surface are the fine clay and clay-humus particles which are rich in plant nutrients, since they absorb all those fertilizer components that soils can hold in relatively insoluble form. Uncontrolled water run-off from steep slopes or erosive soils also increases flood hazards during periods of heavy rain and drought hazards in periods of low rainfall since this water runs off the land instead of percolating into the soil.

Side effects of fertilizers residues

Not all the nutrient ions in a fertilizer applied to a field soil are taken up by the growing crop, and the fate of the remainder is very important in any discussion on the effects of their long-term intensive use. Three things can happen to these residues in the soil; they may remain in the soil, they may be removed in the water leaching through the soil or running offthe surface of the soil, or they may be lost to the atmosphere by volatilisation. The relative importance of these depends on the physico-chemical and biological reactions the ions take part in.

Phosphate anions

When a water-soluble phosphate fertilizer is added to a soil, the phosphate portion is rapidly converted into forms having a very low solubility in the soil water, unless the soil is an almost pure sand or peat low in active iron or aluminium ions. Thus although the solution diffusing out of a pellet of granular superphosphate placed in a moist soil has a phosphate concentration of about 4 molar (120g/l), its concentration a few millimetres from the granule will probably be about 10^{-5} to 10^{-6} molar (300-30 μg/l), that is about a million times more dilute. Phosphate is, in fact, an example of a nutrient ion that is extremely immobile in the soil. It is absorbed very strongly by surfaces of iron, aluminium and manganese oxides and hydroxides, it is absorbed by clay particles, and it is precipitated by calcium ions to give calcium phosphates such as hydroxyapatite or, in calcareous soils, calcium octaphosphate. Thus in so far as fertilizer phosphate is not removed in the harvested crop, it remains in the soil except when the soil is washed off the land by run-off, or exceptionally, if heavy rain falls shortly after the phosphate has been applied to a wet soil surface. Phosphate can, however, occur in higher concentrations in the soil solution of some inundated soils, and high levels of phosphate fertilizer given to swamp rice may raise the concentration of phosphate in the drainage water to levels appreciably above that found from better aerated soils.

Crops may remove in the first year so much as 20 percent of the phosphate added, if growing in a soil low in phosphate and the phosphate is placed close to the plant, but in normal well-farmed land considerably lower recoveries are more common. Since many progressive farmers add phosphate to their soils every year or every second year, the phosphate status of their soils is now high and they use their phosphate fertilizers either on crops requiring a high level of soluble phosphate for high yields, such as potatoes for example, or to maintain rather than increase the present satisfactory levels.

The Panel concluded that only a negligible proportion of fertilizer phosphate is leached from soils into the drainage water, since it is very immobile in most soils. Fertilizer phosphate will however be carried into rivers if adsorbed on any soil particles carried off the land by soil erosion, and as soluble organic wastes via fodder plants and the bodies of livestock.

Potassium cations

Almost all potassium fertilizers in use are very soluble in water, but once dissolved in the soil water, they also are subject to absorption by the soil particles. But they are held by a different process from phosphate, for they take part in cation exchange. When potassium ions are absorbed by a clay or humus particle, an equivalent amount of other cations are displaced into the solution. In normal fertile soils the displaced cations are predominantly calcium though they will usually include some magnesium in addition. But these ions are held much less tightly than are the phosphates, so that the potassium ion concentration in the soil solution is usually in the range of 10^{-4} to 10^{-5} molar, though on soils well supplied with potassium it may rise to 10^{-3} molar. If the level of exchangeable potassium is increased by adding a potassium fertilizer, it is commonly found that a proportion of the added exchangeable ions is converted to a form that is much less accessible to the soil solution - the ions are said to be fixed - and this fixation takes place within the layers of micaceous and vermiculitic clay perticles. Since most soils that are not exclusively composed of very strongly weathered minerals contain these types of clay, they have a great ability to hold potassium when soluble potassium salts are added to the soil.

Added potassium that is not taken up by a crop is in consequence, not very mobile in soils containing much clay. On clay and loam soils it is unlikely that any appreciable amount will move more than 50-70 cm below the depth of incorporation. Some crop will however take up large amounts of potassium from a soil. Thus grass crops, will remove very large amounts of potassium from the soil if the harvested grass be removed completely. Cereal straw is also fairly high in potassium - though much lower than heavily-manured grass - as are the leaves of many fodder plants, so that a large amount of potassium may be in cycle on farms feeding their crops to livestock. Since most of the potassium excreted by cattle and pigs is in the urine, there is a tendency for there to be large potassium losses from the farm in the liquid manures that get washed away from the farmyards and dairies.

The Panel concluded that only a small proportion of fertilizer potassium can be lost by leaching because most soils hold added potassium sufficiently strongly for only little to enter the soil solution.

Calcium and Magnesium

In so far as the use of nitrogen fertilizers increases the amount of nitrate leaching out of the soil, this nitrate will be lost as calcium and, to a lesser extent, magnesium nitrate. Their use therefore involves the regular application of liming materials to non-calcareous soils, in order to restore the extracted calcium and magnesium in the soil and thus prevent acidification.

Nitrogen Fertilizers

The effects of adding nitrogen fertilizers to soils on the movement of soluble nitrogen compounds through the soil are complex. The typical nitrogen fertilizers of commerce are urea, ammonia, ammonium salts and nitrate salts; though there is a very restricted use of proteinaceous residues such as wool waste, dried blood and some types of meat and bone waste. In addition on farms on which livestock are kept, there is likely to be a return of farmyard manure or slurry to the land. Under normal farming conditions, on well-drained soils when the soil is warm, all soluble nitrogen compounds are usually fairly rapidly oxidised to nitrate, and nitrate is not absorbed to any appreciable extent by soils particles. It is therefore all present in the soil solution, and will diffuse fairly rapidly through the soil solution, including that within the very fine soil pores.

Some fertilizer nitrogen can be lost to the atmosphere by volatilization of ammonia shortly after it has been applied. When anhydrous ammonia is being injected into a soil, a certain proportion is often not absorbed by the soil but escapes into the air. Again if urea is spread on the surface of a damp soil with a pH above 6, and the weather remains dry after spreading, it will hydrolyse to ammonium carbonate, which will decompose giving off ammonia to the atmosphere; and the same loss occurs if ammonium sulphate is spread on the surface of a calcareous soil.

The nitrate can be removed from the soil in four ways: it may be taken up by the crop, it may be taken up by the soil microorganisms and converted into humus, it may be washed out of the soil as nitrate, or it may be denitrified and lost to the atmosphere either as nitrogen gas or as oxides of nitrogen, principally nitrous oxide N_2O.

The technical difficulties in determining the fate of the added nitrogen are firstly that it is not usually possible to determine either the amount of nitrate being leached out of the soil or the amount that is denitrified in normal field soils; and secondly that only a part of the nitrate present in the soil is derived from the fertilizer, for a portion, and in some systems the greater portion has been derived from the decomposition of some of the soil organic matter. Further the total amount of nitrate produced in the soil during the growing season is small compared with the total amount of organic nitrogen it contains, and it cannot usually be determined from the change in the total soil nitrogen over the season as it is of the same order of magnitude as the sampling and analytical errors in the total soil nitrogen determinations.

This problem is still further complicated on most farms carrying livestock because a proportion of forage crops are grown which include leguminous plants such as clover or lucerne, often admixed with grass. These plants have nodules on their roots which fix atmospheric nitrogen, converting it into organic compounds, and some of these are left in the soil. It is common practice for farmers using this type of cropping not to give any nitrogen fertilizer to the first crop after the forage crop has been ploughed in, and even then the amount of nitrate released is more than the crop can take up. Further it is now possible to prove that blue-green algae fix atmospheric nitrogen in many arable soils and non-symbiotic nitrogen-fixing bacteria are operative in both arable and grassland soils. A proportion of these organic nitrogen compounds are relatively easily oxidised in the soil, even on farms growing no leguminous crops, a portion of the nitrate present in the soil solution may have been derived biologically from the air.

These complications have the consequence that it is not yet possible to prove conclusively what proportion of the nitrates in streams draining out of well-farmed land has been derived directly from nitrogen fertilizers added to the soil. The evidence from changes in the nitrate content of river waters over the last 10-20 years, in regions where fertilizer use has been greatly increased, is poor and inconclusive - poor because of the relatively few streams and rivers draining predominantly agricultural areas whose flow has been gauged and whose water has been regularly analysed, and inconclusive because the results obtained from the few long-term records of rivers so gauged and analysed have not been consistent. Thus research in Great Britain has shown that of the 18 rivers for which records are available, the correlation coefficient between the amount of nitrogen fertilizer estimated to be used in their catchments and the nitrate leaving the catchment in the river was over 0.7 for only four, but one of the largest of these coefficients (r=0.9) was negative, which means that the increasing use of nitrogen fertilizer appears to have decreased significantly the amount of nitrate leaving the area.

However this method of judging the effect of nitrogen fertilizer in this way is invalid unless it can be proved that the only factor affecting the nitrate content of river water is the change in the amount of nitrate draining out of fields due to the use of nitrogen fertilizers. This is naturally very difficult to prove, but the possibility that this assumption is valid cannot be ruled out because the nitrate concentration in the water of some rivers was higher in winter, when the flow was high, than in summer, when it was low; and this is probably a reflection of the concentration of nitrates in the soil water. The reason for the nitrates being higher in winter than in summer, is that few English arable soils carry an actively growing crop in late autumn or early winter, yet the soil temperatures are adequate for a moderate rate of nitrate production, and this nitrate accumulates in the soil and in part washes out after enough rain has fallen to wet the soil profile. In summer time the land is carrying an actively growing crop, so that although nitrification is taking place more rapidly than in winter, the crop is drawing strongly on this supply. Thus in western Europe, nitrate losses from the soil are much larger in winter than in summer time, and in so far as the drainage waters are not being impounded in reservoirs for long periods of time, the periods of high nitrate concentration in the water tend to occur when the water is cold and algal activity low. These winter losses of nitrates can be reduced if a fast growing catch crop is planted directly after the main wheat or barly crops have been harvested on land that is to be spring sown. However there was a clear indication that for one English river, in a year with an abnormally wet April, the peak of river flow due to this rain was also a peak of nitrate concentration in the water, due almost certainly to some of the nitrogen fertilizer applied to the land in March or early April being washed out of the soil by this heavy rain.

Very little is known about the losses of nitrate from soils by denitrification. All attempts at drawing up balance sheets for the fate of fertilizer nitrogen applied to crops growing in lysimeters show that, for most soils, a considerable amount, usually of the order of one-third, of the added nitrogen cannot be accounted for and is presumed to have been lost by denitrification. Present-day knowledge on the biological and biochemical processes responsible for denitrification is concordant with the existence of appreciable losses because the first effect of a restriction of oxygen supply is for all the soil nitrate to be reduced to gaseous forms before reduction of ferric to ferrous iron can begin. Field soils are likely to contain many volumes or pockets of soil that rapidly become anaerobic during wet weather, due to compaction by tractors and cultivation and harvesting machinery, so that denitrification can take place actively at intervals during the growing season even in soils that appear to be well-drained. Denitrification studies in lysimeters are likely to under-estimate the amount taking place in the field due to neglect of these isolated volumes of compacted soil. This subject of the amount of denitrification taking place in the field, particularly under conditions of high nitrogen fertilizer use, is in urgent need of more intensive research.

The Panel concluded that nitrogen is the most likely fertilizer element to be leached out of the soil, but there was still no good evidence that their use has had any appreciable effect on the composition of river waters. The Panel recognised, however, that it is technically very difficult to interpret changes in the nitrate content of drainage waters in terms of changes in fertilizer nitrogen use due to our present inability to measure sufficiently accurately the ratio of biological nitrogen fixation, the rate of oxidation of soil organic nitrogen to nitrate, and the rate of reduction of nitrate to nitrous oxide and nitrogen gas. The problem is still further complicated if livestock are kept, for some of the nitrates draining out of the farm will have been derived from their wastes.

Effects of fertilizers on food quality

Fertilizers, and particularly nitrogen fertilizers, will raise the nutritional value of grass for livestock feed; and very high amounts of fertilizer nitrogen, can be effectively converted into grass protein during a growing season, provided the water supply is not limiting growth. But, in general, the application of fertilizers to well-farmed land has little effect on either the nutritional quality or the flavour of crops grown for human consumption; and in so far as they have an effect, they are more likely to raise than to lower the nutritional value of food. This is because adding a nitrogen fertilizer, for example, tends to raise the protein content of the crop, though it may not raise the content of all the constituent amino-acids in the same proportion. In the same way adding a phosphate fertilizer may raise, but will not lower, the phosphate content of the crop. The effect is usually small and rarely of economic significance. There are however examples of nitrogen fertilizers, applied at the proper time, increasing the market value of a crop due to the increase in protein content. Thus an example from Germany was mentioned, where nitrogen fertilizers are considered to increase the protein content of wheat sufficiently to bring the flour up to Manitoba quality for bread-making. Nitrogen fertilizers are also known to increase the protein content of barley - a desirable effect if the grain is for animal food but undesirable if for some types of malt.

The heavy use of nitrogen fertilizers on crops when the leaf is consumed can however have an undesirable effect. The effect of moderate dressings is to increase the content of leaf proteins, a desirable effects as they have a high nutritional quality; but at high dressings some of the nitrate taken up by the plant is translocated to the leaf and concentrates in the leaf petioles, presumably because the biochemical processes for reducing nitrate and incorporating the nitrogen into amino-acids cannot keep pace with the translocation from the soil. The consequences of high nitrate on food will be discussed in the next section.

Heavy nitrogen use can have a number of other undesirable consequences. It increases the liability of crop leaves to attack by a number of pests and diseases, it increases the tendency of cereals to lodge, and it may reduce the quality of the crop in an obvious manner. Thus too high a level of fertilizer nitrogen is likely to lower the storage and cooking quality of potatoes, and it will make sugar from sugarbeet more difficult to refine. In general, therefore, it is in the farmer's immediate interest to keep the level of nitrogen used below that which will give these complications. But this does not apply to the horticulturist growing salad and leaf vegetable crops, for high nitrogen gives rapid leaf growth and soft succulent leaves; characters which may have a positive market value. Thus the profitable short-term over-use of nitrogen fertilizer giving an undesirable effect on food quality is primarily restricted to the high nitrate content that it may cause in leaf vegetable and salad crops.

Consequences of high nitrates in water and vegetables for human health.

A number of medical specialists have expressed concern about the undesirable effects of a high nitrate intake on human health, and in particular on the health of babies up to about 4 months of age. The cause of the concern is due to the effects of nitrite on health, for nitrate may become reduced to nitrite in the intestinal tract, which is then absorbed into the blood stream. Babies below a certain age may be unable to detoxify this nitrite, which combines with haemoglobin to give methaemoglobin, and this reduces the capacity of the blood to transport oxygen. Some medical specialists have also claimed that, even for adults, a high nitrate intake is undesirable because some of the nitrite produced may be converted to nitrosamines, which could, in turn, cause some hazards to health.

The Panel was not competent to discuss this problem since it contained no medical specialists, but it noted the importance of a critically based assessment of maximum permissible nitrate levels in drinking water and in food, particularly for babies. It was also told that in America there is an important body of medical opinion which considers a high nitrate intake by babies is not in itself directly harmful, the harmful effect being due to the combination of a high nitrate intake coupled with entero-gastritis caused by coliform and doubtless other pathogenic bacteria. This view is, in effect, that it is due to inadequately purified sewage.

The F.A.O. Soils Bulletin No. 13, issued in 1971 and made available to all members of the Panel contains a short discussion on the hazards of nitrate in drinking water and vegetables. This Bulletin had contributions from W.H.O., and on page 76 it states that there had not been, up to the time of writing, any reports of nitrate poisoning associated with the ingestion of food high in nitrates, and confirmed that in America no cases of methaemoglobinaemia had been reported in babies using public water supplies, even when the nitrate content was in excess of the limits set by the U.S. Public Health Service: all the cases reported involved the use of unpurified private well water.

The Panel considered that, in view of the fears expressed by many doctors and environmentalists, W.H.O. should be asked to make a definite assessment of the hazards to health of various levels of nitrates in drinking water and in vegetables. In the meantime agricultural advisers should be recommended to take special care in the use of nitrogen fertilizers, leguminous crops and and livestock wastes in critical areas where an appreciable hazard to health might arise.

Effect on the composition of river water: Eutrophication

A number of environmental scientists have claimed that the use of fertilizers on farm land has seriously increased the liability of inland water to become eutrophic, causing pollution in lakes and reservoirs both by the algal pigments becoming distributed in the water and by creating anaerobic conditions in the subsurface waters. The Panel did not contain freshwater biologists, and could therefore only discuss in general terms the conditions necessary for undesirable consequences of eutrophication to become important. They noted that eutrophication need not lead to pollution, and in fact eutrophic waters can be very productive for freshwater fish.

The harmful effects of eutrophication may be due to consequences of algae multiplying rapidly throughout the depth of water which receives sunlight, or it may be due to consequences of algal cells and simple aquatic plants multiplying rapidly on the surface of the water giving a green scum which reduces very seriously the amount of light penetrating the water layers below the surface. This prevents algal cells in these subsurface waters photosynthesing and excreting oxygen in the water, which keeps it aerobic. Further when the plants die, their organic remains sink into the subsurface waters or fall on to the bottom where they are further decomposed by bacteria, which set up severe anaerobic conditions in the water and which excrete into the water undesirable products of biological reduction processes. In addition, under some rare conditions, a few species of algae suddenly bloom and excrete a brown pigment into the water, which cannot easily be removed by the normal purification processes used by water supply authorities.

The exact conditions that are required for these undesirable effects of eutrophication to occur are not known. The mere presence of phosphate and nitrate above definite threshold concentrations is not sufficient, for they can occur in waters of very low phosphate content, although a number of workers consider that the phosphate content is the most important factor contributing to the creation of these conditions. These undesirable effects are not solely due to man's interference with the environment, for they have occurred in regions where man's activity has been minimal. However the Panel noted that algae have a demand for suitable carbon sources that is more than several hundred times their demand for phosphorus if they are to make active growth, so that a rapid growth of algae can only take place in water having a large supply of carbon dioxide, and the most likely source of this is from active decomposition of readily metabolisable organic substances in the water. This suggests that water receiving farm wastes or inadequately treated sewage would be much more likely to develop these troubles than water derived solely from percolation through cultivated soils. The Panel considers it very important for intensive agricultural development that more research be conducted on the exact conditions required for eutrophication troubles to occur, so that the essential precautions that must be taken on farms can be established, if farmers are to play their full part in minimising their onset.

Maximising the Efficiency of Fertilizers

In so far as fertilizers have any undesirable side-effects on the human environment, these will be minimised if fertilizers are used with the maximum efficiency on the farm, for this will reduce the tendency for their over-use. It is naturally in the farmers interest, as well as the environmentalist's, that research be continued on this problem by agronomists; and in fact research on these problems has always been of major importance in all crop and animal husbandry development programmes. The Panel heard examples of how the use of the correct of choice of fertilizer, correctly formulated, and applied at the most appropriate time, can minimise the amount of nutrients that are liable to be washed or leached into the drainage water. But it also noted that there are often serious practical problems in giving fertilizer at a time when the maximum proportion will be taken up by the crop, due both to the inability to make accurate long-range weather forecasts and to the difficulty of applying the fertilizer without harming the crop.

These difficulties can, in theory, be overcome if fertilizers could be developed in which the nitrogen was held in an insoluble form in the soil, but which released their nitrogen as nitrate into the soil solution during the growing season at a rate comparable to the needs of the crop for nitrate. Compounds of this type, or nitrogen fertilizers formulated with suitable inhibitors to achieve this purpose, are known as slow-release fertilizers. There are still no satisfactory slow-release fertilizers available for general farm use, but this is a problem which is actively being studied both by the fertilizer industry itself and official laboratories such as those of the American T.V.A.

The recycling of livestock and human organic waste on the farm

The Panel's attention was repeatedly drawn during the meeting to the problem of disposing of the waste products of livestock without causing pollution in the drainage or run-off water leaving the farm. Soluble waste organic matter from manure heaps for example, will carry considerable amounts of phosphate with them, and in so far as more intensive farming increases the phosphate content of the water, this will be due much more to phosphate derived from manure than from fertilizer. As an example of the amount of phosphate in cycly on western European farms, it was noted that the total phosphate content of the fodder fed to livestock was 10 times greater than in the food consumed by the human population. If the nutrients in livestock wastes could be efficiently re-cycled on the farm, it would be of great importance for the conservation of some of the world's exploitable natural resources, and particularly of the phosphate resources.

The great difficulty in recycling the nutrients in livestock wastes is the prevention of soluble organic compounds getting into the drainage ditches and streams, for this causes very serious pollution. The spreading of manure or slurry on frozen or wet soil in winter or early spring is very likely to be the cause of run-off of these soluble organic wastes; but when the surface becomes dry in late spring or early summer, there is commonly little land available on which these wastes can be spread. If the amount of organic matter is reduced before spreading, by encouraging aerobic oxidation, it is likely that a considerable part of the nitrogen may be lost by denitrification; and it may turn out that with intensive livestock husbandry, attention should be concentrated on recycling phosphate and the other mineral elements, and allowing most of the carbon and nitrogen to be converted into gaseous products. It is quite clear that in future farmers following such systems of intensive livestock production will have to be prepared to spend much more money on the safe disposal of these animal wastes.

In some regions sewage sludge, or decomposable household waste that has been composted in a large municipal plant, is spread on the land, which helps to recycle the plant nutrients present in the organic wastes of modern human society. The problems of this method of disposal of domestic and industrial waste were not discussed, as they did not come within the Panel's terms of reference, but it was noted that sewage sludges may contain sufficiently high levels of heavy metals for their repeated use to poison the soil. Thus it is essential that, if a policy of sludge disposal on the land is to be adopted, all industrial electrolytic wastes, and other wastes containing potentially toxic elements in a soluble form, be treated separately from normal town sewage.

CONCLUSIONS

1. Fertilizers are essential for high yields per hectare, and for bringing many inherently poor soils into production.

2. The efficient use of fertilizers allows for the intensive cropping of high quality land, and the withdrawal of low quality land from cultivation.

3. If fertilizers are used efficiently, there is no evidence that they lower the nutritional quality of food, and under some conditions they will increase it.

4. If fertilizers are used efficiently, and good farm practices adopted, there is no evidence that they harm the soil.

5. The efficient use of fertilizers involves the adoption of farm practices that will allow the crops to make the best possible use of the added fertilizers. These practices include the correct choice of crop variety, plant population, time of sowing and planting, adequate disease, pest and weed control and suitable soil conservation practices.

6. The addition of phosphate fertilizers to soils has no biologically significant effect on the phosphate content of the water leaching through a soil, unless the soil is almost a pure sand, or is subject to flooding. However if phosphate fertilizer is added to the surface of a wet soil, and heavy rain follows, some of the phosphate may be carried off the soil with the run-off water.

7. The experimental evidence for the proportion of the nitrogen added in a fertilizer that percolates through the soil into the groundwater and streams draining the area is still poor. This is due to the technical difficulty of distinguishing between the nitrates in the water that have been directly derived from the fertilizer from those derived from other sources, especially from the mineralisation of soil organic matter. This latter source is often larger than the former.

8. There is still inadequate evidence on the fate of surplus inorganic nitrogen compounds that accumulate in the soil when the amount of nitrogen added as fertilizer is much larger than the amount taken up by the crop. This is because of the complete lack of knowledge of the proportion of this surplus that is lost to the atmosphere by denitrification in different soils that appear to be well-drained. However if a nitrogen fertilizer is added to a soil in spring before the crop has made appreciable growth, and sufficient rain falls to cause an appreciable amount of drainage to take place, a significant proportion of the nitrogen may be washed out into the drains or groundwater. This is also likely to happen if much nitrogen fertilizer is added in late autumn or winter to crops which are unable to take up much nitrogen at that time.

9. Very heavy use of nitrogen fertilizers on certain salad and leaf vegetable crops may raise their nitrate content to undesirable levels.

10. Water running off the land may carry away fine particles from the soil surface which have absorbed nutrients of the added fertilizer and thus enrich the nutrient content of surface waters. The use of fertilizers therefore should be combined with proper soil conservation practices.

11. The importance of fertilizer use for agricultural production warrant support being given to a continued monitoring of its effects on the environment, so should any unforeseen undesirable consequences arise, suitable action can be taken to minimize them.

RECOMMENDATIONS

As a result of its deliberations the expert group recommended that:

1. F.A.O. continue and expand its work of promoting the efficient (and correct) use of fertilizers, to help combat malnutrition by the increased production of high quality and nutritious foodstuffs, and so to help raise standards of living throughout the world.

2. F.A.O. draw the attention of land use planning officers to the possibility of using the increased production of foodstuffs made possible by the efficient use of fertilizers on high quality land to withdraw marginal land and land very liable to erosion from cultivation. Fine surface soil particles washed into rivers and lakes by erosion are a serious cause of pollution due to the plant nutrients they hold.

3. Experimental and extension workers continue to develop as a matter of urgency improved methods for maximising the uptake of nutrients added in fertilizers by improved farm practices, as for example, the use of high-yielding varieties of crops that are also pest and disease resistant, and by the selection of the most suitable form of the fertilizer, and the most suitable methods of application. In the case of nitrogen fertilizers, more research is desirable on the development of slow-acting nitrogen fertilizers so formulated that the rate of release of their nitrogen as nitrate during the growing season corresponds as closely as possible with the rate of uptake by the crop required for optimum production.

4. More attention be given to the consequences for the environment of changing the system of agriculture, due to the increased use of fertilizers. Two problems in particular need attention: the effect of such a change on the level of soil organic matter, and on the disposal of animal wastes when a more intensive system of livestock husbandry is introduced. It is particularly important to develop systems which allow the recycling on farms of the nutrients present in the animal wastes, and if possible in municipal wastes also, in such a way that there is a minimum risk of the organic wastes themselves entering the drainage system.

5. Cooperative research projects be developed between agricultural and nutritional scientists on the effects of the level of fertilizers used, and on the methods and times of their application, on the nutritional and market quality of foodstuffs; and in particular there should be cooperative work between these groups and public health and medical authorities to establish acceptable limits for, for example, the nitrate content of different foodstuffs.

6. Fertilizer use recommendations should take into account the undesirable effects of an irrational use of fertilizers, particularly excessively high use on farms where intensive livestock husbandry is practiced, and where wide-spaced crops with a poorly developed root system are grown. They should also take into account the possibility that, in some areas, their rational use may cause depletion in the soil of nutrients not contained in the fertilizers being applied.

7. More research be undertaken to establish the levels in soils and plants at which some heavy metals present in electrolytic and other industrial wastes become toxic to plant and animal life, and to develop methods for minimising the harmful effect of any of these metals should they begin to accumulate in the soil due to the use of sewage sludge or from any other causes.

8. More attention be given to research on establishing the complete nitrogen balance sheet for fields, with particular reference to the development of new techniques for measuring the magnitude of the various components. It is particularly important that more work be done on measuring the losses of nitrogen by denitrification, by leaching and by the volatilisation of ammonia from soils.

9. More attention be paid by research workers to determining the sources of the nutrient elements in all studies on the nutrient content of surface or ground-waters.

10. More research be undertaken on the factors that control the population density of algae and aquatic plants in water, to allow a more accurate assessment of the conditions under which farm wastes and percolates may influence the size or rate of multiplication of this population.

11. W.H.O. be requested to obtain the considered views of public health authorities on the hazards to the health of a community of different levels of nitrate in the drinking water, in view of the statement made that in the United States of America high nitrates in the drinking water have only caused serious trouble in babies already suffering from gastro-enteritis caused by a B. coliforme infection.

12. Accurate and adequate ancillary data on the physical environment should always accompany all research reports on the influence of fertilizer on the human environment. The type of data needed for the proper appreciation of such reports include a description of the kind of soil and its condition at relevant times, the system of farming being practiced and the hydrological regime during the course of the experiment. In particular, the correct names should be given to all the soils investigated in regions where a soil survey has been made.

13. Member governments should ensure that their agricultural extension services be kept up-to-date on all research findings relevant to the optimum use of fertilizers, both so that their farmers can obtain the maximum benefit from their efficient use, and also that any possible undesirable effects from their misuse can be minimised.

14. FAO continue to play an active role in assembling information on this topic and in pointing the way to improving the quality of the environment in an increasingly densely populated world. The expert group welcomed the initiative of SIDA in making this meeting possible and expresses the hope that further support would be extended to this field of work.

EFFECTS OF INTENSIVE FERTILIZER USE ON THE HUMAN ENVIRONMENT

A Summary Review

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Agriculture must come first in the path to national prosperity in the developing countries of the world. Establishment of a heavy industry base first will not meet the nutritional needs of the people manning the machines. It is further necessary that the entire agricultural enterprise be profit motivated for providing incentive to the native farmers concerned. Introduction of fertilizer has greater immediate impact than any other input for effecting the latter objective in most primitive farming situations. On the other hand, there is some evidence that excessive fertilizer use may cause deterioration in water quality with potential hazards to human health and the aesthetic environment. Thus, the fundamental responsibility of this Panel is to advise FAO in how far this international organization should support the extension of intensive fertilizer use into the developing world.

FERTILIZER BENEFITS TO THE HUMAN ENVIRONMENT

A logical first question to be answered in this summary concerns what is good about fertilizers, if anything, in relation to the human environment, prior to a look at the converse. Something other than a profit motive alone must have been responsible for the mushrooming production of fertilizer products that has taken place since World War II. The current world-wide consumption rate of fertilizer nutrients of 50 million metric tons (25) in contrast with 1/5 that amount 25 years earlier represents an approximate annual growth rate of 15 percent and strongly implies that some worthwhile results accrued from the development. Some of these follow.

Hope for a Food Hungry World

Dr. Norman Borlaug in accepting his Nobel Peace Prize in 1970 made a strong point of the fact that the work of many dedicated workers and the integration of several agricultural production practices were responsible for the recognition accorded him. The improved wheat varieties developed under his direction depended very heavily on improved water management practices, the use of adequate fertilizer, and measures for weed, disease and pest control.

In consequence of the breakthroughs achieved by CIMMYT, IRRI, IRI, CIAT, FAO, AID and others working in the developing countries a bright ray of hope began to appear in the late 1960's that the world's current 3.5 billion people could indeed be adequately fed with the technology in sight, a technology very heavily hinged to fertilizer use (13, 47). A few specific examples are (a) the complete or near satisfaction of country needs for wheat in Pakistan, India and Turkey from a previous situation of serious shortage coming from introduction of Mexican wheats and systems for their effective production; (b) satisfaction of rice requirements of the Philippines and vastly improved supplies of this staple food in several other countries of SE Asia by the miracle rice varieties of IRRI, again when properly managed with adequate fertilizer; (c) means developed for conversion of the Campo Serrada of Brazil and adjacent South American countries from very low productivity rangeland to productive cropland by appropriate fertilizer treatments through work of CIAT, IRI and others; and (d) demonstration by the Fertilizer Programme of FAO through hundreds of demonstrations and trials that production of food crops in the developing countries could be increased over 50 percent by simple introduction of the appropriate fertilizer treatment to the existing agricultural system (47). The Green Revolution is far more than a figment of someone's imagination, but will continue to evolve only as it is fueled with adequate nutrients.

Most will agree that the food problem is basically one of too many people. Major efforts must be made toward controlling the world population explosion as a final solution to freedom from hunger. In the meantime, humanity dictates that all of those now living should have an equal right to their 2500 ± calories per day with associated necessary protein and minerals. The continued existence of FAO is predicated upon this principle.

Soils are Improved by Fertilizers

Nature did very poorly by most soils found in humid regions of the world, especially those in subtropical and tropical areas where a majority of the people live. Inherent nutrient supplies commonly will allow only 2-3 years economic cropping followed by 20-30 years bush fallow. The pristine environment leaves very much to be desired in this case, and can be notably improved by the introduction of fertilizers (32).

It is quite fanciful to suggest that production of legumes and spreading of animal manures should be practiced for achieving the soil improvement objective on these poor soils. The quantities of manure required would not be available, nor would it be possible to get useful legumes to grow without extensive soil amendments. Even if it were possible to supply the amount of N needed by this procedure, its pollution potential would be just as great as that afforded presently from chemical sources.

Contrary to some contentions that fertilizers are destroying good soils, substantial evidence exists to the contrary. The humus and organic N contents of certain New Zealand and Australian soils have been increased by grass-legume pastures when adequately treated with P and S fertilizers (63). The Broadbalk plots of Rothamsted which have now received chemical fertilizers since 1843 are more productive today than at anytime in the recorded past. The same can be said for the soil of the Askov station in Denmark where chemical fertilizers proved more effective than the same amount of nutrients from organic sources over more than a half century period (5). The aggregating action from enhanced root proliferation and greater amount of decaying residues from well fertilized crops have actually helped make soils more friable, tillable and receptive to water. With the modern advent of extensive fertilizer use, an entirely new equilibrium relationship of soil nutrients has come into being (66), one in which the declining fertili process from cropping of the past has been reversed.

Granted that reports exist where $NaNO_3$ used as the source of N over extended periods has caused soil structure deterioration, this would be predicted today on the basis of the known deflocculating action of the Na ion. Fortunately, $NaNO_3$ has been an insignificant component of the fertilizer N market during the past two decades of rapid increase in fertilizer N consumption. Other cases of poor soil management exist for which fertilizers have sometimes been unjustly blamed.

Farming Efficiency is Improved by Fertilizers

The extensive-intensive type of farming as practised in the highly developed countries of the world, providing massive quantitites of food materials at minimum cost, would be quite impossible today without fertilizers. Without the benefit of fertilizers farmers would have to cover substantially more area to achieve the same total production and would necessarily break out lands which should never be cultivated. Foodstuffs would immediately become more expensive. Depending on soil conditions where grown and type of crop, the yield loss would be modest to very severe in the first year fertilizer was excluded, magnitude of loss reflecting how much residual fertility had been stored. Table 1 summarizes first year losses that could be expected on a few important crops of the U.S. Additional percentage losses would occur with each succeeding year until some much lower equilibrium level of production was reached.

Table 1. Effect of eliminating N and P fertilizers on yield loss for agricultural subregions of the U.S. (28).

Crop	Agricultural subregion	Fertilizer used		First year loss (1964) from excluding fertilizer
		N	P	
		kg/ha		%
Maize	S. E. Iowa	77	20	20
	E. C. Illinois	73	19	37
Vegetables	Delaware	35	31	43
Wheat	W. & C. Kansas	34	9	11
Rice	C. Valley Calif.	102	16	49
Potatoes	S. Idaho	141	45	36
Celery	C. Florida	113	98	69

Crop Quality Improved by Fertilizer

The mineral, protein and vitamin contents of crops may be improved as judicious fertilization corrects a previously existing inadequate level of nutrient availability (48). Baking quality of wheat flour and the color, crispness and textural character of various vegetable crops are often beneficially influenced by appropriate fertilization. There is no assurance, however, that optimum growth of a given plant assures adequacy of all mineral elements in it for the nutrition of animals or man. Different species of plants vary greatly in their mineral concentrations as do varieties within a species. Moreover, mammalian requirements for specific nutrients vary with stage of maturity and with gestation periods among adults.

Nitrogen fertilization of nonlegume crops will usually increase protein levels with rates at and above that required for maximum yield. The increases so effected, however, will never convert a low protein grain such as grain sorghum to the level attainable in an inherently higher protein crop like wheat. The data of Fig. 1 in a dryfarming situation (42) are representative. Neither is there any probability that the protein quality of the fertilized crop will be improved, i.e., the ratio of essential amino acids (required by monogastric animals including man) to the total present (48). An exception, of course, is the case of the ruminant animals which are capable of synthesizing their own required amino acids, and in this case, with improved plant protein production from fertilization a greater production of both milk and meat products and more essential amino acids result. As pointed out by Allaway (1) the diets of high quality protein in people of New Zealand is indirectly due to effective pasture and forage crop fertilization as practised in that country.

There are many cases of record where fertilization of crops with P, Mg, S, Co, Cu, Mo, Se has reduced or eliminated deficiencies in diets of animals consuming the crops (1). Large areas of the western U.S., Australia and New Zealand have been opened to effective livestock production by discovery of the required nutritional roles served by certain of these elements added as fertilizer.

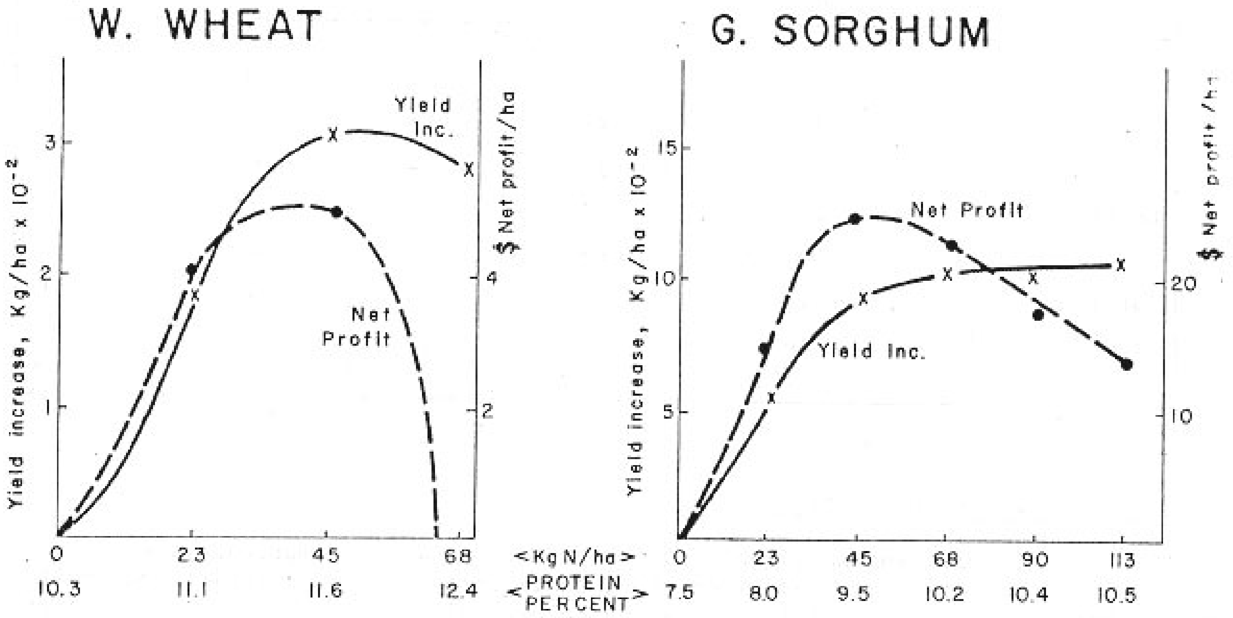

Figure 1 Response of winter wheat and grain sorghum to varied rate of N fertilizer under dryfarming conditions in western Nebraska (10 experiments on grain sorghum, 1959-62, and 54 experiments on winter wheat, 1952-67; calculations based on wheat valued at $2.20 and grain sorghum at $1.30/cwt, nitrogen at 22¢/kg.)

Effective Fertilizer Use Retards Erosion

A well fertilized soil supporting a thriftily growing crop is much less erosion prone in sloping positions than a corresponding soil supporting a poor crop. The greater surface canopy for protection against wind and water action and the greater binding action of a more prolific root system accompanying the crop that enjoys adequate nutrition are initially responsible. The residual effects of the greater organic production are significant, too, in the improved soil aggregation imparted by the larger quantity of fresh organic return.

It is well recognized that sediment from agricultural lands is a prime source of water pollution, both from the sediment itself and the nutrients adsorbed on clay particles or contained as part of organic molecules. Thus, Wadleigh (60) reports an average annual sediment burden of the Mississippi River of 500 million short tons containing 500,000 tons of N and 750,000 tons of P_2O_5. Fertilizer use enters the picture in a different context here by allowing intensive production on better soils of favourable topography thereby making it possible to relegate inaccessible parcels and highly erosive soil areas to permanent cover. This not only promotes efficiency in the farming operation but can additionally result in pollution abatement by keeping erosional sediments out of the streams.

Effective Fertilization Conserves Water

Agriculture is being increasingly pinched in the developed countries of the world for the share of water that can be devoted to it. The problem is particularly acute in the drier farming regions where crop production is heavily dependent on irrigation practice. A similar problem is certain to become evident with increasing affluence, and accompanying heavy use of water, in the developing nations.

Earlier papers of this Panel have delved into the interactions between fertilizer N and water management. The literature cited there makes it quite clear that fertilizer will not substitute for water. The water cooled engine of a crop plant is not very efficient in its transpirational process supporting photo-synthesis in any case, but is vastly improved when transformed from a state of starvation to thrifty growth by judicious fertilization. Where water is in short supply and can be controlled, then, it is essential that something approaching the economic maximum of plant material be produced to assure a high water use efficiency. This objective will be achieved only with a well nourished plant.

Fertilizers Promote Air Purification

Physiologists stress the role of living plants in air purification, absorbing CO_2 from the atmosphere for use in the photosynthesis of carbohydrates, and releasing O_2. Smith (50) has estimated that some 18.5 short tons of CO_2 is removed from the atmosphere over a maize field producing 6 300 kg grain/ha as approximately 15 tons O_2 is released. This hectare of maize would produce enough oxygen in a year for about 30 people. Stimulated vegetative production with the aid of fertilizers clearly means more fresh air for mankind, a real bonus as we take inventory of the increasing amounts of CO_2 that man's ever expanding activities are releasing to the atmosphere.

Other volatiles of air contamination such as SO_2 and NH_3 are additionally absorbed from the air in proportion to the total growth of crop. The crop plant growing thriftily with adequate available N, P and K will always prove a better 'atmosphere scrubber' than a spindling, starving plant. Cropping is perhaps the only production process known to actually improve the surrounding environment as the end product develops.

DAMAGES CAUSED BY FERTILIZERS TO THE HUMAN ENVIRONMENT

How serious is the impact that fertilizer technology may be having on the environment? Some claims of dire consequences have been levelled against fertilizers, and most particularly against the nitrogen sector (7). The most commonly cited hazards are the eutrophication of surface waters, the toxicity potentials of high NO_3 - levels in ground and surface waters, crop damage, and ruination of soils by destruction of the natural N cycle.

Damage to Crops

Fertilizer use at excessive rates has been known to have deleterious effects on crop growth. Examples are the lodging of small grains and the low sugar content of sugar beets from excessive N, nutritional disorders involving such trace elements as Zn and Fe incurred by excessive P fertilizer and lime, damaging salt effects on seed germination and seedling injury from too much soluble fertilizer salt adjacent to the seed row, acidifying action of excessive fertilizer N on soil and induced Al and Mn toxicities when compansating lime is not applied, increased incidence of plant disease and pest attacks with excessive N, etc. Jaag (29) in his report to this Panel notes a new concept in plant nutrition evolved by Voisin and Matile to complement Liebig's"Law of the Minimum" which would be called the "Law of Maximum". Its purpose is to establish fertilizer rate ceilings above which losses in quantity as well as quality of crops could be expected.

Damage to Soil Micro- and Macro-organisms

Lately some argument in favour of organic manuring has centered around the fate of the earthworm with intensive fertilization. It is possible to demonstrate the lethal effects of fertilizer salts and anhydrous ammonia when applied in contact with a living worm. But it is only a very small portion of the soil habitat occupied by worms that applied fertilizers directly contact, and the proportion of the total population detrimentally affected is small. Of far greater significance to the earthworm is the greater supply of fresh organic material for its sustenance afforded through fertilization. Size and numbers of earthworms invariably increase as soils are brought from a low to high level of fertility through effective fertilization.

Heavy use of N fertilizer is known to be inimical to the activity of symbiotic N fixing organisms such as Rhizobium sp. The legume plant well supplied with soil and fertilizer N is not a very efficient N fixer. We can perhaps best pin the blame in this matter to the lazy character of the symbiotic relationship than to the N fertilizer. Farmers do need to recognize the situation and to limit N fertilizer use prior to growth of the legume if they are to obtain maximum benefit from the free N source.

Contention has also been made that fertilizer use, most particularly N, will inhibit soils' capacity to nitrify N from the native organic matter source. Numerous studies have demonstrated the beneficial effects to nitrification derived from providing deficient nutrients as P, Ca and N to the soil. The many kinds of organisms supporting or competing with the nitrification process require a N supply just as do higher plants. In the absence of a sufficient N level with plentiful carbonaceous material present, i.e., a high C/N ratio of the total soil environment, there will be essentially no release of available N through nitrification for crop use because the microorganisms 'eat at the first table'. On the other hand, NO_3 - release from organic sources is enhanced with soil N levels maintained high enough for economic crop production.

To say that extended fertilizer use results in sterile, unproductive soil is to disregard the long term results of Rothamsted's Broadbalk plots, the Askov field of Denmark, and others. The two fields mentioned have not only demonstrated the effectiveness of inorganic fertilizers for maintaining productivity, but have shown equivalence if not superiority of the inorganic source when compared with equal amounts of nutrients added as manure.

The Eutrophication Process

Much has been written and said concerning eutrophication in this Panel session. None will disagree that it is an unsightly process that degrades the aesthetic qualities of surface water bodies that traditionally provide the base for summer water sports. Degradation may be in respect of excessive algal scum and aquatic weeds as well as undesirable color, taste and odor of the water. Nor can anyone dispute that eutrophication is a natural process which has gone on for ages as evidenced by the tremendous areas of peat bogs found in the higher latitudes which were created prior to the advent of modern man on the scene. We can see the process taking place even today in wilderness areas where man's agricultural technologies have not yet been expressed.

Factors that have been pinpointed as triggering the eutrophication process are nutrient enrichment (54), especially P and N, a carbon source of CO_2, favourable temperature and non-turbid water. If the latter three are favourable and nutrient concentrations reach 0.3 ppm N + and 10 ppb P the algal and various water plant growths are likely to follow (23). Other nutrients are involved as well, just as with higher plants, although K^+ concentration has probably never limited the eutrophication process (21). Not to be overlooked is the fact that shallow farm ponds devoted to commercial fish production will commonly receive in the order of 80-100 kg/ha of each of N and P_2O_5 annually to assure the growth of plankton and other water plants that will allow economic fish production. These rates applied at one time produce N and P concentrations in the water well in excess of those specified above.

Although N and P concentrations have dominant influence on stream or lake productivity, others including trace element nutrients are involved and definition of the significance of any single nutrient to the water-nutrient-plant-animal system is difficult (15).

A major source of most nutrients found in surface waters is in sediments dislodged and carried in runoff from the soil surface. The organic fraction with its substantially higher cation exchange capacity than possessed by soil mineral particles is particularly significant in this regard. Moreover, the organic fraction by some obscure complexing reaction protects a number of trace elements from precipitation reactions that would remove them from the nutritionally available status (38). In fact, there is increasing evidence that organic material from livestock or other sources must be added to the water, supplying energy material for bacteria that would generate CO_2 for the photosynthetic algae, for triggering the eutrophication process (17).

In areas of limited leaching during soil formation and especially where soil forming materials were initially high in nutrients (as with most loess), P and N levels in impounded waters are almost certain to be more than adequate to support eutrophication. Thus, sampling ground water from some 1200 irrigation wells in semiarid/subhumid Nebraska (33) showed an average concentration of 0.25 ppm P, far more than enough to support eutrophication once the water was impounded and sufficiently warmed.

Nutrients in Water and Foods Inimical to Human and Animal Welfare

Many factors of chemical, physical and biological character contribute to water quality, and what is high quality water for one segment of society may be quite undesirable to another. The basic theme of this Panel in dealing with fertilizer contributions to quality degradation, however, consideration is given only to those aspects of mineral concentration that might be influenced by fertilizer and most particularly nitrogen.

A permissible level of no more than 10 ppm NO_3^- plus NO_2^- N has been established for water to be used for human consumption in the U.S. (57), not because of the toxicity of NO_3 but due to the possibility of the NO_3^- being reduced to NO_2^- after ingestion. The latter combining with hemoglobin in the blood produces methemoglobin, reducing the capacity of the blood to transport oxygen. Local state law in California allows up to 20 ppm with continuous surveillance [1]. It is generally recognized now that many cases in infants previously diagnosed as methemoglobinemia were likely confounded with enteric infection from water containing fecal contamination (59). The question of what is acceptable NO_3^- concentration of water remains a debatable issue for humans since no reports of methemoglobinemia have been made of infants drinking from public water supply systems in the United States. It is even more conjectural in the case of animals, but perhaps higher by a factor of 4-5.

Nitrate levels have similarly been established for various fresh vegetables and for canned baby foods from natural sources as well as NO_3^- + NO_2^- in preserved fish and meats. The vegetables spinach, celery, lettuce and kale have a substantial capacity to accumulate nitrate, as do such forages as sudan grass, annual grasses, immature cereals and maize cut for silage. Some weed species as pigweed are also notable accumulators of NO_3^-. A factor that must be considered in this connection is that man in the developed countries eats a variety of foods such that consumption of substantial NO_3 from a given source is not likely, whereas dairy cattle eat much of a single source of food material over extended periods of time. Not only are man and animal subject to nitrate/nitrite toxicity from high NO_3^- crop produce, but lethal NO, NO_2 and N_2O_4 may be produced when forages high in NO_3^- are ensiled. A further danger is the possibility of NO_2^- in high NO_3^- vegetables reacting with secondary amines to produce nitrosamines. Substantial evidence exists for a decreased shelflife of various fruits and vegetables, for loss in flavour of some commodities, for increased contents of undesired free amino acids, and for decreased ascorbic acid and K contents of produce when excessive fertilizer N has been used, the problems being notably worse with some cultivars than others (48).

Deficiency of Mg has been recognized as a major problem in the nutrition of cattle in many different regions of the world. It is one of many factors responsible for "grass tetany" noticed especially in lactating cows grazing certain grasses during cool seasons. The problem is commonly associated with a wide ratio of K to Mg in the grass and is accentuated by very high soil levels of available K relative to Mg. Heavy fertilization with K salts or manure has been known to bring on the malady. It should be mentioned, however, that many serious outbreaks have been recorded in areas where no K fertilizers have been used and the understanding of all causes remains a complex problem (22).

Excessive rates of P fertilizer have been known to cause substantial reduction in the above-ground concentration of such elements as Fe and Zn in plants. In many cases of record, particularly on soils of high pH, the reduction has been great enough to cause depressions in crop yield. The elements Fe and Zn being essential for animals as well, it is conceivable that heavy P fertilization could reduce animal intake to deficiency levels although no cases have been recorded to date (1).

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[1] WHO recommended standards for drinking water in Europe are: 0-11.3 ppm $NO_3 - N$ recommended, 11.3 - 22.6 ppm acceptable, and above 22.6 ppm not recommended.

A permissible level of no more than 10 ppm NO_3^- plus NO_2^- N has been established for water to be used for human consumption in the U.S. (57), not because of the toxicity of NO_3 but due to the possibility of the NO_3^- being reduced to NO_2^- after ingestion. The latter combining with hemoglobin in the blood produces methemoglobin, reducing the capacity of the blood to transport oxygen. Local state law in California allows up to 20 ppm with continuous surveillance [1/]. It is generally recognized now that many cases in infants previously diagnosed as methemoglobinemia were likely confounded with enteric infection from water containing fecal contamination (59). The question of what is acceptable NO_3^- concentration of water remains a debatable issue for humans since no reports of methemoglobinemia have been made of infants drinking from public water supply systems in the United States. It is even more conjectural in the case of animals, but perhaps higher by a factor of 4-5.

Nitrate levels have similarly been established for various fresh vegetables and for canned baby foods from natural sources as well as NO_3^- + NO_2^- in preserved fish and meats. The vegetables spinach, celery, lettuce and kale have a substantial capacity to accumulate nitrate, as do such forages as sudan grass, annual grasses, immature cereals and maize out for silage. Some weed species as pigweed are also notable accumulators of NO_3^-. A factor that must be considered in this connection is that man in the developed countries eats a variety of foods such that consumption of substantial NO_3 from a given source is not likely, whereas dairy cattle eat much of a single source of food material over extended periods of time. Not only are man and animal subject to nitrate/nitrite toxicity from high NO_3^- crop produce, but lethal NO, NO_2 and N_2O_4 may be produced when forages high in NO_3^- are ensiled. A further danger is the possibility of NO_2^- in high NO_3^- vegetables reacting with secondary amines to produce nitrosamines. Substantial evidence exists for a decreased shelflife of various fruits and vegetables, for loss in flavour of some commodities, for increased contents of undesired free amino acids, and for decreased ascorbic acid and K contents of produce when excessive fertilizer N has been used, the problems being notably worse with some cultivars than others (48).

Deficiency of Mg has been recognized as a major problem in the nutrition of cattle in many different regions of the world. It is one of many factors responsible for "grass tetany" noticed especially in lactating cows grazing certain grasses during cool seasons. The problem is commonly associated with a wide ratio of K to Mg in the grass and is accentuated by very high soil levels of available K relative to Mg. Heavy fertilization with K salts or manure has been known to bring on the malady. It should be mentioned, however, that many serious outbreaks have been recorded in areas where no K fertilizers have been used and the understanding of all causes remains a complex problem (22).

Excessive rates of P fertilizer have been known to cause substantial reduction in the above-ground concentration of such elements as Fe and Zn in plants. In many cases of record, particularly on soils of high pH, the reduction has been great enough to cause depressions in crop yield. The elements Fe and Zn being essential for animals as well, it is conceivable that heavy P fertilization could reduce animal intake to deficiency levels although no cases have been recorded to date (1).

[1/] WHO recommended standards for drinking water in Europe are: 0-11.3 ppm NO_3 - N recommended, 11.3 - 22.6 ppm acceptable, and above 22.6 ppm not recommended.

Table 2. Estimated amounts of nutrients contributed from various sources for water supplies of the U.S. (37).

Nutrient Source	Nitrogen	Phosphorus
	Millions of kg/year	
Domestic waste	500 - 730	91 - 227
Industrial waste	455	
Rural runoff		
Agricultural land	680 - 6800	55 - 550
Nonagricultural land	180 - 860	68 - 340
Farm animal waste	455	
Urban runoff	50 - 500	5 - 77
Rainfall	14 - 270	1.4- 4

Study of the Potomac River watershed (61), on the other hand, gave indication of a substantially lower agricultural contribtuion of nutrients than proposed in Table 2. Some 24 million pounds of N and 8 million pounds P were reported as being released annually into the Potomac from sewage plants of Washington, D.C. Between January and August, 1969, only 34 percent of the N and 14 percent of the P in the river came from the 12,000 square mile Potomac watershed above the city and considerable of these amounts could be attributed to sewer facilities of smaller towns upstream.

The high phosphate detergents have had their day in court and been found guilty. They have been a predominant contributor to P pollution of streams in most countries of the developed world and are presently being replaced by other materials of lower P concentration, with much concern now being expressed on potential hazards of the substitutes compared with the former highly efficient phosphate detergents. The summary of nutrient sources in Table 3 for surface waters of the state of Wisconsin emphasizes the need for removing the detergent contribution to the 58 percent of total P coming from municipal and private sewage facilities. U.S. estimates as well as those of Jaag (29) in Switzerland suggest that about half of the sewage P came from detergent source. Alternatively, tertiary treatment would seemingly be called for at early date with substantial increase in taxes for building the treatment facilities. The large loss of N and P from manured lands is due to manure having been spread on frozen soil, a practice to be discouraged. The 42 percent of N in surface waters coming from groundwater suggests that agricultural drainage is supplying a substantial proportion of the total.

Soluble P concentration in streams tends to increase with increasing water flow, presumably due to stirring up of bottom sediments containing relatively soluble ferrous phosphate.(61). Nitrogen also tends to be higher during spring months of temperate regions. Various explanations have been given, but certainly accelerated runoff in the spring from urban areas and feedlots as well as farmed land must have contributed to the portion coming from groundwater.

Table 3. Estimates of sources of plant nutrients entering Wisconsin surface waters (8).

Source	N	P
	%	
Municipal treatment facilities	24.5	55.7
Private sewage systems	5.9	2.2
Industrial wastes	1.8	0.8
Rural sources:		
Manured lands	9.9	21.5
Other cropland	0.7	3.1
Forest land	0.5	0.3
Pasture, woodlot and other lands	0.7	2.9
Groundwater	42.0	2.3
Urban runoff	5.5	10.0
Rainfall on water areas	8.5	1.2

Substantial inorganic P can find its way to streams originating from plant residues through which runoff waters had penetrated in the spring (26). Especially did snow melt water carry higher amounts of P than runoff during other parts of the year, explainable by the fact that frozen soil below allowed minimal contact between the water and soil particles for P adsorption. The lucerne crop with an appreciable organic mat on the surface afforded 3.5 times as much runoff P as water from maize stubble. Such residue source of runoff P certainly cannot be ascribed to fertilizer.

There does not seem to be a significant problem of phosphate fertilizer materials moving to streams and groundwater except as erosional sediments bearing adsorbed P are washed into water courses (31), nor is there likelihood of appreciable K^+ being leached to the groundwater other than through very sandy soils (21). Highly significant is the fact that soluble phosphate concentration of the Kaskaskia River at Shelbyville, Illinois, has remained virtually constant since 1962, a period during which fertilizer P consumption has tripled (24).

Much of the discussion that follows deals with N accumulations since it is an element about the use of which concern has been voiced. There are numerous cases of record of excessively high mineral N contents of ground and surface waters. It is especially important that primary source(s) be recognized for environmental protection as well as protection of any accused innocents.

As pointed out by Viets and Hageman (59), the concentration of feedlot animals into very limited areas, for example in the order of 800 cattle/hectare, has greatly accentuated the pollution control problem associated with animal wastes. The approximate 1.8 billion metric tons of manure (solid plus liquid) produced annually in the U.S. by domestic animals, each cow producing the approximate sewage of 12-16 people, would necessitate sewage plant facilities far in excess of those now existing for the urban population if the wastes were to be so handled. Such an analogy is hardly appropriate in this case, however, since a major portion of the constituents of manure in properly managed feedlots never reaches water courses or groundwater due to surface decomposition, if not incorporated with soil as fertilizer. Concentrations of nutrients contained in animal wastes vary widely depending on type of animal, ration provided the animal, climatic conditions and methods of handling the manure (46). The value of N, P and K contained in manure for crop growth has long been known, but additional potential pollution hazards are various diet additives including Cu, Zn, As and NaCl as well as pesticides and growth hormones. Plant and animal pathogens and undesirable weed seeds may also be disseminated in animal wastes. Aside from the accumulated manure itself, runoff from beef cattle feedlots will often contain very substantial amounts of NO_3^- (19) and presumably other water soluble pollutants. Substantial amounts of NO_3^- may accumulate in the soil below the feedlots (Table 4), as well as in farm water supply systems.(53). Substances which were traced in leaching from feedlots were recognized as the primary source of high NO_3^- in the aquifers studied. Smith (50) in Missouri similarly recognized that local groundwater accumulations of N were associated with concentrations of feedlot animals. The latter two groups of researchers contended that fertilizer N has not contributed significantly to NO_3^- buildup to date, but could become a factor in the future with ever increasing amounts of fertilizer N consumed.

Significant quantities of NO_3^- found in streams can most likely be attributed to seepage from the groundwater or to wastes from cities, feedlots or industries. Less important would be that derived by runoff from soil surfaces by reason of the ready movement of NO_3^- ions downward through soil media. Few cases exist of consistently increasing NO_3^- contents of U.S. streams where fertilizer use on agricultural lands adjacent can be documented as responsible. Perhaps the most comprehensive study that has been made is that of the U.S. Salinity Laboratory (6) in the Upper Rio Grande watershed of New Mexico over the approximate 30 year period of 1934-1963. During this time fertilizer N use on the adjacent irrigated valley land increased many-fold while a substantial decline occurred in the river's NO_3^- load, with the decline being attributed to a decreased river flow. Similarly, nitrate concentrations did not increase in the majority of 17 British streams studied during the period 1953-1967 despite a substantial increase in fertilizer use during the period (23).

Table 4. Average NO_3^- N in the surface 6.5 meters of soil and in the water table below in Colorado (53).

Land use	Profiles sampled	NO_3^- N in 6.5 m of soil	Water tables sampled below	Ground-water NO_3^--N
		kg/ha	no.	ppm
Native grassland	17	101	8	11.5
Dry farming cropland	21	294	4	7.4
Irrigated land				
Excluding alfalfa	28	569	19	11.1
In alfalfa	13	89	11	9.5
Feedlots	47	1,616	33	13.4

Considerable of the recorded data on mineral N contents of surface waters is of questionable value due to the manner of sample processing. It is also important to recognize that 'grab' samples are not especially meaningful in expressing trends of NH_4^+ and NO_3^- loads in streams since quantities found vary tremendously over short time intervals depending on input into the stream above the sample site (62). Concentrations in surface waters tend to vary much more over short distances than in groundwaters due to micro and macroorganism assimilation. A further confounding factor suggested by Viets (58) is that increasing NO_3^- measurements in a stream over time may reflect evidence of the elimination of organic pollution by raw sewage. As BOD associated with sewage is eliminated by effective digestion in sewage plants, more NO_3^- appears in the water. Ultimate solution to this dilemma with increasing numbers of people requires tertiary and much more costly treatment for removing the NO_3^-.

Work of Stout and Burau (56) in California indicated that level of soil fertility was a prime factor influencing NO_3^- concentration of the groundwater below, and that concentration was in proportion to the fraction of applied water passing below the root zone. The study also showed that contaminated irrigation water can be purified by crops if fertilization is adjusted to crop need.

Irrigation of soils in the drier regions is perhaps as much responsible as any other factor for those cases where increased NO_3^- concentration of the groundwater has been observed. Reason for this is not so much a result of composition of the irrigation water itself or fertilization associated with irrigation practice, but rather that some of the very substantial amounts of N coming from decay of the native soil organic matter incident to cultivation moves through with the water.

Contributing locally have been large amounts of ancient nitrate present in the soil profile above the water table. Thus, Glandon and Beck (20) suggest that these high residuals account for larger quantities of nitrogen in drainage waters of California than was provided by fertilizers. Similar observations have been made locally in irrigated

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Kohl et al. (34) have recently attempted to distinguish sources of NO_3^- in Illinois streams by isotopic distribution of ^{15}N and ^{14}N. The approach presumes that fertilizer N has the same isotopic ratio as atmospheric N, while N of biological soil origin is enriched in ^{15}N. Based on ratios measured on drainage water from tile lines and surface waters in an Illinois watershed they estimated that 55-60 percent of the NO_3^- found originated from fertilizer N. A questionable aspect of the interpretations made is that mineralized NO_3^-, which was used as the base for comparison, was generated from soil collected at a single site in the watershed. Delwiche and Steyn (10), for example, have demonstrated that soil N has no fixed isotope ratio due to the complexity of the N transformations involved, which would suggest that quite a range in isotope ratios might have been obtained had nitrified N from many locations in the watershed been measured.

Unquestionably, excessive amounts of N fertilizer have been applied locally, and in particular for speciality crops of very high harvest value like vegetables for the fresh market, citrus and other fruits, and the nut crops. The Arroya-Grande-Grover City area of California is a case in point where average annual application of N for strawberries was reported to be 163 kg/ha and for celery 326 kg (64). Nitrate concentration of the shallow groundwater in this area is very high. Similarly, Bingham et al. (4) report an average 146 kg N/ha being applied to a small watershed devoted to citrus production in southern California with NO_3^- in the percolate equaling about 45 percent of the N applied. The USDA SRS report showing Nebraska with the highest rate of N use on maize of all states in the U.S. in 1968 at 168 kg/ha suggests that a number of farmers have been using rates well in excess of need, presumably due to low cost of fertilizer. Some lessons have been learned too well in places, in this case crop removal vs return, for which some unlearning will be required. A case in point is the state of Illinois which in 1970 added 29 percent more N and 67 percent more P than was harvested in crops (65). We cannot condone cases of known excesses, and must strongly advocate that all industry and agricultural advisory services adjust N rate recommendations to realistic levels. The developing countries, on the other hand, are far below the use levels employed in developed countries of the world and there should be no cause for concern in the foreseeable future if for no other reason than the cost of N there.

Rate of fertilizer N should afford best return in quantity and quality of crop and at the same time minimize loss to the environment. Some agronomists are now suggesting that yield levels in the order of 90 percent of potential should be the objective where fertilizer N is involved because of the rapid decline in utilization efficiency that accompanies rates approaching and above the economic maximum. An additional reason that has been cited by Schuphan(48) is the need with some crops to apply a N rate below the level required for maximum yield in order to assure best biological value of the produce. As nominal rates of N are employed, time of application of the N becomes of the essence because the longer the residence of fertilizer N in soil before root uptake the greater is the probability of its loss by one mechanism or another. Consequently, the same yield can be produced with less N the closer application time can be adjusted to the time of maximum crop demand (35, 43). Loss potential of greatest concern from the environmental standpoint is that from leaching. Greatest likelihood of leaching loss to the groundwater can be anticipated with coarse textured soils that are well aerated from the surface to the water table, and least in those poorly drained types in which denitrification can occur during and immediately after periods of rain or irrigation. Otherwise, there is not likely to be significant leaching loss of NO_3^- during the growing season of temperate regions since rate of crop water use normally exceeds rainfall received during that period. This principle may not hold for tropical regions, however, where the crop grows during the rainy season (17). Losses are also related to the kind of cropping practised, with least loss occurring with grass production (30).

In the event detrimental effects from widespread use of N and P fertilizers do become apparent, we know of several ways to reduce losses without sacrificing the very important benefits to be derived from fertilizers (39). Rates and times of N application can be adjusted to better satisfy the crop's needs without loss potentials (30, 43, 44), delayed release N products can be employed (44), better control of irrigation water can be achieved, and improved soil conservation practices can be used to retard surface losses of soil N and P (32). Calibration of soil testing procedures with the majority of nutrient elements has progressed to the stage that we can confidently predict not only deficiency but excess levels of nutrients in the rooting profile for specified crops: we have only to give credence to these calibrations and abide by them.

CONCLUSIONS

Clearly, fertilizers have done much toward making this world a better place in which to live. They are presently and will become increasingly indispensable for providing food for those now living and the generations to come. The long-term evidence that is available far from proving that fertilizers are damaging to soils and their organic reserves shows the contrary. Less apparent but genuine benefits derived from proper fertilizer use are an enhanced water use efficiency and a cleaner atmosphere from the better crop growth achieved. Abuses to the environment have been induced by excessive fertilizer use in certain localities, and it is important that correction be effected in these cases. On a world-wide basis, however, it seems reasonable to predict there would be a strong backlash to the environmental crusade if food became more dear through restrictions on fertilizer use.

What may be envisaged as requirements for the future to preserve the integrity of the environment insofar as fertilizer use is concerned? In my humble opinion, the two key words are moderation and monitoring. Neither will be too difficult to put into practice. The underlying question will revolve around how much we are willing to pay to accomplish the objective.

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MAXIMIZING THE UTILIZATION EFFICIENCY OF FERTILIZER N BY SOIL AND CROP MANAGEMENT *

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Introduction

Fertilizer N at some 27 million metric tons is the most extensively required and used nutrient world-wide for economic crop production. With projections of a doubled consumption in the next 15 years, it clearly constitutes a major input cost for the world's farmers.

Evidence of the impact of fertilizer N on modern crop production is presented in Figure 1 (updated from Barber and Olson, 1968). It is obvious that fertilizer N played a major role in the near tripling of state average yields which occurred between 1948-1970 in Nebraska and Indiana representing the western and eastern portions of the Corn Belt, U.S.A. Other technological advances during the period undoubtedly contributed to the portrayed yield improvements including improved hybrids, better tillage and weed control methods, expanded irrigation development, etc., but the N contribution was predominant. Implications for the developing countries of the world are clearly apparent.

With the emphasis that has recently been placed on environmental quality, and in special consideration of the mobility of N in soil, it is essential that fertilizer N management be directed toward maximum crop utilization efficiency. It will be the objective of this paper to detail practices which have proved effective to this end.

Impact of Cultivation on Soil N

Many investigators have reported sharp declines in soil C and N from the native state after land has been placed under cultivation. Thus, Haas et al. (1957) report an average loss of 39 percent of the N from the virgin surface soil of 14 locations in a subhumid temperate region over a 36-year cropping period, or slightly more than one percent loss per year of cultivation. They also reported loss of 15 percent of the total N in the 15-30 cm depth of soil from 35 years' cropping at seven locations. This and other similar studies have demonstrated a linear decline of N with time for 30-50 years in temperate regions when a new and substantially lower equilibrium level is reached. The decline in N involved invariably greatly exceeds the amount of N taken off in crops and thus suggests other avenues of loss, predominant among which are removal by erosion, leaching of nitrate, volatilization of ammonia and denitrification.

Nitrate leaching depends on a number of factors, most important of which, according to Allison (1965), are: (1) Amount and form of soluble and unadsorbed N present or added; (2) time and amount of rainfall; (3) infiltration and percolation rates, both markedly influenced by soil physical properties and tillage practice; (4) soil water holding capacity and profile moisture content when rain or irrigation occurs; (5) character of crop, if present; (6) amount of evapotranspiration; (7) N removal rate by the crop; (8) extent of upward N movement during drouth periods; and (9) extent to which N is leached below the root zone. Allison as well as Nelson and Uhland (1955) have expressed the belief that leaching losses generally occur when no crop is growing on the soil and that precipitation in a subhumid temperate region as expressed in midwestern U.S.A. is usually inadequate to cause significant leaching during the growing season.

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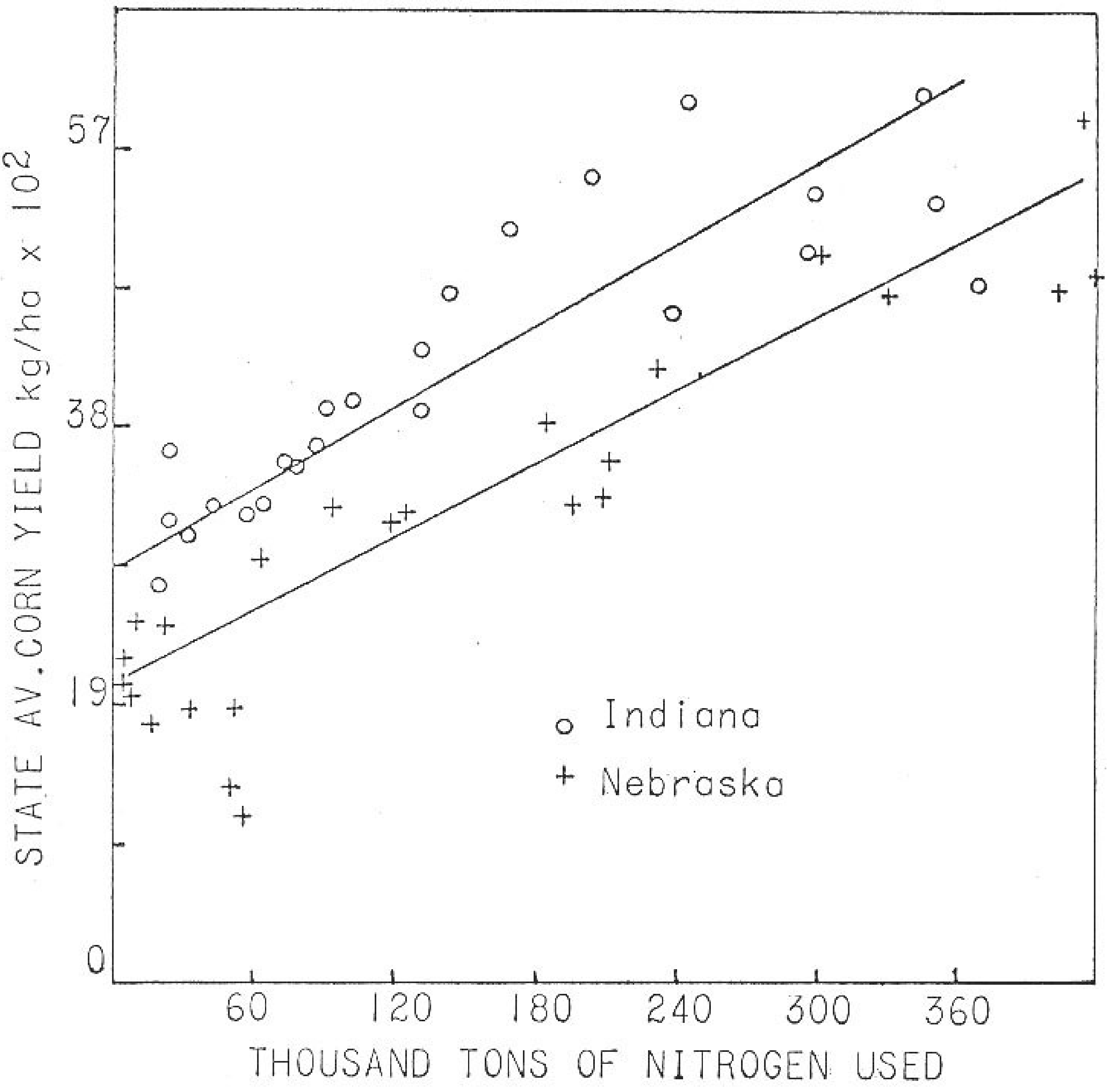

Fig. 1. Relation between nitrogen use and state average maize yields for Indiana & Nebraska in the period 1948-1970.

Irrespective of the chemical form added as fertilizer, N is readily converted into NO_3^- under aerobic conditions and is then readily leachable, especially in the fall and spring months in the absence of an established crop root system.

Volatilization losses of N can occur in several ways, including evolution as molecular ammonia from NH_4^+ sources, and as N_2 and N_2O from biological and 'chemical' denitrification of NO_3^- and NO_2^- sources. Ammonia losses are most likely to occur from surface applications of NH_4^+ -containing or producing materials to soils of high pH, while N_2 and N_2O volatilization is especially associated with low oxygen tensions accompanying poor drainage.

In a summary of 51 lysimeter studies involving cropping to non-legumes in the U.S., Allison (1955) concluded that 15 percent or more of the total N applied was unexplainably lost, above and beyond that found in percolating waters, and presumably due to volatilization. Viets (1960) reported some notably larger unexplained losses, in the range of 20-92 percent of the N applied, in a series of long term field experiments in the western U.S. Greatest losses were noted on fine textured calcareous soils in which aeration could be poor following rain or irrigation.

Loss of N with eroded sediments from cultivated land varies from insignificant at non-erosive sites to very great where wind or water removals are large. Much of the removal in this case is in the form of very finely divided soil organic matter particles containing N and as adsorbed NH_4^+ on fine mineral particles.

Result of the combination of these losses is that economic agricultural production requires the use of supplemental N of one sort or another in a relatively few years after intensive cultivation begins. The simple act of removing the indigenous vegetation and exposing the bare soil to the elements by cropping constitutes a breach of the natural regime with concomitant reduction in the soil's capacity for holding N in virtually all situations except that of the irrigated desert soil. Recognition of these natural loss avenues must be given in the case of fertilizer N as well, and those management practices which will retard losses must be promoted for economic and pollution control reasons.

Crop Utilization of Applied N

Long-term field experiments summarized by Allison (1966) indicated that no more than 50-60 percent of applied fertilizer N is utilized by crops as the general rule, even with immobilization taken into account. An understanding of crop morphology in relation to nutrient uptake is fundamental to the development of effective fertilization practices that might hopefully improve on this low degree of efficiency. Examples will be developed in this regard for two of the most important cereal crops, viz., winter wheat and maize.

As reported by Olson and Rhoades (1953), the winter wheat crop took up from 5 to 50 percent of its total N between germination and the time when growth recommenced in the following spring, the amount depending on extent of fall growth which is governed by fall temperature, moisture, time of planting and soil N level. The period between resumption of growth in the spring and heading accounted for up to 80 percent of the total N assimilated. This interval coincided with the time of greatest dry matter production, although maximum dry matter weight was not usually reached until about two weeks after maximum N accumulation had been accomplished. Between heading and harvest up to 20 percent of the total N was absorbed, and in this 5-6 weeks' period 25-75 percent of the N previously accumulated in leaves and stems was translocated to the grain. A decline in total dry matter and N content was observed after flowering as has been reported for rice. Also, the period of most rapid vegetative growth was earlier with supplemental N applied. Spring application of N fertilizer (ammonium nitrate) afforded greater accumulation of N in the plants and ultimately in the grain than resulted from fall application.

The studies on wheat evidenced that a major part of the N required can be utilized between the resumption of spring growth and heading. Thus, the hazards of leaching, microbial tieup and denitrification could theoretically be minimized from that likely with planting time application. Spring treatment would also allow an evaluation of crop stand and soil moisture conditions fairly late in the crop season before deciding on the feasibility of N fertilization.

A review by Nelson (1956) incorporating results of several investigators notes that the curve for N accumulation with time in the whole maize plant slightly precedes the curve for dry matter production until shortly after tasseling and silking. Hanway (1962) found a characteristic distribution of N in different plant parts of maize irrespective of cropping system and fertilizer treatment. Nitrogen accumulated in each plant part as that part grew with little translocation from one part to another until after grain formation began, when N was translocated from all other plant parts to the grain. Hanway observed that translocation of N from cob, husk and stalk preceded that from the leaves, and that by silking time the plant had taken up 65 percent of the total crop accumulation of N. At maturity 2/3 of the crop's total above-ground N supply was concentrated in the grain, and about 1/2 of this amount appeared to have been translocated from other above-ground parts. Especially significant is his observation that 50 percent of the leaf growth and 31 percent of the crops' total N uptake occurred in one 2-week period just before tasseling.

Gass (1971) applying fertilizer tagged with ^{15}N 11 days before silking, at silking and 14 days after silking found increasing concentrations of the tagged N in the grain with delay in time of tracer application on soil with modest residual mineral N. On plots containing a very high level of residual mineral N, however, the most delayed N application resulted in decreased ^{15}N level of the grain. Conclusion of this and a companion study was that, with favourable moisture conditions, N fertilizer supplied during the early stages of the vegetative maize plant's maximum N uptake and leaf development period, i.e., from 5-7 weeks after emergence, was more efficiently absorbed and utilized than either earlier or later applications.

Soil Residuals from Applied N

Depending on intensity of crop utilization and environmental factors subsequent to harvest of the crop treated, there may be substantial residual mineral N remaining in the soil for the next crop's use as has been documented in many studies (Lehane et al., 1933; Michalyna and Hedlin, 1959; White and Pesek, 1959; Pearson et al., 1961; Soper and Huang, 1963; Olson et al., 1964a; Peterson and Attoe, 1965; Kurtz and Smith, 1966; Herron et al., 1968). Soil texture and amounts of rainfall or irrigation are most significant determinants of residual N as they control magnitude of leaching and denitrification losses. Residuals are least significant in very sandy soils of low water holding capacity and in regions where rainfall notably exceeds water use by crops, but do occur to some degree even with humid conditions (Pearson et al., 1961). More often than not a general correlation is found to exist between amount of residual mineral N in the surface 30 or 60 cm of soil and the total amount in the 180 cm profile, a depth below which most annual crop roots do not extensively penetrate in search of water and nutrients. There is also general agreement on the depressing effect of accumulated NO_3^- N on soil pH.

Work of Herron et al. (1971) on an irrigated Brunizem soil over a three-year period showed substantially greater mineral N accumulation in the 180 cm profile of soil where fertilizer N had been applied as a summer sidedressing for maize than where applied preplant. This was in spite of the fact that yield averaged somewhat higher with summer application. Not only was a greater total quantity of mineral N measured but a greater proportion was preserved in the upper 60 cm of the profile with application delayed until an active root system for absorption of the N existed. Contributing to this observation was a substantially greater persistence of NH_4^+ -N in the surface 30 cm of soil with delayed time of application.

The same authors investigated the impact of varied moisture regime on maize yields and residual N of the silty clay loam soil in the subhumid region involved. At the highest N application rate of 253 kg/ha annually, the greatest profile accumulation of 838 kg/ha occurred with no irrigation and least of 674 kg/ha with optimum irrigation, limited irrigation having intermediate accumulation. These large accumulations occurred over the 3-year period despite yields in the order of 6300 - 8800 kg/ha per annum. A greater residual nitrate value at the 180 cm depth with the 253 kg/ha treatments than with the no N treatment indicated that at least some mineral N had also leached from the profile by the end of the third year. Of further interest among the data of this experiment was the fact that soil mineralization of N from native sources increased with increasing rate of N applied, contrary to the contentions of some environmentalists.

In cases where follow-up yields were measured, as by Soper and Huang (1963) and Herron et al. (1968), good correlation has been found between nitrate in the rooting profile and crop yields without applied N the following year. Thus, the studies of Herron et al. (1971) evidenced yields in the fourth year, when no N was applied and the crop was entirely dependent on residual N and nitrification, to be in the same range as during the previous three years with N treatments. A high degree of correlation existed between the residual mineral N of the surface 60 cm of soil (as well as 180 cm profile) and yields obtained (Figure 2). Consensus from the several sites reported was that maximum yields of maize resulted whenever soil residual N in the 180 cm profile or the sum of residual plus applied N approximated 200 kg/ha. A farmer's disregarding the residual N would result in low utilization efficiency of any large increment applied and would have potential pollution implications.

Herron et al. (1968) demonstrated that maize utilized applied N tagged with ^{15}N progressively more from increasing depths as the season advanced. By harvest time, ^{15}N had been utilized about equally from all placement depths including the deepest of 137 cm. Gass et al. (1971) applied ^{15}N labeled nitrate at depths of 9, 60, 120, and 180 cm in field plots that varied in residual mineral N from 400-600 kg/ha. Use of the tagged N from the various depths was very much influenced by the amount of residual mineral N in the profile. Maize growing on plots with the highest amount of residual N used very little of the tagged N from below 90 cm, whereas on the plots of lowest residual N, utilization was essentially uniform throughout the 135 cm depth, and some 11 percent of the uptake even took place from the 180 cm placement. Similar results were obtained with varied depths of tagged N placement in studying uptake and utilization of residual N by the sugar beet crop (Anderson et al., 1971). These studies make it clear that continued excessive increments of applied N to the soil surface will restrict a crop's utilization of N that has accumulated in the lower profile that might be utilized with a more judicious application rate, and thereby contribute to potential leaching losses of the N. They further demonstrate the need for taking into account residual N existing throughout the entire crop rooting depth.

Fertilizer N Management for Enhanced Crop Utilization

Primary evaluations required for determining effective fertilizer N management are time, rate and method of application and efficiency of chemical carrier of the N.

Rate. Optimum rate can be elaborated only in terms of specific crops at specified yield levels as influenced by time and method of application. From the discussion in the previous section it is also apparent that rate evaluations to be meaningful must take into account the amount of residual N from previous applications and from natural microbial mineralization from the soil organic matter. At the beginning point of extensive N fertilization with soils that have been depleted by long-term cropping a few experiments with specified crops in a given locality may give a fairly sound indication of the most economic rate of N to employ. Other than the more humid localities of extensive annual percolation loss of water or where soil remains water logged for extended periods, profile

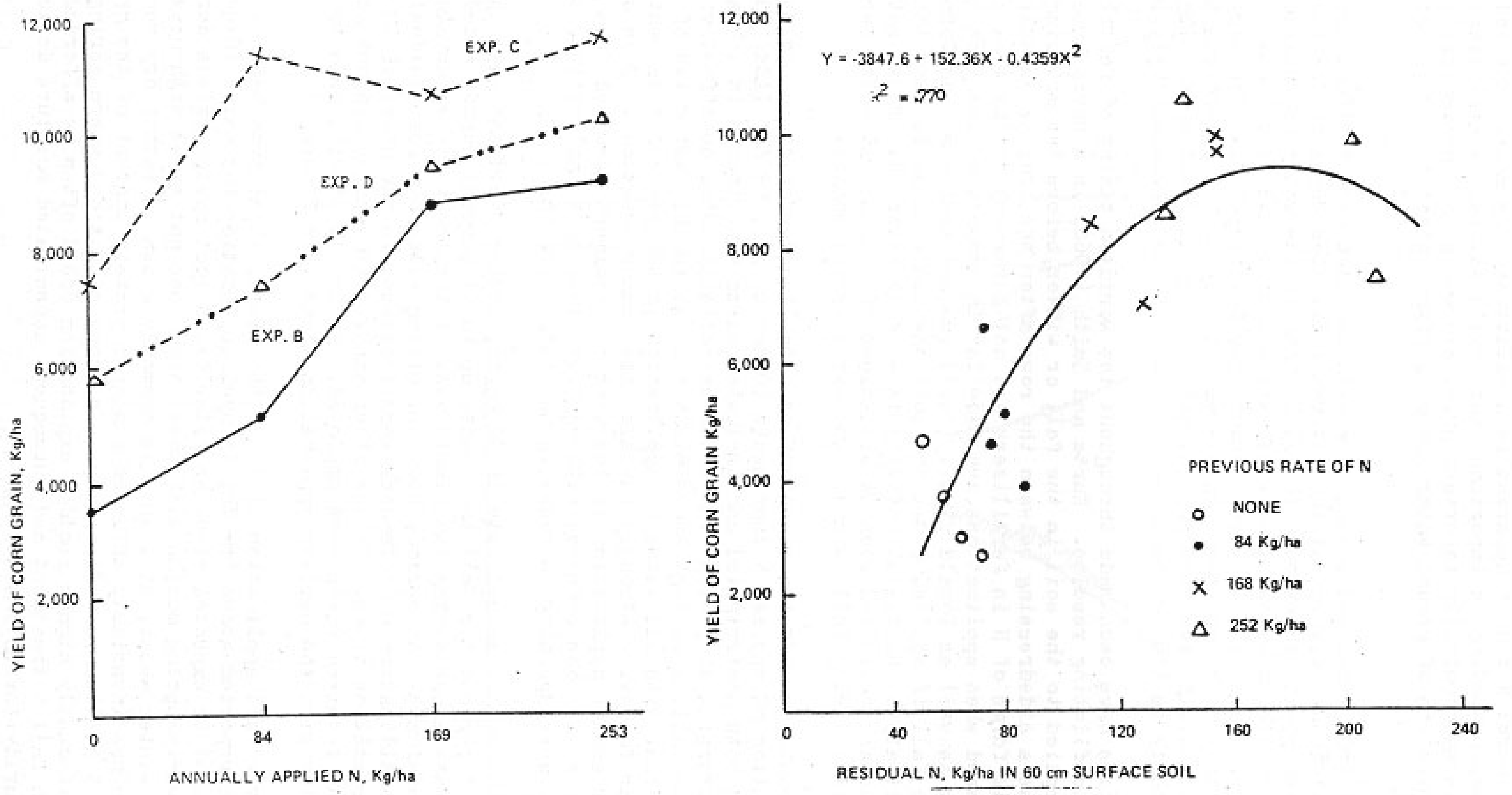

Fig. 2. Residual effect of N treatments in the previous three years on yield of maize in 1967 (left), and the correlation between measured residual mineral N in the surface 60 cm of soil on grain yield without additional N applied (right).

accumulations of residual mineral N become apparent in a relatively few years that modify the initial rate indications, exceeding in importance the soil's natural mineralization capacity. Disregard of this agronomically important principle would indeed eventually lead to fertilizer N contamination of ground water and of surface waters fed by the ground water.

Variety of a specified crop grown and season of growth can have marked effects on optimum rate of N to apply. Thus, research at the International Rice Research Institute (DeDatta et al., 1968) showed positive response to 120 kg N/ha in the sunny dry season of one of the dwarf varieties developed by the Institute, whereas most tall traditional varieties peaked out at 30-60 kg N/ha. The dwarf variety yielded less during the cloudy wet season than in the dry season and achieved its maximum at only 60 kg/ha, whereas the tall varieties yielded substantially less and reached their maxima at 20-40 kg N. Implication is that as light intensity is low, N requirement by the crop is correspondingly lower.

Timing. Numerous studies have been made throughout the world on timing of fertilizer N application with rather conflicting results. Kurtz and Smith (1966) in a review state that fertilizer N may be applied to the soil in the fall or winter before the cropping season, in the spring, or as a sidedressing between the rows after the crop is established. They indicate that available forms of N in fertilizers are not permanent in the soil and that risk of loss is increased when applications are made far in advance of the time of crop use. The same authors as well as Donald et al. (1963) suggest that ammonium forms of N can be safely used in the fall if applied after the soil has cooled down to less than 10° C when conversion to nitrate by bacterial activity is sharply retarded. Thus, potential leaching and denitrification are minimized even in situations of substantial water percolation and restricted aeration during fall, winter, and early spring months.

Many studies have demonstrated the importance of an established root system in assuring most effective crop utilization of applied N increments (Olson et al., 1964a; IAEA, 1969; Lathwell et al., 1970). In both nonirrigated and irrigated maize experiments in Nebraska, N applied as a summer sidedressing at nominal rates was essentially twice as effective for yield as that applied in the fall or spring before planting. At the highest rates of application yields were similar with all times of application in the year of treatment, but residual effects in the year following strongly favoured the summer treatment. Much of the beneficial yield effect for summer application in the year of treatment resulted from a notably larger grain/stover ratio than occurred with earlier times of N application, thus a greater grain yield without corresponding increase in vegetative growth.

Fertilizer N utilization with a modest rate of 90 kg/ha, taking yield and grain protein into account, ranged from 31 percent for fall treatment, up to 51 percent summer sidedressed in the 14 Nebraska experiments above during the single year of treatment. When uptake was determined in experiments over a 3-year period, however, giving allowance for residuals from one year to the next, utilization efficiencies were increased in the order of 10 percent for the respective application times. On the other hand, efficiencies did not improve with time where heavier than required rates were employed, presumably attributable to accentuated losses especially with the earlier application times (see Figure 3).

Benefit from spring over fall application of N for the winter wheat crop has not usually been as striking as reported above for the delayed application for maize (Olson and Dreier, 1970). This might be expected since an established root system exists during the late fall, winter and early spring months with wheat that does not exist with maize and the fact that hard red winter wheat, at least, is commonly grown in rather dry regions. Even so, spring application has invariably afforded a higher protein content of the grain and consequently a greater N utilization efficiency. In those situations where spring treatment resulted in significantly higher yields, explanation could often be afforded by the extra moisture use with fall N treatment and subsequent accentuated moisture deficiency as the crop approached maturity (overstimulation).

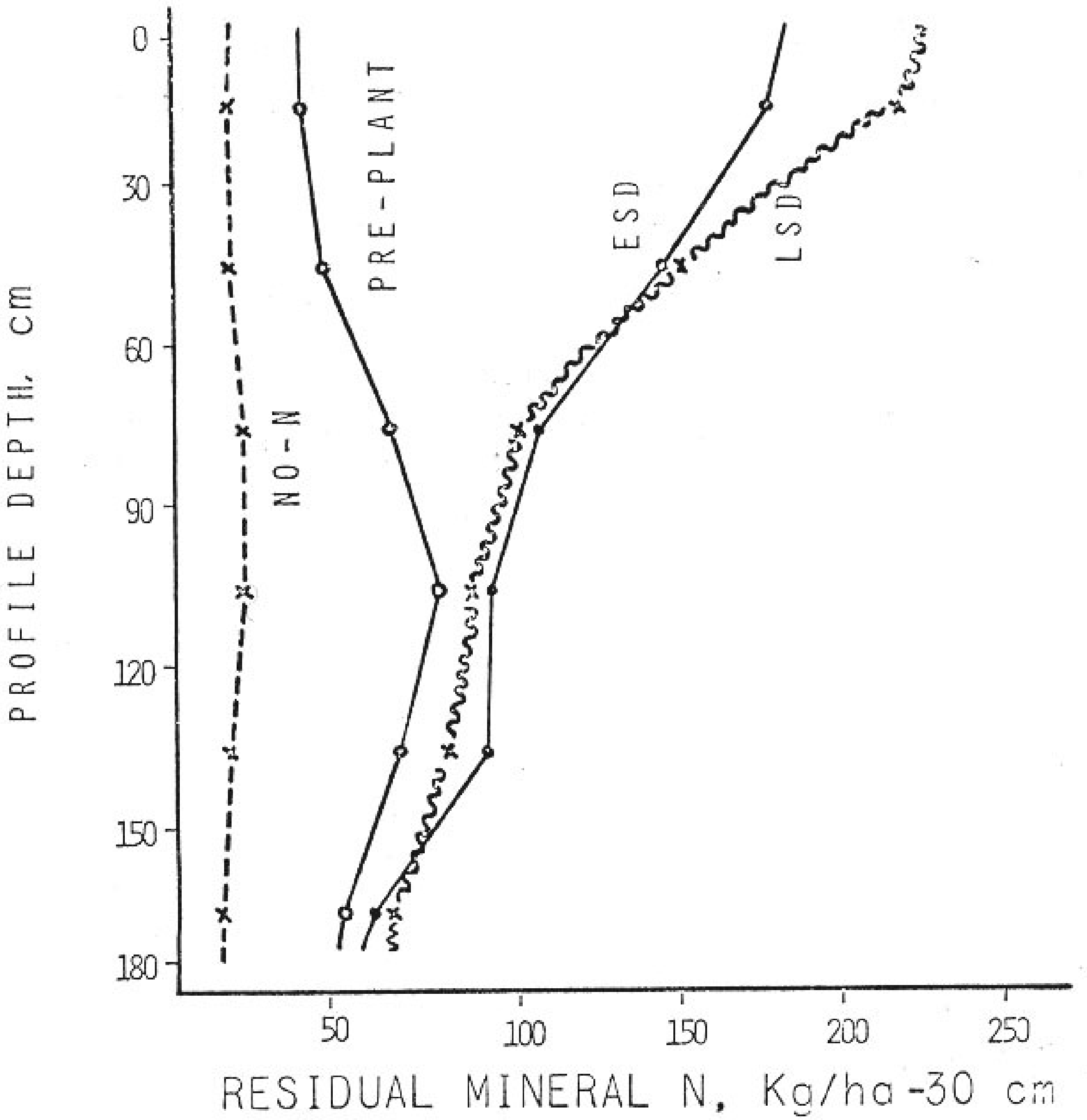

Fig. 3. Residual mineral N in the 180-cm profile of soil after treatment of the maize crop in the three preceding years with 210 kg N/ha applied preplant, early sidedress (ESD), or late sidedress (LSD).

Investigations with crops produced in humid tropical regions and by rice in submerged culture have commonly shown a need for delaying N application and/or spreading applications over two or more times when a crop root system is well established for assuring good fertilizer N utilization (Beacher and Wells, 1960; Singh and Tekahashi, 1962; Patnaik and Broadbent, 1967; Joint FAO/IAEA Div., 1970). No doubt both leaching and gaseous losses have been retarded by the presence of an active root system for absorbing the N. Furthermore, split applications for rice resulted in greatly reduced straw growth and lodging, earlier maturity and greater yield than with singular applications made at or shortly after seeding or at 5 weeks after seedling emergence (Sims et al., 1965), indicating physiological effects as well were involved. Field experiments of the joint FAO/IAEA Division (1970) throughout S.E. Asia, however, generally found the highest percentage of N derived from fertilizer when the ammonium sulfate carrier was applied in a single dose two weeks before primordial initiation. Although split applications that included one at primordial initiation often gave good uptake results, rarely did the results match those of a singular late treatment. More recent studies by Sims et al. (1967) showed grain yields of rice to be inversely related to plant height and lodging and to increase with delay in time of application of the second 45 kg N increment (the first 45 kg/ha applied at emergence as flooding was initiated). Most effective time of the second treatment ranged from 50-70 days after emergence depending on variety employed. Patnaik and Broadbent (1967) determined that topdressed labeled ammonium sulfate caused highest N recovery and grain yield of rice when application was delayed until the boot stage, with 51 percent recovery of the N applied at boot stage compared with 37 percent when placed in the soil at transplanting.

Conclusion can only be made from these observations that greatest crop use and least loss of applied N is likely to occur if application is held up until an active crop root system exists. Thereby immobilization, denitrification and leaching losses have less opportunity to take place if the N is immediately absorbed into the root. Certain chemical carrier, placement, and environmental aspects may enter in, however, to compromise this general axiom, as will be detailed in subsequent sections. Moreover, in a locality of very extensive fertilizer N use it would be physically impossible to supply the volume of materials required in the short time interval when most efficient utilization of the N would result. A substantial portion of necessity will be applied prior to that time, thus selection of chemical carrier and placement method should be made so as to minimize losses to the extent possible during the period when there is no crop root for absorbing nutrient.

Placement. Surface application of ammonium fertilizer carriers and of urea which hydrolyzes rapidly to ammonium carbonate is recognized as hazardous from the ammonia volatilization standpoint, especially on soils that are calcareous or otherwise of high pH (Mitsui, 1954; Martin and Chapman, 1951; Volk, 1959; Meyer et al., 1961). Loss from this channel can range up to 100 percent with the additional conditions of applied N subtended on surface residue, insufficient moisture for penetration into the soil, and accelerated drying by wind action. Curbing of this loss entails immediate watering into the soil or some incorporation of the fertilizer with soil to permit adsorption of the ammonium ion on the soil's exchange complex where it is fairly secure (Volk, 1959; Meyer et al., 1961).

Surface application of ammonium materials for even submerged rice may be responsible for high denitrification losses. This is for the reason that nitrification is possible at the surface of the submerged soil due to the oxygen carried in the water. Reducing conditions do not begin until some few cm below the surface, the depth depending on textural and structural conditions. Following nitrification, the resulting nitrate moving down into the reduced zone is lost to denitrification. The earlier the ammonium carrier is applied, the greater the probability of this loss occurring. Thus, Mitsui (1956) has reported losses of 30-50 percent of surface applied ammonium for flooded rice in Japan compared with deep placement. Similarly Mikkelsen and Finfrock (1957) found that N incorporated 5-10 cm deep in dry soil before flooding resulted in 25-35 percent greater yield than the same amount surface broadcast. By reason of the field experiments of the Joint FAO/IAEA Division (1970) on rice reported earlier, conclusion was drawn that shallow placement of ammonium sulfate resulted in 30-40 percent higher utilization of the applied N on slightly acid soils than with surface broadcasting. Little or no difference occurred with varied placement on calcareous soils of pH above 7.

Otherwise, placement of N fertilizer is important with respect to where moist soil exists and root activity for absorption is possible. Some investigators have obtained poor results from delayed broadcasting of N between the rows of well established maize, for example, when the surface soil was dry at application and rain was not received shortly for carrying the soluble nutrient into the root zone (IAEA, 1969; Olson et al., 1964a). Sometimes a modest incorporation of the N by a tillage implement penetrating to moist soil would alleviate the problem, although rain or irrigation would be essential before many days had passed for optimum use. In other cases poor results from a delayed application have occurred where the N was inserted into the ridge of the maize row only to be carried to the surface of the ridge by capillary movement of water as irrigation was begun.

The placing of soluble N fertilizer materials on the surface of frozen ground should be discouraged. Not only is there potential for serious runoff loss with rain or snow melt, but the NH_3 volatilization potential over an extended period could be substantial. Potential gaseous loss from application of anhydrous ammonia as N fertilizer must also ever be recognized. The anhydrous must be injected to a sufficient depth to assure that its diffusion volume in the soil does not reach the land surface, requiring care to equate application rate with shank spacing and cation exchange capacity of the soil treated. Additionally, application should never be made when the soil is excessively dry or wet due to volatilization loss accompanying the poor closing of the injection slot.

Nitrogen Carriers. These chemical carriers of N that play a significant role in crop fertilization throughout the world have been generally recognized as equivalent in effectiveness for most crops. This presupposes that each carrier will be managed in accordance with its own limitations, such as: incorporation of urea and NH_4^+ -base materials rather than surface broadcasting, especially on calcareous soils; application of NO_3^- products after wetting regimes which could cause leaching or temporary water logging; proper depth and spacing of ammonia applicator shanks in relation to soil and moisture conditions; timely application, proper placement for optimum use, judicious rate of application, etc.

There are notable exceptions to the equivalence noted above, however. Ammoniacal N has been generally accepted as a more efficient source than other N forms for flooded rice. Nitrate carriers are usually found to be quite inefficient under the submerged conditions, although their performance is improved with delayed application and may prove acceptable when applied immediately before the boot stage of development (Joint FAO/IAEA Div., 1970).

Ammonium sulfate has long been used as the standard fertilizer N carrier in much of the humid tropical regions of the world because of its low deliquescence and consequent excellent storage properties. Most other carriers have been quite unacceptable in this respect until recent times following development of advanced technology in the coating of particles and bagging procedures. The sulfur contained in ammonium sulfate is also very often beneficial to yield in heavily leached soils. Especially in the upland savanna are soils likely to be inherently deficient in sulfur (McClung et al., 1959). It is well recognized now, however, that the extended use of ammonium sulfate on tropical soils of low cation exchange capacity will result in substantial loss of soil calcium and reduction in soil pH (Russell, 1968). Contention is made that the acidity induced by ammonium sulfate in a few years is more damaging to crops than that caused by natural processes over millennia of time, and presumably related to subsoil acidification and release of active aluminum. General consensus now is that use of ammonium sulfate should be curtailed on inherently acid soils of low exchange capacity in the tropics unless it is possible to compensate with approximately 100 kg of effective lime for each 100 kg of the N carrier applied. Virtually all other N carriers (except sodium nitrate and calcium ammonium nitrate) also have residual acidifying effects on the soil, but only to the extent of 1/3 to 1/2 that of ammonium sulfate.

Interactions of N and Water Management

Fertilizer N and water interact in various ways in affecting the efficiency of crop utilization of the applied N. Crop yields are benefited in well-drained soils by timely irrigation even in those situations where substantial available water remains in deeper portions of the soil rooting profile prior to irrigation (Herron et al., 1971). This has been interpreted to mean that replenishing the moisture supply of the surface layer of soil has resulted in greater root activity for nutrient uptake as supplemental watering kept that nutrient-rich zone more continuously moist. Relevant is the reported 31 percent uptake of the maize crop's total N requirement in one 2-week period just prior to tasseling (Hanway, 1962). The recent innovation of center pivot sprinkler systems lend themselves especially well to keeping the surface soil reasonably moist during the growing season while simultaneously spoon feeding the crop with N by fertilization.

As crops are brought from a deficiency condition to optimum N nutrition by fertilization, water use efficiency (WUE) is enhanced significantly if yield is increased (Viets, 1962). A group of 33 field experiments in Nebraska, for example, measuring consumptive use of water found 130 kg maize produced per ha-cm water consumed by maize without N treatment (Olson et al., 1964b). With adequate N, the crop produced 189 kg grain/ha-cm water consumed or an increase of 43 percent in WUE as grain yield increased from 4950 to 7425 kg/ha. Corresponding increases in WUE for wheat, oats and grain sorghum were 12, 33, and 28 percent, respectively. In no case did percentage increase in WUE match percentage yield increase, a result of the fact that the small amount of approximately 2 cm additional water was used in producing the larger crop. It is, therefore, appropriate to say that judicious use of fertilizer may very well enhance the efficiency with which a crop uses water, but not that fertilizer will substitute for water.

Cases have been recorded under moisture deficiency conditions where supplemental N not needed for yield by causing superfluous vegetative growth actually reduced crop WUE. The data of Table 1 have been borrowed from a 3-year wheat experiment on Chernozem soil at the boundary between the semiarid and subhumid climatic regions where mean annual growing season rainfall averages 30 cm (Ramig and Rhoades, 1963). Note that WUE declined when more than 22 kg N/ha was applied to plots with no moisture reserve at planting in the 180-cm profile. There was a reduction in WUE from more than 45 kg N/ha when only 7 cm available water storage existed at planting. With 15 or more cm available water at planting, WUE increased through all rates of N applied including the heaviest 90 kg/ha. The lower WUE values for the 21 cm moisture storage at all N levels than occurred with 15 cm storage was prompted by the fact that this amount plus seasonal rainfall represented more moisture than was desirable for optimum wheat yields in the years involved. In effect, for that dryfarming area and period, the data say that winter wheat produced maximum yields with the use of 22.5 kg N/ha for each 7 cm of preplanting available soil moisture in the 180 cm profile.

Fertilizer N applications should be adjusted to the water regime existing or expected in soil to the extent that is possible. If N must be applied prior to a monsoon or heavy irrigation, an ammonium rather than nitrate carrier should be selected. More feasible would be application of the major quantity of N for the crop at some later time when leaching would be less likely to move the oxidized end product beyond the reach of crop roots or when conditions for denitrification were less likely to occur. In the interests of crop use economy, by the same token, it is necessary that application be made at a time and in a way to assure that the applied N moves into the rooting zone by the period of most active crop uptake for maximum yield.

Table 1. Water use efficiency of winter wheat as influenced by preplanting soil moisture and rate of applied N (North Platte, Nebraska).

Applied N	Available soil water at planting, cm 1/			
	0	7	15	21
kg N/ha	kg grain/ha-cm H_2 O			
0	16.3	25.7	31.9	29.4
22	21.7	35.3	44.2	40.5
45	19.0	43.5	47.9	46.9
90	16.3	40.8	53.4	50.9

1/ Available soil water established in the 180-cm soil profile before planting by irrigation.

On the other side of the soil drainage ledger, submergence has long been recognized as a necessary practice for optimum rice culture. This fact has been proved to be nutritionally related with a number of elements, but not beneficially so insofar as N is concerned. Rather, N management practices must be adjusted to compensate for the flooded condition compared with usual crop culture on well-drained soils. Duration and depth of the water cover then become important.management considerations. Continuous coverage from first flooding until physiological maturity, with no intermediate drying for nitrate formation and subsequent denitrification after waterlogging, has proved essential for top yields in many studies of the question (Patrick et al., 1967). As for depth, a shallow water covering of 4 cm during the growing season caused higher yields than intermediate depth (8 cm) or fluctuating (4 then 18 cm depth) in a California experiment. A greater number of panicles per square meter and more total N in the shoots at 30 days and in the grain at maturity were characteristics associated with the higher yield from shallow water coverage (Oelke and Mueller, 1969).

Crop Management for Maximum N Use Efficiency

It perhaps goes without saying that those crop management practices which effect maximum yield are also likely to promote maximum efficiency in use of fertilizer N at the same time that losses are minimized. Among important crop management practices influencing yield of maize, for example, are row spacing and plant population when water and nutrient supplies are adequate for high levels of production. Note in Figure 4 that narrowing rows from 40 to 20 inches (102 and 51 cm) with N limiting had no impact on yield when population was 16000 plants per acre (39,500/ha) and had only slight effect with 24000 plants (59,000/ha) (Barber and Olson, 1968). When N treatment was adequate for maximum yield in this 3-year irrigated experiment, however, yield increased modestly from narrowing rows to 51 cm at the lower plant population and very appreciably with the higher population. Furthermore, the residual mineral N in the 180 cm profile of 51 cm row width plots at the end of the study where 253 kg N/ha had been applied annually was only 62 percent of that in the 102 cm row plots, corresponding with the heavier N use from larger yields with the narrow rows. Thus, less remained in the soil subject to potential leaching loss.

The proper selection of crop variety or hybrid can also make the difference between efficient and poor utilization of the fertilizer N applied. The data of Table 2 give indication of the differential responses that may be obtained with varied population along with N treatment of different maize hybrids (Barber and Olson, 1968). In addition to the fact that the first hybrid listed was not benefited by the higher plant population while the other two were, note that the B14 x N6 was particularly superior when the high plant

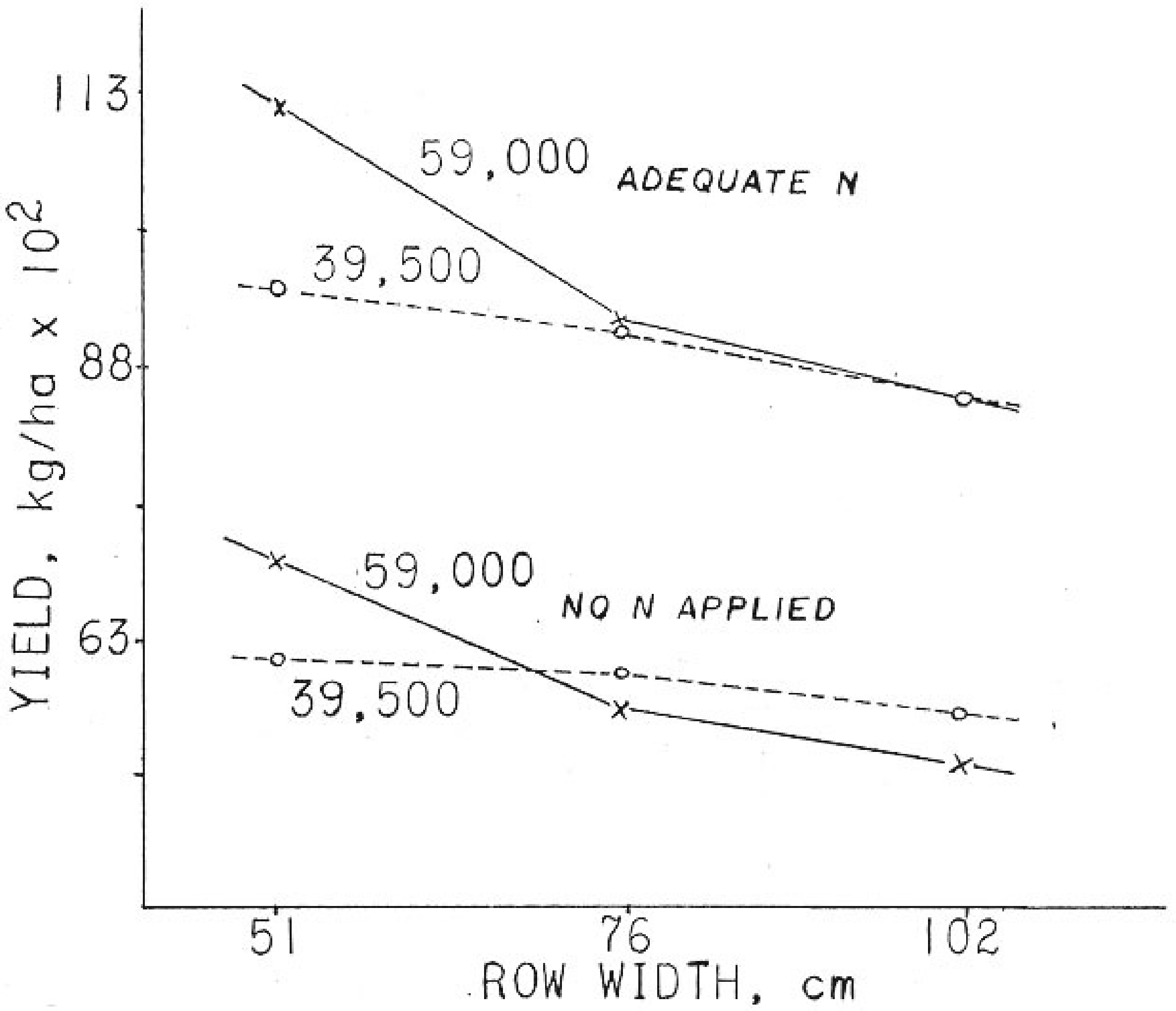

Fig. 4. Interactions among row spacing, plant population, and level of applied N for irrigated maize in Nebraska (after Olson & Colville).

population was combined with adequate N. With less than optimum N, conclusion would have been that no real difference in yield potential existed among these three hybrids, further that high plant population was deleterious for two of them.

Table 2. Effect of plant population on response of three corn hybrids to fertilizer N under irrigation in eastern Nebraska, 3-year average (from Colville and Olson).

Hybrid	Plants/ha	Rate of N, kg/ha	
		0	84 1/
N28 x H51	39,500	8316	9702
	59,000	7938	9765
N6 x N28	39,500	8316	9324
	59,000	8505	10080
B14 x N6	39,500	8442	9450
	59,000	7938	10395

1/ N rates above 84 kg/ha gave no further yield increase on this highly productive Sharpsburg soil.

Another procedure in the crop management area for minimizing N losses from the cultivated soil is to include a sod crop and/or a deep taprooted legume periodically for soaking up the residual N that has accumulated from fertilization of annual crop. Grasses are especially effective at seeking out any available N in the upper soil solum (1 meter ±) while a deep taprooted legume as lucerne will absorb substantial quantities of mineral N that may have penetrated beyond the rooting depth of annual crops (Stewart et al., 1967). Such crops grown periodically not only assist in maintaining desirable soil physical properties but now have a place in alleviating potential pollution from excessive N that may have inadvertently accumulated in the soil profile. Somewhat analogous is the small grain or other cover crop that makes some growth during a wet period between cropping seasons and in the process soaks up mineral N that might otherwise have leached from drop rooting depth.

Use of Slow Release N and Nitrification Inhibitors

Considerable interest has developed recently on the subject of controlled release N fertilizers and inhibitors of nitrification. Objectives of product development in this area are to obtain materials that supply N to the crop continuously over an extended time interval, to reduce leaching and runoff losses, to retard gaseous losses, to limit biological immobilization reactions in the soil, and to minimize luxury consumption of N. Involved are coatings for soluble materials, materials of limited solubility, products which are soluble but decompose slowly and therewith release the N contained, and products which inhibit nitrification of the ammonium in fertilizer applied concurrently (Hauck and Koshino, 1971).

Many different products are currently under investigation for securing data that will certify to the economic feasibility when applied to the agricultural enterprise. Some materials among the urea-aldehyde combinations including ureaform (Uramite and Nitroform in the U.S.; Carbamiform, Russia; Azorgan, France) are indeed being produced commercially and sold for such specialty purposes as lawns, gardens and golf courses. Crotonylidene diurea (CDU) and isobutylidene diurea (IBDU) are additional products that have been patented and are produced commercially, especially in Germany and Japan. Some commercial production has begun as well with several nitrification inhibitors, especially in Japan where nine inhibitors had been certified by Japanese fertilizer law as of September, 1969. Commercial products include a pyridine (N-Serve of Dow Chemical Co.), a pyrimidine (AM of Mitsui Toatsu) and dicyandiamide (AUF of Sumitomo Chemical Ind.). Among coatings for restricting release of N from soluble materials, resins and sulfur have been most extensively investigated. The only commercially produced material known to the moment is coated with a resin (Osmocote of Archer Daniels Midland Co.), but sulfur coated products have probably attracted the greatest academic interest from the standpoints of cost, technology of preparation, and presence of a second important plant nutrient in the coating. (Rindt et al., 1968).

There is experimental evidence to show that N conservancy can be effected by some of the materials under consideration when properly used in conjunction with intensive agricultural production. It seems quite probable that some of the delimitations specified concerning timing, placement, and water x N interaction may be modified if and when these materials are readily accessible and economic. Success or failure of the products in commerce will ultimately hinge on the economics questions.

Summary

Fertilizer N today is responsible for upwards of 30 percent of all agricultural production in the advanced countries of the world. Significance of its present and future role in feeding the peoples of the world cannot be disputed. We can look forward to a doubling in fertilizer N production and use in the next very few years as it becomes an accepted input in the agricultural industry of the developing countries.

Fertilizer nitrogen may be lost from soils in several ways, consequence of which is that rarely more than 50 percent of that applied as fertilizer can be accounted for in the crops treated. Loss of any kind is serious from the economic standpoint, but that to leaching is of utmost concern relative to environmental pollution.

Mineral N does accumulate in soil profiles from continued heavy fertilizer treatments except where the soil is waterlogged for extended periods and/or where seasonal rainfall or irrigation notably exceeds crop water use. In consequence it is essential to determine the amount of residual mineral N in the soil rooting profile for equating with rate of fertilizer N to be applied for the current crop. Thereby most economic returns are assured at the same time that pollution potential is minimized. Species and variety of crop, climatic environment determining yield potentials, as well as time and method of application influence what is to be an optimum rate of applied N in any given situation.

Risk of loss of fertilizer N is increased when applications are made far in advance of the time of crop use. The importance of an established root system for assuring most effective utilization of an applied increment of N has been demonstrated for crops grown in well drained as well as submerged culture. Of course it would be impossible to supply the large volumes of fertilizer N during the short time interval when maximum uptake and utilization would occur, necessitating that carrier selection and method of application with earlier treatment be made with objective of minimum loss potential during the period when no active root system exists.

Optimum placement of N is dictated in large part by the chemical carrier of the nutrient and by environmental conditions. Surface applications of ammonium and urea base materials should be avoided, especially on calcareous soil. Incorporation with the soil is good insurance for both well drained and flooded cultures.

As long as each is used in accord with its own limitations different carriers of fertilizer N have proved equivalent in most cropping situations. Notable exceptions are the better performance of ammonium over nitrate carriers with submerged rice production and the detrimental acidifying effects from extended use of ammonium sulfate on tropical soils of low exchange capacity.

Effective use of fertilizer N must take into account interactions between the N and water management practices employed, likewise crop management. Where crop, water and nitrogen management are carefully integrated utilization efficiency of the N is maximized. There is further promise that slow release N products and nitrification inhibitors when fully developed will assist in curbing the losses of concern and make fertilizer N even more effective as the backbone to future crop production.

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CHEMICAL AND BIOCHEMICAL CONSIDERATIONS FOR MAXIMIZING THE EFFICIENCY OF FERTILIZER NITROGEN

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Fertilizer nitrogen (N) use efficiency may be defined as the percentage recovery of fertilizer N by a crop. It is measured as the difference in N uptake by the aboveground portions of fertilized and unfertilized plants, and expressed as a percent of the N applied. Efficiency will vary widely depending on the chemical nature of the N source itself, the rate, method, and time of application, type of crop grown and its N requirement, extent of microbiological and chemical immobilization of the applied N, and a host of soil, climatic, and management factors. Under favorable conditions, 80 percent or more of the fertilizer N may be recovered by the crop to which it was applied. However, under many soil and cropping conditions, efficiencies of 50 percent or less are not uncommon (Allison, 1955). While there is general agreement that the low efficiency of fertilizer N is due largely to a net loss of N from the soil-root zone by leaching and denitrification, a soil N balance sheet approach to the problem has merely shown that much of the N is unaccounted for, providing little reliable information concerning the exact fate of the applied N (Allison, 1955).

There are several ways in which fertilizer N use efficiency could be increased, first, by minimizing losses of N from the soil-root zone, and second, by manipulating environmental and management factors to allow the plant to fulfill its genetic capability for maximum yield and high product quality, which in itself would enhance the recovery of applied N.

In view of (a) the increased use of fertilizer, particularly N, to sustain maximum yields for economic production, and (b) Agriculture's potential contribution to the eutrophication of surface water resources, as well as nitrate enrichment of groundwater from deep percolation, and the possible health hazards which could result therefrom, the principal objective of this paper is to consider certain chemical and biochemical approaches for maximizing the efficiency of fertilizer N. Initially, a discussion of the fate of fertilizer N in soil, consumption patterns and trends, recent evidence of enrichment of natural waters by fertilizer N, and the relationship between N use efficiency and maximum yields is pertinent to this objective.

Fate of Fertilizer Nitrogen in Soil

Most N fertilizers are subject to certain chemical, physical, and biochemical events which can result in significant losses of N from the soil-root zone after application. A schematic representation of the fate of both soluble and slow-release fertilizer N in soil is shown in figure 1. Losses occur principally through (a) leaching of nitrite (NO_2^-) and nitrate (NO_3^-), (b) biological denitrification of both NO_2^- and NO_3^-, and (c) volatilization of ammonia (NH_3) from improper application of anhydrous or aqua NH_3, and surface application of urea and other ammoniacal N sources to alkaline soils. In reviewing (d) chemical denitrification mechanisms that could contribute to the loss of fertilizer N, Allison (1963) suggested that a major pathway may involve the formation and subsequent decomposition of ammonium nitrite to N_2. Moreover, in acid soil environments ($\angle$ pH 5.5) NO_2^- can undergo chemical decomposition to nitric oxide (NO). The extent to which chemical denitrification contributes to loss of fertilizer N from soil, however, is not known.

Fertilizer N can also be lost from the soluble N pool (figure 1) through (e) surface runoff and erosion, (f) inter-lattice fixation of ammonium (NH_4+) by clay minerals, (g) microbiological immobilization, and (h) chemical immobilization involving reactions of fertilizer N with soil organic components.

Slow-release or controlled-release N fertilizer sources, reviewed recently by Prasad et al. (1971), would either enter the soluble N pool directly, depending on specific dissolution properties and "release" characteristics, or possible undergo immediate immobilization (microbiological or chemical) into the soil organic N pool. The probability for rapid immobilization of slow-release N in cases where the microbiological demand for N greatly exceeds the rate of release was discussed earlier by Hauck(1968). Apparently, the mineralization potential of immobilized slow-release N is not known. Moreover, according to Mortland (1958), relatively little is known of the exact chemical nature of the ammonia-organic complex resulting from the reaction of NH_3 with soil organic matter, or of its susceptibility to microbial attack and subsequent availability to plants. Immobilization of either slow-release N or more soluble N sources into organic compounds that are more or less resistant to mineralization than natural residues, could indeed affect the efficiency of fertilizer N.

Since fertilizer N can be immobilized into organic forms unavailable to plants, or lost entirely from the soil-root zone by the mechanisms described, it is not surprising that fertilizer N use efficiency is only about 50 percent under many soil and cropping conditions (Allison, 1955, 1963, 1964, 1966). Ammoniacal fertilizers in most soils are subject to loss only after nitrification of NH_4+ to the NO_2^- and NO_3^- forms by autotrophic bacteria. The NH_4+ form, a cation, is electrostatically adsorbed by the exchange complex and thus relatively immobile compared with the NO_3^- anion which is subject to leaching and bio-denitrification. It appears that most crop plants can absorb and assimilate either the NH_4+ or NO_3^- form of N, often with equal effectiveness, provided certain conditions are met (Kirkby and Hughes, 1970); however, further discussion of this topic relative to fertilizer N efficiency will appear later.

Fertilizer Nitrogen Consumption: Patterns and Trends

The dramatic increase in U.S. consumption of fertilizer N in recent years is shown in figure 2. Where little more than 0.5 million metric tons were applied in 1945, 6.6 million tons were applied in 1970, a 12-fold increase. According to Ibach (1966), the estimated consumption of fertilizer N should reach about 11 million tons by 1980. Total U.S. fertilizer consumption (N plus all other nutrients) was 14.3 million metric tons in 1970 with estimates projecting 23 million tons by 1980 (Nelson, 1971). However, these statistics indicate that U.S. consumption of fertilizer N and other nutrients during the remainder of this decade will increase less rapidly than in the past..

It is noteworthy that the U.S. consumption of fertilizer N in 1969 approached 25 percent of the total world consumption. Undoubtedly, this statistic will change markedly during the present decade as lesser-developed nations increase their agricultural production through modern technology and increased use of N as well as other fertilizer nutrients.

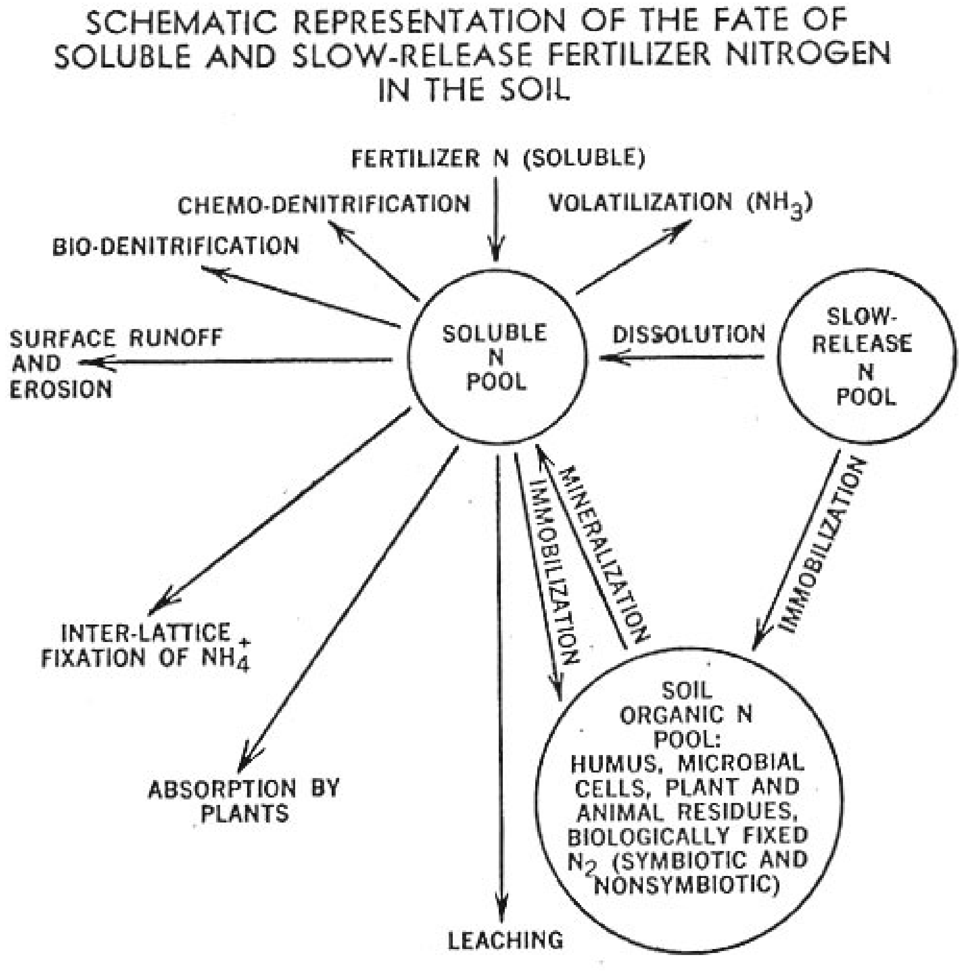

Figure 1. Schematic representation of the fate of soluble and slow-release N in the soil, and relationship to the soil organic N pool.

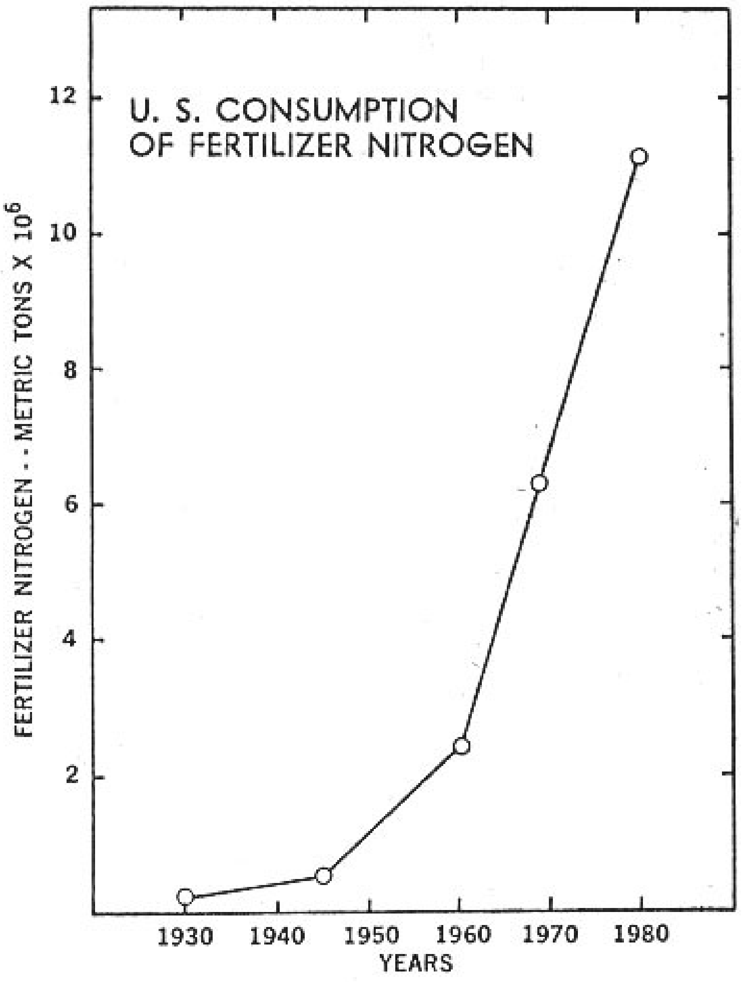

Figure 2. Consumption of fertilizer N in the United States since 1930 with a projected estimate to 1980.

These N consumption patterns for U.S. agriculture are directly related to increased N fertilizer rates for basic crops such as corn, which have increased in several Corn Belt States from 10 kg N/ha in 1950 to about 120 kg/ha in 1967 (figure 3). When one considers that during this time the U.S. population increased by 50 million people, while the area of cropland decreased by about 10 million hectares, the intensity of N fertilizer use relative to increased crop production is particularly apparent.

Table 1 is of interest since it shown the estimated changes in inputs and outputs (i.e. removals) of fertilizer and soil N since 1930, with data projected to 1980. Certainly, all of these estimates, except the inputs from fertilizer N, must be regarded as somewhat speculative. On a national average, through 1969, more N was removed in harvested crops than was applied by N fertilizers, which has prompted some agricultural spokesmen to conclude that agriculture cannot be contributing to nutrient pollution of natural waters. However, the fallacy of this assumption is apparent when considering the regional differences in cropping systems and fertilizer N use patterns. Indeed, the more progressive farmers tend to add more nutrients than their crops recover, while the opposite is true for those who are still "mining" the native soil fertility (Frink, 1971). According to White (1965), the total nutrients applied as fertilizers to corn, cotton, and sugarcane in the U.S. now exceeds the total nutrients removed in harvested material.

The question marks on estimates of leaching of fertilizer N and denitrification indicate how little is known concerning the magnitude of these losses. Even so, up until 1947, the total N removed far exceeded the total input. However, by 1969, this pattern had been reversed, while projected estimates for 1980 suggest that total N input will probable exceed N removal by an even greater margin than in 1969. These projections allow for some speculation as to what extent fertilizer N might be contributing to enrichment of natural waters by 1980.

According to Nelson (1971),

> "Future increases in fertilizer consumption in the USA must come largely from increased application on presently low fertilizer-using crops and low fertilizer-using areas because many of the present high fertilizer-using crops, including corn, already are approaching the maximum profitable rates of application.

This assessment is in agreement with recent trends concerning fertilizer N rates for corn as shown in figure 3, where it appears that some states have already reached such a plateau. A pertinent question then is whether increased application of fertilizer N to low N-requiring crops, such as soy-beans, and the expanded use of fertilizer N in areas where, presently, crop production is limited by certain soil and climatic factors, will pose an even greater potential for loss of applied N. A real challenge for agricultural scientists in the future will be to seek ways and means of maximizing the efficient use of fertilizer N on low N-using crops and in presently low N-using areas.

Nitrogen Fertilizer Use and Environmental Quality

That some loss of fertilizer N does indeed occur from the soil-root zone is an undenialbe fact of a progressive agriculture. However, the magnitude and possible consequences of these losses are currently the basis of considerable controversy. More and more, ecologists are associating the increased use of fertilizers, particularly N and P sources, with environmental pollution. They contend that such intensive and possible overuse of fertilizer N is contributing significantly, through runoff and leaching, to accumulation of NO_3^- in

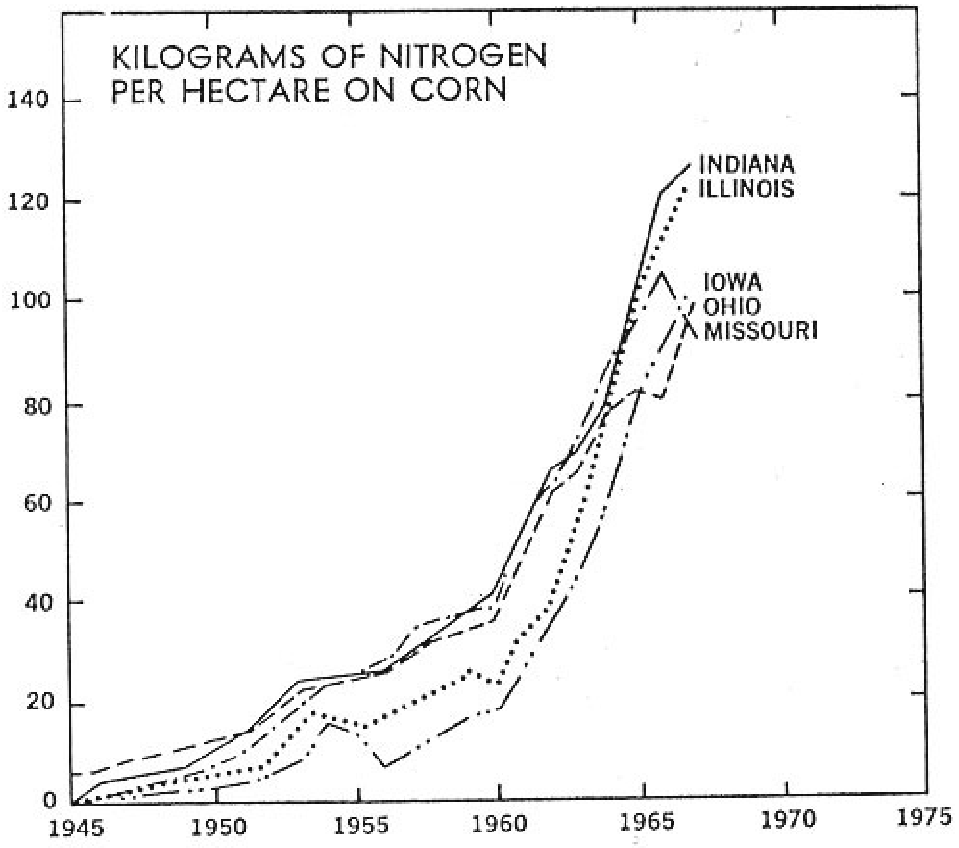

Figure 3. Trend in use of fertilizer N in several Midwestern States (Thompson, 1969).

Table 1. Balance sheet of nitrogen in the United States: estimated changes from 1930 to 1980 on harvested cropland

Item	Nitrogen--millions of tons			
	1930[1]	1947[2]	1969[3]	1980[4]
Inputs of nitrogen from:				
1. Fertilizer N	0.3	0.7	6.8	12.2
2. N fixed by legumes	1.7	1.7	2.0	2.5
3. N fixed (nonsymbiotic)	1.0	1.0	1.0	1.0
4. Barnyard manure	1.9	1.3	1.0	0.9
5. Roots of unharvested portions of crops	1.1	1.5	2.5	3.0
6. Rainfall	0.8	1.0	1.5	1.8
Total	6.8	7.2	14.8	21.4
Removals of nitrogen by:				
7. Harvested crops	4.6	6.5	9.5	13.0
8. Erosion	5.0	4.0	3.0	2.0
9. Leaching of soil N	4.0	3.0	2.0	1.5
10. Leaching of fertilizer N	0	0	?	1.2
11. Denitrification	?	?	?	2.2
Total	13.6	13.5	14.5	19.9

[1] Lipman and Conybeare (1936)

[2] Mehring and Parks (1950)

[3] Stanford *et al.* (1970)

[4] Estimates by the author after procedures cited by Stanford *et al.* (1970). Leaching of fertilizer N and denitrification removals are based on 10 and 18% of fertilizer N applied, respectively.

surface and groundwater (Commoner, 1968). This, in turn, is related to increased eutrophication of streams, lakes, and reservoirs, and to potential health hazards[1] to humans (particularly infants, from methemoglobinemia) and livestock (particularly ruminants) which might consume surface and groundwaters of excessive NO_3^- content. They also charge that the high NO_3^- content of certain vegetables (e.g., beets, cabage, and spinach) is related to excessive use of fertilizer N, and also constitutes a health hazard, especially in baby foods.

Agriculturists, on the other hand, have responded to these accusations in a particularly defensive way, insisting that fertilizers are not currently a serious source of enrichment of surface and groundwaters, and that increased NO_3^- levels monitored in streams and groundwater in close proximity to agricultural areas are not sufficient proof that fertilizers are involved. They point out that sources of NO_3^- other than fertilizers could be contributing in a much more significant way to this phenomenon, including treated and untreated sewage effluent, animal wastes, food processing wastes, industrial effluent, biological N_2 fixation in aquatic environments, mineralization of soil organic N, and movement of water through geologic formations of high NO_3^- content. Support for this thesis can be found in several recent reviews, wherein the authors conclude that nutrient enrichment of water resources from fertilizers is probably minimal under most conditions (Aldrich, 1970; Viets, 1970; Viets and Hageman, 1971).

A number of agricultural spokesmen, however, will readily admit that, at the present time, there is not sufficient reliable experimental data to adequately evaluate the real and/or potential contribution of fertilizers to the pollution of natural waters. For example, Nelson (1970) states:

> Field research is needed as soon as possible to determine whether fertilizers contribute to contamination of natural waters; if so, how much, where and under what conditions; and whether, in relation to other sources of N and P, the fertilizer contribution is enough to justify strong control measures. Such information does not exist.

He also urges that, "field research should be initiated on amount, time, method of application, and kinds of fertilizer needed to improve crop recovery and reduce nutrient losses". Accordingly, Nelson (1971) suggested several approaches to determining the contribution of fertilizer nutrients to surface and groundwaters. One involves the use of small confined watersheds or tile-drain plots where the fate of different fertilizers could be accurately evaluated by continuous or frequent monitoring of the nutrient content of the runoff, leachate, and groundwater. Another approach could involve the application of fertilizers to conventional erosion plots, and subsequent monitoring of the nutrient content of runoff, sediment, soil (by depth increments), and groundwater.

Viets (1970) also points out the need for such information. In discussing the countless field experiments of the last 30 years to assess crop response to fertilizers, he states:

> "Almost universally the experiments have failed to determine how much of the fertilizer runs off, is carried off on eroding particles of soil, or percolates below the root zone".

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[1] The U.S. Public Health Service Drinking Water Standards recommend that the nitrate content of water for this purpose not exceed 45 mg/l (ppm) as NO_3^- (equivalent to 10 mg/l as NO_3^--N). The subject of "Health effects of nitrates in water" is discussed in detail elsewhere (Case et al., 1970).

Furthermore, he emphasizes:

> "We do not have a balance sheet of inputs and outputs of nutrients applied to a cropping system over a long period of time in any section of the country".

Comment by Viets and Hageman (1971) regarding NO_3^- enrichment of groundwater in the Midwestern U.S. are also appropriate:

> "The rate of water recharge is so slow that the possible nitrate pollution of aquifers from our modern technology will take decades. However, once nitrate gets into the aquifer, decades will be required to replace the water with low nitrate water. Fifty to 100 years might be required to establish a time trend, considering the heterogeneity of the aquifers. By the time the trend was established, a dangerous situation could be in the making that could not be corrected in a time shorter than it took to create".

One wonders as to just how far we might be into this time trend already for certain aquifers.

Since so little information is available on this subject, on might seriously question the validity of certain assumptions and conclusions expressed by some agriculturists in attempting to refute the charges of some ecologists on the plant nutrient-water quality issue.

Evidence of the Enrichment of Natural Waters by Fertilizer Nitrogen

Based on a number of recent reports, a few of which are cited here, it would appear, at least to this writer, that in some situations fertilizer N may indeed be contributing significantly to NO_3^- enrichment of surface and groundwaters.

Bingham et al. (1971) evaluated the NO_3^- leaching losses from an irrigated 384 hectare citrus watershed in California which received 144 kg N/ha/year. The mean concentration of NO_3^- in the effluent drainage water over a three year period was 50 to 60 mg/l and represented a loss of 45 percent of the applied N.

Stewart et al. (1967, 1968) analyzed soil core samples from the South Platte Valley of Colorado, an area subject to intensive farming, and found that the mean NO_3^--N concentration to a depth of 6.7 meters as related to land use was: alfalfa 70, native grassland 81, cultivated dryland 233, irrigated fields (excluding alfalfa) 452, and feedlots 1282 kg/ha. They estimated that 28 to 33 kg N/ha/year were lost to the water table from irrigated fields.

In a summary of groundwater investigations in California, Ward (1970) reported on five problem areas where from 1953 to 1968 the NO_3^- content of water pumped for domestic use exceeded the USPHS standard of 45 mg/l. The major contributor of NO_3^- to groundwater in one area was domestic sewage discharge. However, the principal sources of NO_3^- enrichment in at least two areas were directly related to irrigation agriculture and the increased use of fertilizer N. In one of these two areas, domestic sewage was excluded as a source of NO_3^- since the volume of sewage discharged by percolation was negligible compared with the amount of fertilizer N applied.

Harmeson and Larson (1970) and Harmeson et al. (1971) reported analytical data on the NO_3^- content of surface waters in Illinois, which show that prior to 1956 the USPHS standard of 45 mg/l was not exceeded in any of the streams sampled. However, since then this standard has been equalled or exceeded in at least 9 major streams. High NO_3^- concentrations were consistently found in areas of intensive agricultural production where soils are well-drained, fertile, rich in organic N, and where high levels of fertilizer N are applied.

These authors also reported that increased NO_3^- concentrations were correlated with increased stream flow, both reaching maximums during late winter and early spring, with minimums attained in late summer and early fall (figure 4). This seasonal variation would tend to implicate an agricultural source(s) of NO_3^- as the principal contributor, in view of the constancy of seasonal N outputs from sewage treatment plants. Moreover, if such plants were a significant source of NO_3^-, the pattern would be quite different, since the NO_3^- content of sewage discharge would be diluted during periods of high flow. Thus, a reasonable assumption is that peak flows in late winter would coincide with NO_3^- (possibly accumulated in soil from the previous season) leaching and draining from agricultural areas during periods of excessive precipitation. With the advent of mineralization and nitrification of soil organic N, and nitrification of fertilizer N in the spring, the phenomenon is reinforced.

In a detailed study of the Kaskaskia watershed above Shelbyville, Illinois, these authors estimated the potential sources and their total N contribution to the Kaskaskia River as:

a.	Soils	61.5 %
b.	Commercial Fertilizers	28.8 %
c.	Animal Wastes	7.6 %
d.	Atmospheric Sources	3.8 %
e.	Domestic Wastes	0.3 %

It is of interest that the Illinois Pollution Control Board (IPCB) is now in the process of holding hearings on a proposal which, if adopted, would regulate the application of fertilizers (especially N and P sources) and animal manure on Illinois farms.

Therefore, it would seem that it is time for agriculturists to assume a less defensive, and indeed, more positive point of view in their approach to the plant nutrient-water quality issue. We may have no alternative but to accept the fact that in some cases Agriculture is contributing to environmental pollution. Where these situations exist we must seek to impose corrective and preventive measures. However, responding to emotional accusations by issuing equally emotional and blatant denials of any and all evidence which might implicate the contribution of fertilizers to impaired water quality- and to do so with little evidence to the contrary - will gain neither the support nor respect of the general public which is so essential to Agriculture.

Hopefully, the emotion that has clouded both sides of this controversy will soon give way to reason and objectivity. Our goal as agricultural scientists is to produce the necessary food and fiber with the least possible damage to our environment, and at the same time provide as many options to our farmers as possible. There are a number of options and alternatives for minimizing the loss of fertilizer N from the soil-root zone and increasing its utilization efficiency, which will subsequently be discussed.

Efficiency of fertilizer nitrogen and maximum yields

It is apparent from the foregoing that for the past three decades U.S. farmers have been using N fertilizers in ever increasing quantities. This has been brought about princi-

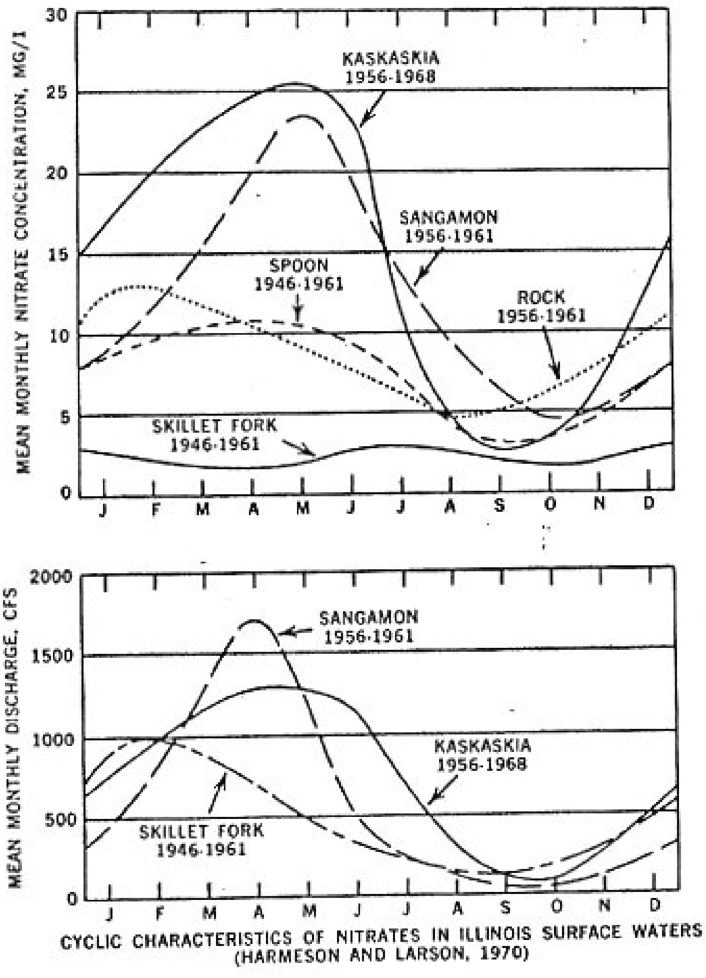


Figure 4. Relationship of mean monthly discharge and nitrate concentration in some Illinois streams (Harmeson and Larson, 1970).

pally by State and Federal research and extension agencies, as well as the fertilizer industry, who have emphasized that the highest permissible or recommended rate of fertilizer usage was necessary to achieve maximum yields. Thus, a discussion of the efficient use of fertilizer N relative to maximum crop yields is pertinent to the subject of this paper. An example cited by Lathwell et al. (1970) is particularly appropriate. Based on figure 3, they point out that N consumption increased by about 10 kg/N/ha/year from 1960 to 1967, while at the same time corn yields increased at a rate of 180 kg/ha/year. Assuming that only the grain was removed from the field, some two-thirds of the N applied cannot be accounted for in the crop.

Additional data by Lathwell et al. (1970) is used here to illustrate yield response of corn to applied N for high, intermediate, and low-yielding experiments in New York State (figure 5). These data, typical of such experiments, show that response to applied N increases with increasing yield; that is, response to N was greater at Group I sites compared with Group III sites. Moreover, these results show the characteristic diminishing response with each additional increment of applied N. Corresponding data by these authors (figure 6) illustrate the fact that the N content of the above-ground portion of the plants parallels the yield curves. The values shown in figure 6 indicate the efficiency of recovery of applied N by the crop- Two points here are of considerable significance. First, as the rate of applied N increased, the percentage recovery (i. e. efficiency) decreased progressively for each yield level. Second, for each increment of N applied, the percentage recovery increased as the yield level increased. These dat are quite typical of most experiments conducted to evaluate crop response (yield or uptake) as a function of N rate, and illustrate the diminishing response ot successive fertilizer N increments, and the rapid decrease in efficiency of utilization with increased application rates. These data also suggest that if one could increase the yield potential of a crop, fertilizer N use efficiency would also increase from utilization of "excess" N, thereby, decreasing the potential losses described earlier.

However, until such time that soil and crop scientists can find the ways and means of moving Agriculture off the yield plateau that presently exists for most crops, we are confronted with a situation similar to that discussed in the foregoing paragraph and illustrated in figure 7, where farmers must apply progressively less efficient increments of fertilizer N to attain maximum yields. In this hypothetical example, corresponding values for corn grain yields, profit gains, and probable recoveries of N in the grain from successive increments of fertilizer N (56 kg N/ha) are shown in table 2. As before, the first increment of N was the most efficient, with a recovery of 80 percent, an increase in grain yield of 50 bu/A (3000 kg/ha), and a gross profit of $50 (based on a corn price of $1.00/bu). Considering the cost of fertilizer N applied at $0.08/lb/A ($0.07/kg/ha) this farmer's profit gain was $50 minus $4, or $46. Similarly, the second and third increments of fertilizer N were also profitable, yielding gains of $21 and $4, respectively, although values for efficiency of N utilization were only 40 and 15 percent, respectively.

The result of the fourth increment of fertilizer N is of particular interest since it produced only 4 bu/A (240 kg/ha) of corn grain, and based on the selling price of corn and the cost of N applied, the profit gain was zero. The point here is that it didn't pay this farmer to apply the last increment of fertilizer even though he did reach the point of maximum yield by doing so. There are those who would argue that this last increment of N is absolutely necessary to ensure economic production and low food costs. However, in this example, as in most cases where the point of greatest economic return to applied N is usually somewhere below the point of maximum yield, it is doubtful whether the last

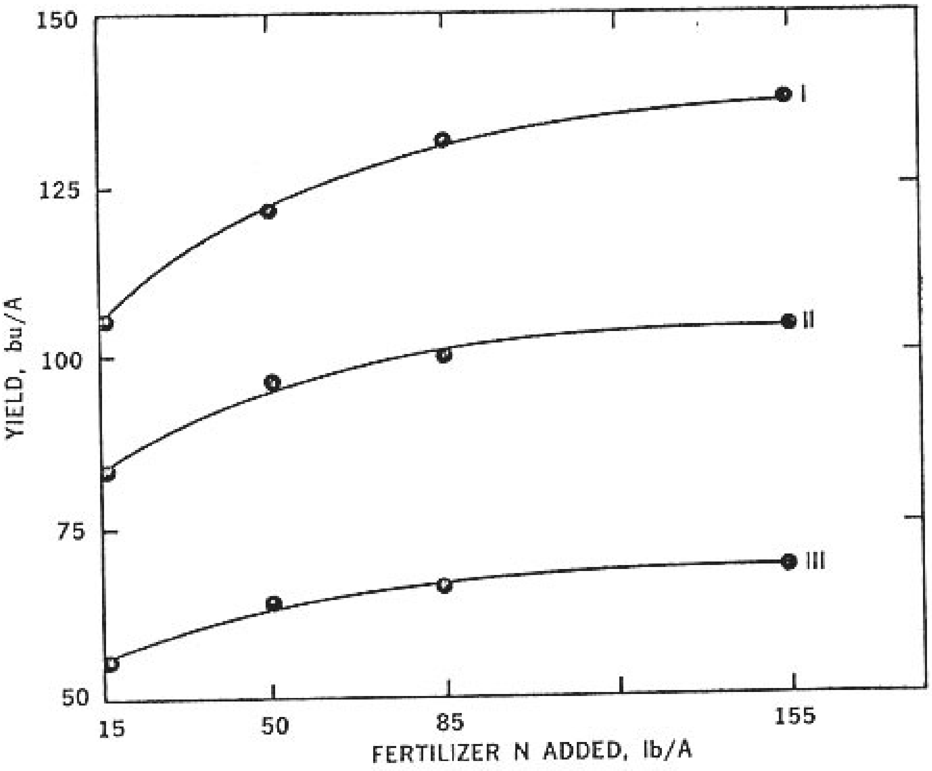


Figure 5. Response of corn (grain) to applied N for 21 location-years of data in New York. The curve labeled I is the mean of the 7 highest yielding experiments, curve II the mean of 7 intermediate experiments, and curve III the mean of the 7 lowest yielding experiments (Lathwell *et al.*, 1970).

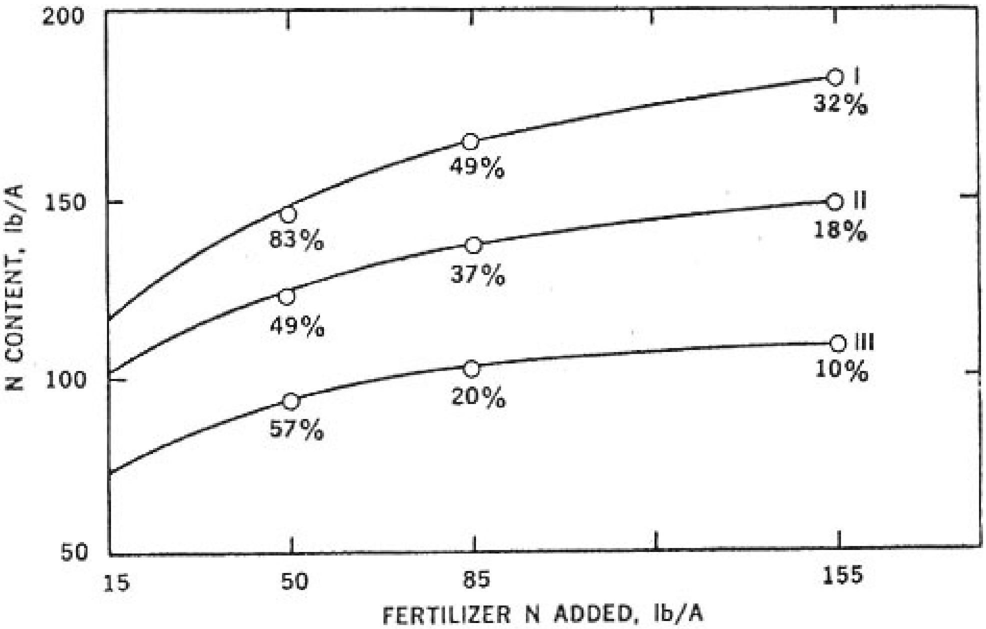


Figure 6. N content of the above ground dry matter of corn relative to applied N for 21 location-years of data in New York. Curves I, II, and III correspond to the definitions given in Figure 5. Numbers adjacent to the curves are the increases in N content resulting from each increment of N expressed as percent of the fertilizer N applied (Lathwell *et al.*, 1970).

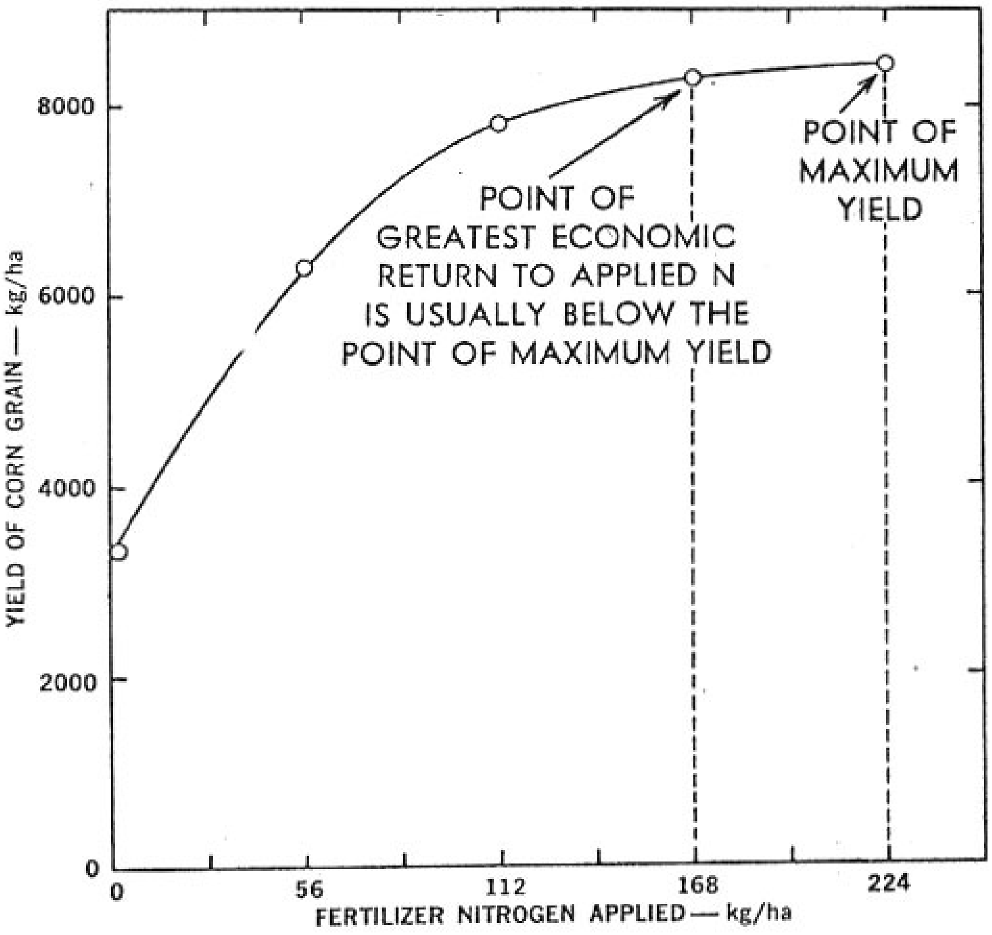
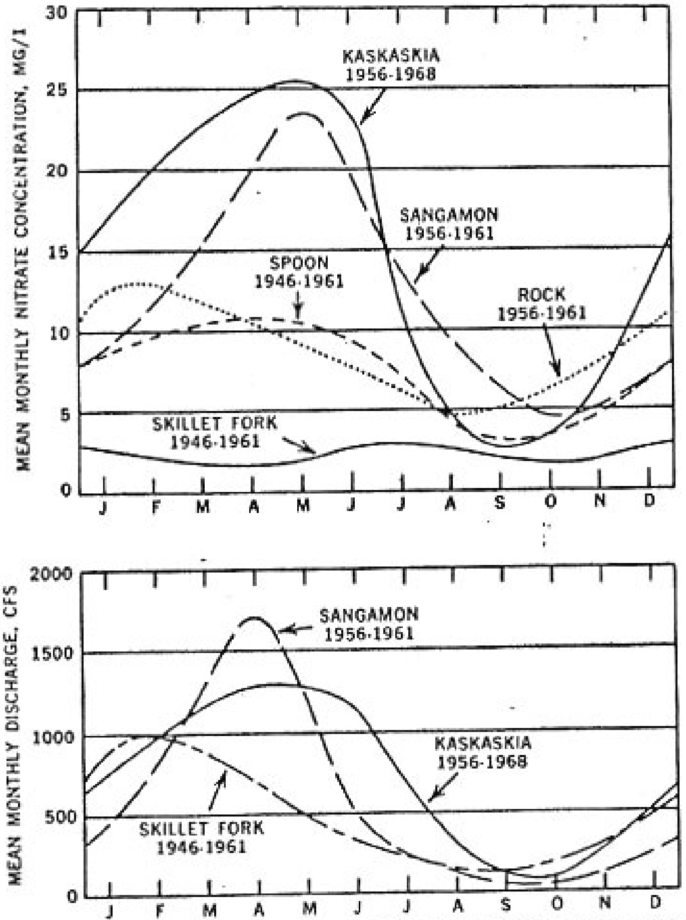


Figure 7. Hypothetical representation of crop response as a function of N rate, illustrating the point of greatest economic return to applied N and the point of maximum yield.



CYCLIC CHARACTERISTICS OF NITRATES IN ILLINOIS SURFACE WATERS
(HARMESON AND LARSON, 1970)

Figure 4. Relationship of mean monthly discharge and nitrate concentration in some Illinois streams (Harmeson and Larson, 1970).

increment of N could be justified. Since yield response curves are relatively flat between these two points, which are somewhat difficult to predict accurately over a wide range of field conditions, the prevailing philosophy (in view of the low cost of fertilizer N) has been that the farmer had little to gain or lose even if he exceeded the "optimum" N rate by 50 or 100 kg N/ha. Indeed, where N fertilizer is considered as a production input, most U.S. farmers think in terms of maximum yields rather than the point of greatest economic return.

In view of the fact that little more than 5 percent of the applied N was recovered from the fourth increment, leaving 90 percent (45 lb/A or 50 kg/ha) as a potential pollution hazard, it is also questionable whether this last increment of fertilizer N could be justified. While the cost of fertilizer N is low enough to tolerate such low recoveries from a strictly economic standpoint, they will probably not be tolerated by the general public from the pollution standpoint. This reasoning was also reflected by Lathwell et al. (1970) who concluded that, "a careful economic analysis of application rates (N) must be made since at high rates little yield response to the final increment is obtained and the efficiency of use is very low. Thus, rate of application must be adjusted to maximize return and minimize loss to the environment". Olsen et al. (1970) also suggested that fertilizer N rates be limited to approximately that required by the crop, as did Linville and Smith (1971) who concluded that to avoid unnecessary contributions of NO_3^- to groundwater, fertilizer N greatly in excess of that required by the crop should not be applied.

It would therefore seem that increasing the efficiency of fertilizer N is among Agriculture's highest research priorities. A breakthrough in this area might allow a significant reduction in fertilizer N rates without lowering the yield potential.

A rational approach to fertilizer N recommendations

There is a need for a more rational approach to fertilizer N recommendations. Fertilizer N use practices are influenced primarily by such considerations as (a) field experiments relating crop response to N rate, (b) expected crop yields, (c) cost of fertilizer N, (d) availability of applicating equipment, and (e) experience and preference of the grower. While these factors are often important, consideration of the amount of mineralizable soil N and residual fertilizer N, both of which can contributesignificantly toward the N requirement of crops, are largely ignored in formulating N fertilizer recommendations. In view of the high rates of fertilizer N currently applied, decreased utilization efficiency at maximum yields, and the potential for N loss to natural waters, it is important that we eliminate, as much as possible, the "guesswork" presently involved in making fertilizer N recommendations. Comments by Stanford (1966) are particularly appropriate:

> "In formulating recommendations for nitrogen fertilizer use, agronomists and soil scientists have relied mainly on experience and interpretations of the numerous field and associated laboratory studies conducted over the years. These efforts have served the farmer and the agricultural chemical industry well. Future progress, however, demands that less empirical means be developed for predicting and meeting the nitrogen needs of the crop.

A rational approach to more meaningful N fertilizer recommendations requires a knowledge of three criteria, i.e., the N requirements of crops for expected attainable yields, the mineralization potential of soil organic N, and the amount of residual fertilizer N available from previous applications. An estimate of the efficiency of N use for a specific set of crop, soil, climatic, and management conditions is also essential.

The usual objective or goal in applying fertilizer N is to ensure that crop yields will not be limited by inadequacy of N. However, according to Stanford (1971), relatively few field experiments have provided a specific understanding of the minimum amounts of N that must be absorbed by a crop for various attainable yields to ensure adequacy. The N requirement value for a crop is defined as "the minimum amount of N in the aboveground portion associated with maximum production (Stanford, 1966)". Although this value is quite variable for certain forage grasses, it is now reasonably well-defined for such crops as sugarcane, small grains, and corn. For example, Stanford (1966, 1971) reported that the N requirement for near maximum corn yields, over a wide range of soil and climatic conditions, was from 1.2 to 1.3. percent. As the N content of the plants dropped below 1.2, corn yields (grain) declined accordingly.

According to Bremner (1965a) more than 95 percent of the total N in most surface soils is in the organic form. The organic soil N is mineralized by microbial processes to plant-available inorganic forms (NH_4+ and NO_3^-) at rates ranging from 1 to 3 percent during a cropping season. For example, a soil having 2 percent organic matter would contain about 44, 000 kg of organic matter/ha (based on 2.2×10^6 kg soil/ha to a 15-cm depth), which would be equivalent to approximately 2200 kg N/ha (based on organic matter containing 5 percent N). Allowing for a mineralization rate of 2 percent, the soil would supply the crop with about 44 kg N/ha. Although this is a considerable amount of N for plant growth, it would rarely be sufficient to meet the demand for this nutrient based on current cropping practices (e.g., corn), and obviously would have to be supplemented by the application of fertilizer N.

It should be pointed out, however, that this type of calculation is most unreliable since the specific mineralization rate and amount of potentially mineralizable N for a particular soil is essentially unknown. Soil and crop scientists have long recognized the need for a method that would provide a reliable index of soil N availability - one which would allow an accurate prediction of the amount of fertilizer N necessary to produce the desired yield. Although a number of biological and chemical methods have been developed during the past three decades (Bremner, 1965b), few, if any, have gained widespread application. This can probably be attributed to (a) poor correlations of various laboratory indexes with soil N availability, (b) a recognition of the extreme complexity of the system and the generally pessimistic attitude regarding prospects for developing reliable quantitative methods for assessing soil N availability (Stanford, 1971), and (c) the low cost of fertilizer N relative to other crop production costs.

Presently, there is greater need than ever before for a reliable quantitative index of soil N availability. Recent work in this area by Smith and Stanford (1971) appears to be promising. They reported that the alkali-distillable N fraction of an extract obtained by autoclaving soil in 0.01 M $CaCl_2$ for 16 hours serves as a satisfactory chemical index of soil N availability. This index was highly correlated with soil N mineralized after 4 weeks of either aerobic or anaerobic incubation. In studies with soils from throughout the U.S. they (Stanford and Smith, 1972) observed that the mineralization process obeys first-order kinetics. Thus, from the amount of N mineralized during a series of laboratory incubations, they were able to calculate the specific mineralization rate constant and amount of potentially mineralizable N for each soil. Additional research is in progress to determine the reliability of this index.

The amount of residual fertilizer N in soil, both NO_3^- and NH_4+, should be a primary consideration in formulating N fertilizer recommendations; however, it is largely overlooked. Careful assessment of residual mineral N, especially that leached to lower depths in the soil profile, but still positionally available to plant roots, might allow substantial reduction of current high fertilizer N rates.

Lathwell et al. (1970) concluded that the amount of residual fertilizer N in soils of New York State was negligible. However, in a study of residual N in soils of the Southeastern U.S., where annual precipitation often exceeds 125 cm, Pearson et al. (1961) observed considerable residual effects of spring-applied N over a period of 16 months based on both yield and N uptake by various crops. Mean uptakes of 28 and 38 kg N/ha were attained by the second and third crops of corn from an initial application of 224 kg N/ha. Residual N in these studies produced a mean corn grain yield of 1140 kg/ha. These results emphasize the economic importance of residual N and these authors recommended soil test procedures be developed for its estimation.

Recent reports indicate that residual N also tends to accumulate in soils of the less humid Midwestern U.S., particularly where fertilizer N is applied at high rates. Herron et al. (1968) concluded that utilization of residual NO_3^- - N by plants (corn) was essential for preventing accumulation of nitrates in soil profiles. They suggested that this could be accomplished by reducing N fertilizer rates at 3- to 4-year intervals without appreciably reducing the yield potential. They also point out that most of the soil test correlation work with residual N has been based largely on its content in surface soils. Herron et al. (1968, 1971) and Olsen et al. (1970) suggest the importance of sampling and testing both surface and subsurface soils for residual mineral N to ensure more meaningful and accurate N fertilizer recommendations.

With reliable information on mineralizable soil N and residual mineral N, particularly fertilizer carryover, the following equation, modified from Stanford (1971), would provide a rational basis for predicting the amount of fertilizer N to be applied to corn,

$$N_f = \frac{CR - (N_{om} + N_r)}{E}$$

where:

N_f = amount of fertilizer N to apply

CR = N requirement of crop

[total dry matter (grain + stover) x 1.2%]

N_{om} = N mineralized from soil organic matter

N_r = residual mineral N (NO_3^- and NH_4^+)

E = efficiency factor

An assumption here is that mineralizable and residual N are utilized at the same efficiency as fertilizer N.

A corn crop (grain) of 6000 kg/ha (100 bu/A) contains about 5500 kg of dry matter (10-12% moisture content) and about the same amount of stover for a total dry matter production of 11 000 kg/ha. The N content of this plant material near maximum yield would be about 1.2 percent. The crop requirement for N would be 130 kg/ha (11 000 kg dry matter x .012). In the foregoing equation, if we assume that mineralizable N will be 40 kg/ha, residual N 30 kg/ha, and a 60 percent efficiency factor, the amount of fertilizer N to apply is approximately 100 kg/ha $\left(\frac{130 - 70}{0.6}\right)$.

Thus, the ultimate goal or objective in applying fertilizer N is really two-fold: (a) to supplement the amount of potentially available soil N and residual mineral N, to ensure that crop yields are not limited by inadequacy of N, but also (b) to ensure that the level of fertilizer N applied does not greatly exceed that necessary for attainable crop yields.

Increasing fertilizer nitrogen efficiency through soil and crop management

There are a number of ways in which the efficiency of fertilizer N can be increased through certain soil and crop management practices. This particular subject will be presented in more detail by another speaker; however, several practices are noteworthy here in view of their relationship to the present paper.

Lathwell et al. (1970) concluded that proper timing of application appears to be the most important consideration for increasing the efficiency of fertilizer N. When fertilizer N is applied far in advance of the time of maximum demand by the crop (i.e., the grand stage of growth) there is greater probability of loss by the mechanisms described earlier. If applied just prior to the grand stage of growth, such as in a side-dress application, less N will be required to produce the same yield. For example, they observed that the relative effectiveness of fall applied N compared with sidedress applied N on corn yields in New York State was only 40 percent; whereas, the effectiveness of spring applied N compared with sidedress N was about 80 percent. Similar data were reported by Pearson et al. (1961) which indicated that fall applied N in the Southeastern U.S. was only 50 percent as effective as spring applied N based on corn yields. In terms of nitrogen recovered, the relative effectiveness was about 60 percent.

Another option that could increase the efficiency of applied N, and minimize its movement to groundwater, is the use of deep-rooted crops, such as alfalfa, in rotation with high N-requiring crops. Stewart et al. (1968) reported little accumulation of NO_3^- in soil profiles under alfalfa, suggesting its capability as a "scavanger" for NO_3^- leached below the normal rooting depth of shallow-rooted crops.

In addition to limiting rates of fertilizer N to approximately that required by the crop, Olsen et al. (1970) proposed that the amount of NO_3^--N passing through the soil profile to groundwater could be limited by reducing the acreage and frequency of corn or other crops receiving N in the rotation, and maintaining cover crops on the land where feasible.

The Controlled Release Concept

A growing awareness of the low use efficiency of fertilizer N has caused the fertilizer industry to consider certain chemical and/or physical modification of conventional N fertilizers with the objectives of (a) minimizing leaching, denitrification, volatilization, and immobilization losses of applied N and (b) releasing an adequate amount of available N slightly in excess of the demands of the growing crop. The intended result would be an increase in N fertilizer efficiency. The concept of a controlled release of plant nutrients has been discussed by Nelson and Hauck (1965), Parr (1967), and Lunt (1971).

To achieve the objectives of controlled release, research efforts in this area have led to what might be called the coated granule approach as illustrated in figure 8.

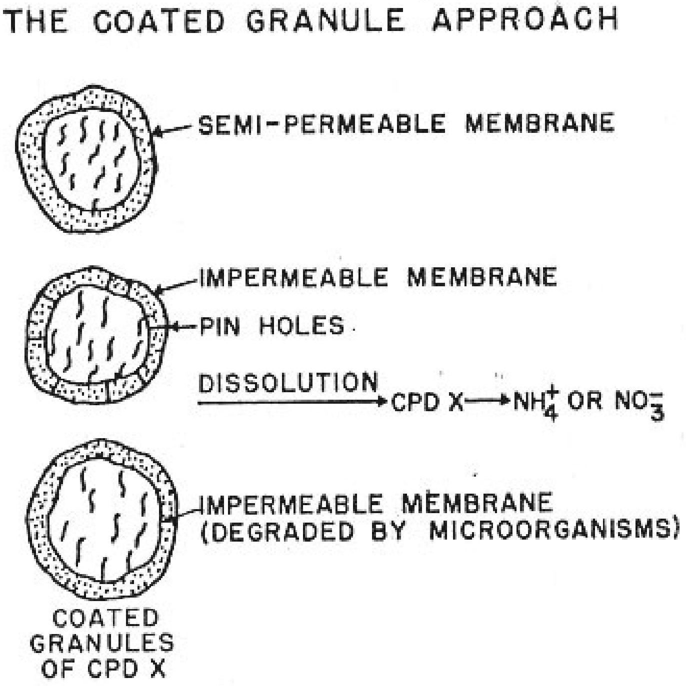


Figure 8. The coated granule approach to controlled release in which fertilizer N granules are coated with plastics, paraffins, or elemental S to achieve a desired release rate.

Fertilizer granules of urea and ammonium nitrate have been coated with various plastics, resins, waxes, paraffins, asphaltic compounds, and elemental sulfur in attempting to control the N release rate to more or less coincide with the daily and seasonal N demands of a growing crop. Coatings can be of three general types:

a. The semi-permeable membrane - Fertilizer N is released upon rupture of the membrane following the increase in osmotic pressure from water moving across the membrane into the granule.

b. The perforated impermeable membrane - Pinholes in the membrane provide the route of release for fertilizer N.

c. The solid impermeable membrane - The chemical nature of the membrane is such that N release is dependent on its degradation by soil microorganisms.

One of the more successful efforts thus far has been TVA's development of sulfur-coated urea (SCU) in which the release mechanism is essentially that of (a). It should be recognized, however, that coating adds to the cost of a fertilizer, and it is likely that N contained in SCU will cost 25 to 50 percent more per pound than uncoated urea N (Prasad, et al., 1971). Moreover, to achieve satisfactory release patterns the material must contain 15 to 25 percent sulfur (weight basis) which would provide little benefit in other than sulfur-deficient soils. Although it is unlikely that such materials will be seriously considered as a complete subsitute for highly soluble forms of fertilizer N, they have been recommended and used successfully on ornamentals, turf, and some forage crops, and offer some promise in certain areas subject to excessive N loss by leaching (Nelson, 1971).

The Balanced Dissolution Approach

The objectives of controlled release might also be achieved by use of N fertilizers of limited water solubility as illustrated in figure 9. Compounds such as oxamide undergo dissolution in soil at rates which vary inversely with the granule size, that is, the smaller the granule, the more rapid the dissolution rate. Thus, a specific N release rate could be achieved through balanced dissolution by selection and blending of different sized granules of oxamide, or similar compounds.

A second example of this approach shown in figure 10 involves the selection and blending of N fertilizers of varying water solubility to provide a range of dissolution rates. Conventional water soluble fertilizers such as urea or ammonium sulfate might be selectively blended with compounds of limited water solubility such as isobutylidenediurea (IBDU), oxamide or ureaform, to achieve the desired N release rate. In this case, the slow-release N fertilizers would be used as an adjunct in formulation with highly soluble N fertilizers and not as a subsitute for them. For example, IBDU, a condensation product from the reaction of urea and isobutyraldehyde can be mixed or blended with a wide spectrum of granular fertilizers, except strongly acidic superphosphate (Prasad, et al., 1971). In addition to IBDU, Mitsubishi Chemical Industries, Ltd., Tokyo, manufactures five blended fertilizers of the type illustrated in figure 10, where part of the N is supplied as IBDU and the balance as ammonium sulfate, urea, or diammonium phosphate. According to Prasad et al., (1971) some mixtures of IBDU and conventional N sources have been more effective (based on yield increases) than either component alone. It would seem that additional research and development is needed in this area, particularly in view of the relative simplicity of bulk-blending granular components and lower probable production costs, compared with the coated granule approach.

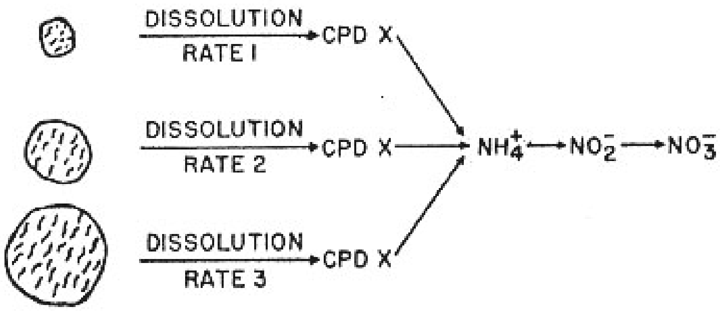

THE BALANCED DISSOLUTION APPROACH

Figure 9. The balanced dissolution approach to controlled release in which different sized granules of N fertilizers of limited water solubility are blended to achieve a desired release rate. In this case, dissolution rate varies inversely with granule size.

THE BALANCED DISSOLUTION APPROACH

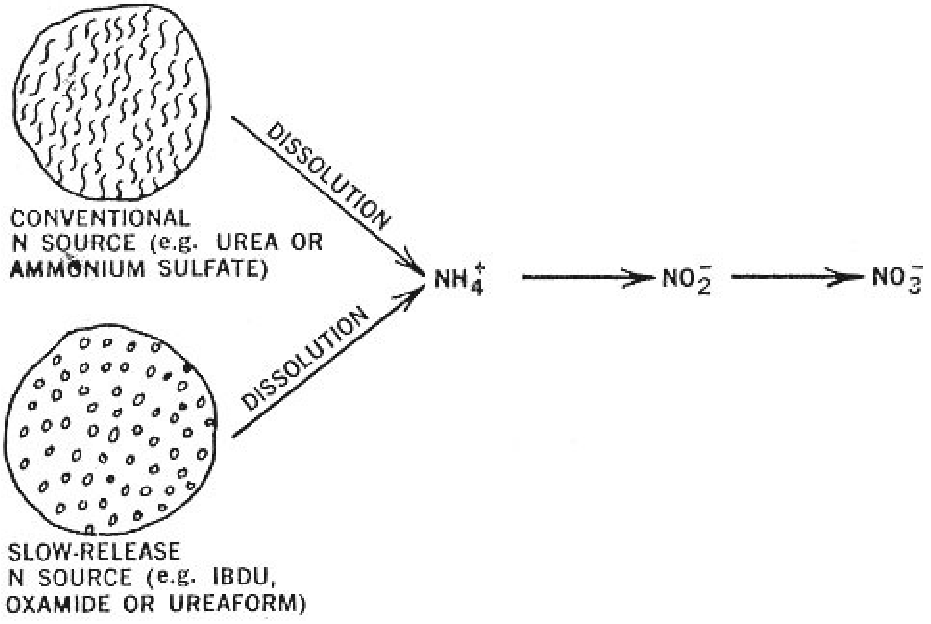


Figure 10. The balanced dissolution approach to controlled release in which N fertilizers of varying water solubility are blended to provide the desired dissolution or release rate. Conventional water soluble fertilizers might be selectively mixed with compounds of limited solubility such as IBDU, oxamide, or ureaform.

The Inhibitor Approach

Conventional ammoniacal N sources as well as those of limited water solubility are subject to nitrification by autotrophic soil bacteria. This approach involves the formulation of ammoniacal fertilizers with certain chemicals to repress or inhibit nitrification. An example of this approach is the use of Dow Chemical Company's N-Serve, 2-chloro-6-(trichloremethyl) pyridine to inhibit the genus Nitrosomonas which oxidizes NH_4^+ to NO_2^- in the initial step of the nitrification sequence. Inhibition of nitrification at this point would maintain fertilizer N in the NH_4^+ form for extended periods, and provide for increased efficiency through enhanced N uptake and yield. Unlike NO_3^-, NH_4^+ is not subject to loss by denitrification and leaching. A number of other organic compounds including thiourea, methionine, dicyandiamide, certain pesticides, and AM (2-amino-4-chloro-6-methyl pyrimidine), manufactured by Toyo Koatsu Industries, Tokyo, have been reported to inhibit nitrification (Prasad et al., 1971); however, these compounds appear to be less specific and usually less effective than N-Serve.

So far, nitrification inhibitors have simply been mixed with granular ammoniacal fertilizers or applied as coatings to the surface of fertilizer granules (Swezey and Turner, 1962; Turner and Goring, 1966), as illustrated in figure 11. Only a few experiments have been reported in which chemical inhibitors, e.g., N-Serve, were formulated (i.e., dissolved) in liquid anhydrous NH_3 and applied directly to soil in an attempt to suppress the rate and extent of nitrification of NH_3^--N (Turner and Goring), 1966; Parr et al., 1971a). The relative ease of formulating and applying liquid fertilizer-inhibitor solutions offers distinct advantages compared with granular preparations.

The recent development of a special field applicator (Smiley and Papendick, 1970) has allowed a rather intensive evaluation of NH_3+N-Serve and NH_3 + potassium azide (KN_3) solutions at several locations in the U.S. Potassium azide, an inorganic pesticide, has been well documented as an effective inhibitor of cytochrome oxidase in respiratory metabolism of many microorganisms, plants, and animals. It is active as a bactericide, fungicide, nematicide, and herbicide, and in certain laboratory tests was effective as a nitrification inhibitor (Parr et al., 1971a).

Papendick et al. (1971) applied solutions of NH_3 + KN_3 (2 and 6% by weight of KN_3) to soils of the winter wheat area of eastern Washington State in the month of August, at a rate of 112 kg N/ha. Two months later, the amount of NO_3^- - N recovered from the retention zone, as percent of total extractable N, was 67, 48, and 36 percent for NH_3 alone, NH_3 +KN_3 (2%), and NH_3 +KN_3 (6%), respectively. Nitrification inhibition due to KN_3 was still evident 6 months after application. These results indicate that KN_3 formulated with anhydrous NH_3 was an effective nitrification inhibitor for this N source under the prevailing soil and climatic conditions.

Parr et al (1971b) evaluated the relative effectiveness of KN_3 and N-Serve formulated in anhydrous NH_3 at levels of 3 and 6 percent by weight, and applied at rates of 112 and 168 kg N/ha to sugarcane in Louisiana. As shown in figure 12, based on the amount of residual NH_4^+ -N in the retention zone, the order of nitrification inhibition was: NH_3+N-Serve > NH_3+KN_3 > NH_3 alone. Ammonia alone was almost completely nitrified after 4 weeks, while N-Serve with NH_3 caused a significant suppression of nitrification for 12 weeks. At the 6 percent inhibitor level, after 4 weeks, KN_3 was only about 30 percent as effective as N-Serve at either N rate. The greater residual activity of N-Serve was apparently related to its low solubility in soil water, compared with the high solubility

THE INHIBITOR APPROACH

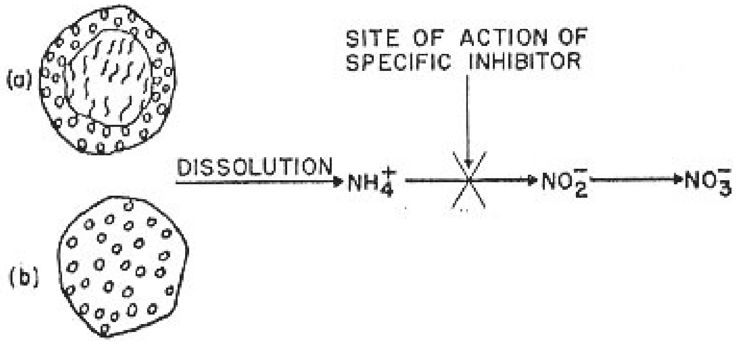


Figure 11. The inhibitor approach in which nitrification inhibitors are either mixed with granular ammoniacal N fertilizers, or applied as surface coatings, thereby maintaining fertilizer N in a cationic form for extended periods.

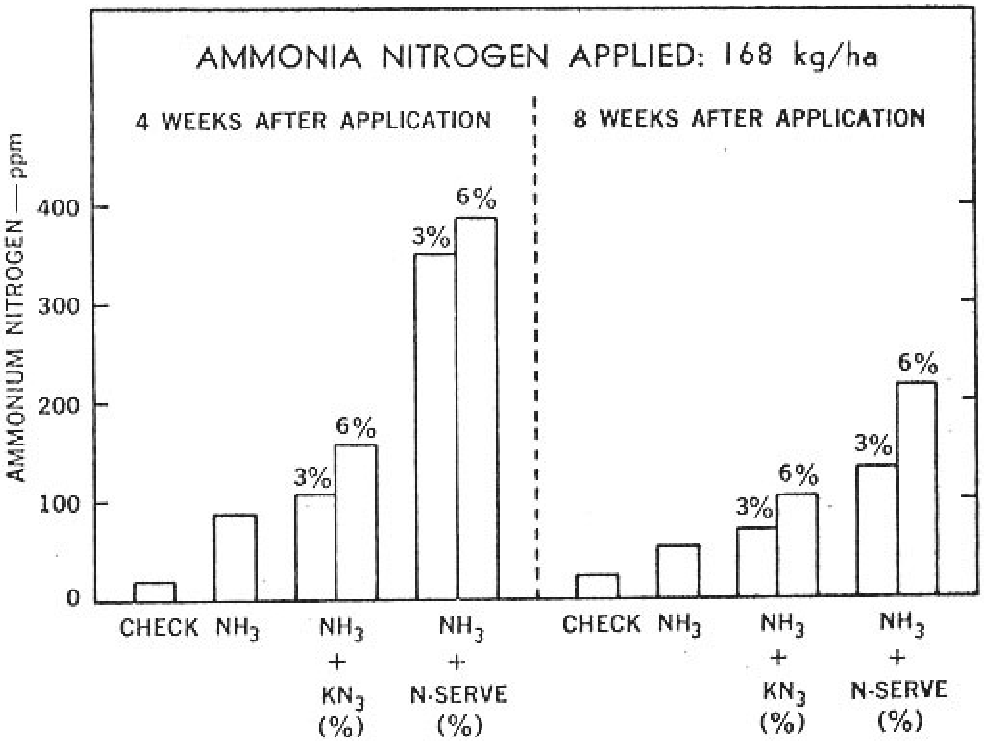


Figure 12. Concentrations of ammonium N 0- to 2-cm around the release point of anhydrous NH_3 and solutions of NH_3 formulated with two inhibitors, 4 and 8 weeks after application to soil in Louisiana.

of KN_3 and its greater leaching potential. Yield increases of about 4500 kg/ha of millable cane were obtained with NH_3 +KN_3 at the 112 kg N/ha rate compared with NH_3 alone; however, no differences between these two treatments were observed at the higher N rate. On the other hand, yield increases of about 12,000 kg/ha were obtained from 112 kg N/ha applied as NH_3 +N-Serve (3 and (%) compared with NH_3 alone, and were equal to yields resulting from 168 kg N/ha without N-Serve. These data indicate that the efficiency of fertilizer N applied to sugarcane can be increased by suppressing nitrification of anhydrous NH_3, particularly with N-Serve.

Inhibition of nitrification would cause plants to utilize NH_4^+ -N to a greater extent than in the absence of such inhibition. The effects of NH_4^+ and NO_3^- ions in plant nutrition have been the subject of investigation for the past 50 years. Although much of the work has been conducted in nutrient solution rather than soil, certain consistent observations have been reported. Plants supplied with NH_4^+-N often contain lower concentrations of certain inorganic cations such as Ca, Mg, and K, and higher concentrations of elements absorbed as anions, i.e., S, P, and Cl, compared with tissues of plants receiving NO_3^- -N. Moreover, plants subject to NH_4^+ nutrition usually contain higher concentrations of amino acids but lower accumulations of organic acids. A number of researchers have reported that plants supplied wholly with an NH_4^+ form of N grow less vigorously than with NO_3^-.

Possible reasons for such differences including (a) effect on electron transfer systems, (b) interrelationships with carbohydrate metabolism, (c) NH_3 toxicity, (d) ion uptake and competitive interactions, and (3) effects of pH were discussed by Kirkby and Hughes (1970). For example, NH_4^+ absorption for most plants reaches a maximum above pH 7, whereas that for NO_3^- is near pH 4. Nevertheless, where adequate pH control of the rooting medium (soil or solution) is maintained, it appears that NH_4^+ is probably as effective a source of N as NO_3^-, providing there is proper balance of other nutrients. Goring (1962a) speculated that the optimal nutrient balance for NH_4^+ nutrition would be somewhat different than the optimal balance for NO_3^- nutrition. He also points out that current fertilization practices are based on NO_3^- nutrition. Thus, with the increased potential for use of nitrification inhibitors, and consequent shift toward NH_4^+ nutrition, such practices may be subject to considerable revision. Future agronomic research in this area should receive high priority.

The Controlled Rhizosphere Approach

It has long been known that soil microorganisms are more abundant in the region of contact between root and soil, i.e., the rhizosphere, than in soil beyond the influence of plant roots. Microbial numbers and activity are increased in this zone because of the availability of carbonaceous and nitrogenous materials arising from sloughed-off root hairs or epidermal cells, or exuded from normal healthy plant roots. Plant root exudates may include sugars, amino acids, vitamins, organic acids, nucleotides, flavonones, auxins, and enzymes (Rovira, 1962).

The quantitative and qualitative nature of the root surface-rhizosphere microbial population is determined to a large extent by the nature of the plant root exudates, which in turn depends on root metabolism. Root metabolism is affected by a whole host of factors, including soil chemical and physical properties, atmospheric conditions, and the stage of plant growth (Starkey, 1958).

The principal objective of this approach to increased fertilizer N efficiency would be to seek ways and means of controlling the root surface-rhizosphere microflora to the nutritional advantage of the host plant. A controlled rhizosphere would be of considerable advantage to the plant if microbiological immobilization of fertilizer N could be avoided. Bartholomew and Clark (1950) and Legg and Allison (1960) concluded that significant amounts of fertilizer N are rapidly assimilated by the rhizosphere microflora, thereby becoming immobilized and temporarily unavailable to the plant. The resulting loss of fertilizer N efficiency is apparent.

There is evidence that the chemical nature of plant root exudates can be markedly changed through foliar application of different chemical compounds, including fertilizers such as urea. Such treatments have reportedly caused significant changes in root surface-rhizosphere populations (Ramachandra-Reddy, 1959; Venkata Ram, 1960). These observations provide a basis for future research which could contribute substantially toward increasing the efficiency of fertilizer N. For example, compound X might be applied to soil or foliage, either in combination with an N fertilizer or separately, to change the chemical nature of plant root exudates, resulting in a shift from rhizosphere population "A", in which there is extensive immobilization of N, to population "B", where there is less immobilization.

Summary and Conclusions

Most N fertilizers are subject to certain chemical, physical, and biochemical events which can result in significant losses of N from the soil-root zone after application. Under many soil and cropping conditions, fertilizer N use efficiency, i.e., the percentage recovery of fertilizer N by the crop, is often 50 percent or less. In view of the increased use of fertilizer N to sustain maximum yields for economic production, and Agriculture's potential contribution to the eutrophication of surface waters, nitrate enrichment of groundwaters, and possible health hazards which could result therefrom, this paper considers a number of approaches for maximizing the efficiency of fertilizer N. There are principally two ways of increasing fertilizer N efficiency, first, by minimizing losses of N from the soil-root zone, and second, by manipulating environmental and management factors to allow the plant to fulfill its genetic capability for maximum yield and quality.

As the rate of applied N increases, fertilizer efficiency (both yield and N uptake) decreases progressively, often to a point where a considerable amount of the last increment of fertilizer N is a potential pollution hazard. Since the point of greatest economic return to applied N is usually somewhere below the point of maximum yield, it may be possible to adjust application rates to maximize return and minimize loss to the environment.

There is a need for a rational approach to more meaningful N fertilizer recommendations. This requires knowledge of three criteria, i.e., the N requirement of the crop for expected attainable yields, the mineralization potential of soil organic N, and the amount of residual fertilizer N. A reliable estimate of the efficiency of N use of a crop for specific soil, climatic, and management conditions is also essential. With this information the ultimate goal in applying fertilizer N is two-fold: (a) to supplement the amount of mineralizable soil N and residual N, thereby ensuring adequacy for crop yields, and also (b) to ensure that the amount of fertilizer N applied does not greatly exceed that necessary for attainable yields.

Fertilizer N efficiency can be increased through certain soil and crop management practices including:

1. Proper timing of application to coincide closely with the grand stage of growth or time of maximum crop demand;
2. Use of deep-rooted crops such as alfalfa in rotation with high N-requiring crops;
3. Maintaining cover crops on the land where feasible.

There are also some chemical and biochemical considerations for increasing the efficiency of fertilizer N by minimizing leaching, denitrification, volatilization, and immobilization losses of applied N, including:

1. Use of coated granules for controlled release, i.e., granules which release an adequate amount of N at a rate coincidental with the daily and seasonal demands of the crop;
2. Use of N fertilizers of limited water solubility to achieve the objectives of controlled release, e.g., a blending of conventional water soluble fertilizers with compounds such as oxamide or IBDU for balanced dissolution to achieve the desired release rate;
3. Use of nitrification inhibitors to maintain fertilizer N in the NH_4^+ form for extended periods. Variations of this approach include mixing or coating fertilizer granules with the inhibitor, or formulating the inhibitors in liquid fertilizer systems such as anhydrous NH_3;
4. Use of a chemical approach for controlling the microflora of the root surface-rhizosphere region of crop plants to minimize immobilization of fertilizer N.

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FACTORS DETERMINING THE LEACHING OF NITROGEN FROM SOIL, INCLUDING SOME ASPECTS OF MAINTENANCE OF WATER QUALITY

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Introduction

When considering the question of eutrophication of flowing and enclosed surface water and the increased nitrate content in upper ground water observed in some areas, it is interesting to establish not only how much nitrogen stems from the waste and sewage of urban areas, but also the amount of this nutrient derived from soil. The fact that the rate of leaching varies so greatly poses the question as to which factors play an important part in removing nitrogen from the topsoil, and what the interrelation of these factors is.

I propose to discuss the most important factors affecting nitrogen leaching, concentrating mainly on conditions encountered in Europe. Most of the results quoted were obtained from lysimeter trials, a large number of which were carried out in the Agricultural Research Station in Limburgerhof, where we have had a lysimeter installation with a total of 232 plots in operation since 1927.

As far as techniques are concerned, it must be borne in mind that the results of lysimeter trials have certain limitations when applied to practice. Some of the reasons for this are the limited profile (depth) of the soil, the lack of contact with ground water and the often relatively loose nature of the soil. However, the lysimeter still provides the best method of obtaining data on nutrient leaching under a great variety of conditions (type of soil, crop, rotation, fertilization etc.). The results of quantitative studies carried out in lysimeters generally represent the upper limit for nitrogen leaching from soil that would be possible under the most unfavourable conditions encountered in practice.

The results obtained so far from lysimeter trials provide abundant material for the study of vertical leaching of nitrogen from soil, both from the point of view of crop production and of environmental protection. It would be useful if we could obtain in the near future the corresponding figures for runoff, even though the amount of nitrogen transmitted to ground water, as sufficient quantities for eutrophication are usually already present in the former. Therefore in this case, nitrogen , in contrast to phosphate, cannot be regarded as a minimum growth factor according to Liebig's law.

2. Effect of amount of rainfall on nitrogen leaching

It is obvious that climatic conditions, and in particular the amount and distribution of rainfall, affect the quantity of water leached and thus indirectly also affect nitrogen leaching. Figure 1 shows an example of the close correlation between rainfall and leaching water in sandy soil over a period of 13 years.

The relation between rainfall, leached water and nitrogen leaching in three years with widely differing amounts of rainfall is shown in table 1. The results were obtained from lysimeter studies in sandy and loamy soils.
It is interesting to note that in some cases the amount of leaching water rises proportionally higher than the increases in rainfall. 1964 was a dry year, and only 25% of the rainfall leached to a depth of 1 metre, whereas 1966, which was moderately wet, the leached water accounted for about 50% of the rain. The figures recorded for 1968, a year with very high rainfall, were 64 and 68%. As was to be expected, the nitrogen losses by leaching increased correspondingly.

Table 1. Rainfall, leached water and nitrogen leaching

	1964 dry		1966 mod. wet		1968 v. wet	
	sand	loam	sand	loam	sand	loam
Rainfall, mm	374		615		779	
Leached water, $1/m^2$	95	93	312	309	527	497
Leached water as %age of rainfall	25		50		68	64
N in leached water, kg/ha	33	21	41	23	56	62

(Jung, Dressel and Buchner, 1969)

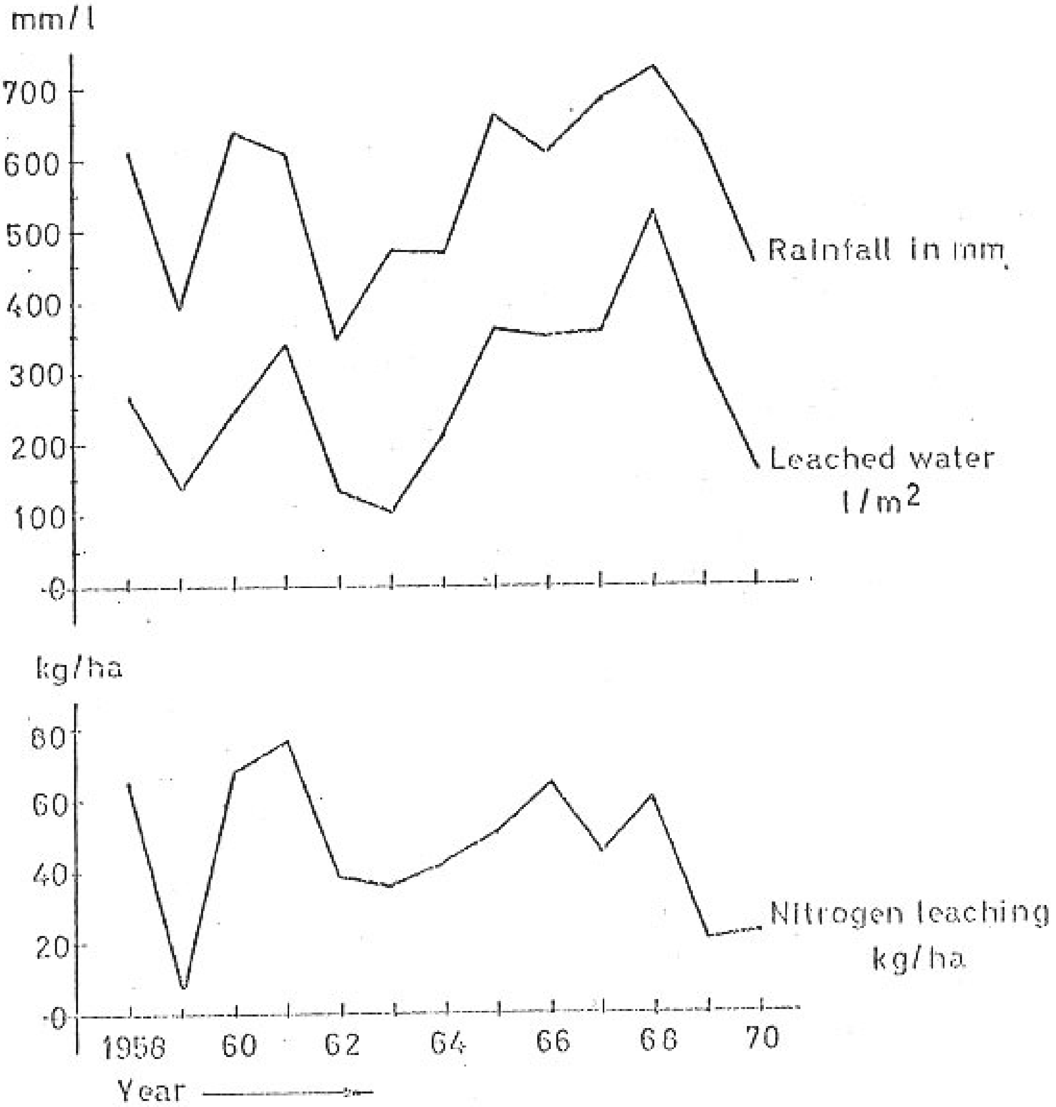
There was relatively little difference in the amounts of leached water from the two types of soil used in these experiments. Similar results can be quoted from earlier lysimeter studies. (Publication of the Research Station, Limburgerhof, 1939). These are to be seen in table 2.

Table 2. Type of soil and amount of leached water (Mean values over several years)

Average annual rainfall in mm	Type of soil	Leached water $1/m^2$/year
617	Sandy, alkaline	254
	Sandy, acid	233
	Loamy, alkaline	244
	Loamy, acid	180

Fig. 1: Rainfall, leached water and nitrogen leaching over a period of 13 years

(Neutral sandy soil, Limburgerhof)



It should be noted that higher rainfall does not necessarily result in increased nitrogen losses by leaching. By promoting growth and thus increasing the nitrogen uptake, additional irrigation in a dry summer can result in quite low leaching losses in the following winter and thus to a low overall loss.

3. Effect of the type of soil on leaching

In spite of the figures in table 1 proving that after the same N application rates there were somewhat reduced leaching losses from loamy soil in the dry and moderately wet years, there is very often no definite relationship between the type of soil (in the sense of the usual classification) and N leaching. Although the texture and structure of the soil do modify the effect to some extent, much more important factors are the soil's nitrogen content, almost 95% of which is organically bound, and its rate of mineralization. Scheffer and Schachtschabel (1966) give figures of 0.02 - 0.4% nitrogen in mineral soils, which is the equivalent jof 600 - 12 000 kg endogenous nitrogen per hectare topsoil. To take an example of an area of fairly good arable land with an endogenous nitrogen content of about 8 000 kg/ha and an average mineralization rate of 2%, which is the usual rate in Europe, every year one hectare of this land would release 160 kg nitrogen from the reserves in the soil. According to the above-mentioned data, it is theoretically possible for this figure to vary between 12 and 240 kg/ha N in the most widely differing types of soil. A. Finck (1969) quotes annual releases from the soil reserves of 30 - 270 kg/ha and leaching losses from humid soils of 5 - 30 kg/ha N.

It is a well known fact that climate also plays an important part in the amount of nitrogen accumulated in the soil and its release from the soil's reserves. This was proved by H. Jenny as long ago as 1930. He demonstrated that in soils with a comparable moisture, the nitrogen content is lower at higher mean temperatures that cause an increase in mineralization. The temperatures at which the observations were made ranged from a mean of 0°C in Canada to 21°C in the Southern United States (v. figure 2). One fact emerges clearly: that there is close correlation between the climate and type of soil, and these two factors are of primary importance in nitrogen balance and the extent of nitrogen leaching.

4. Effect of vegetative cover, cropping system and season on nitrogen leaching

Percolation of nitrogen can be affected to a large extent by the length of the plant's vegetation and by its water and nutrient uptake. This occurs both directly, by the uptake, and indirectly, through transpiration. According to R. Keller in his report on the water cycle in Western Germany, the figure for plant evaporation or transpiration is 370 mm. Thus no less than 45% of the mean annual rainfall of 825 mm is utilized by plants. This figure used to be lower but has risen steadily with the increase in crop production. The high proportion of water used in transpiration in this cycle offers an explanation for the following:

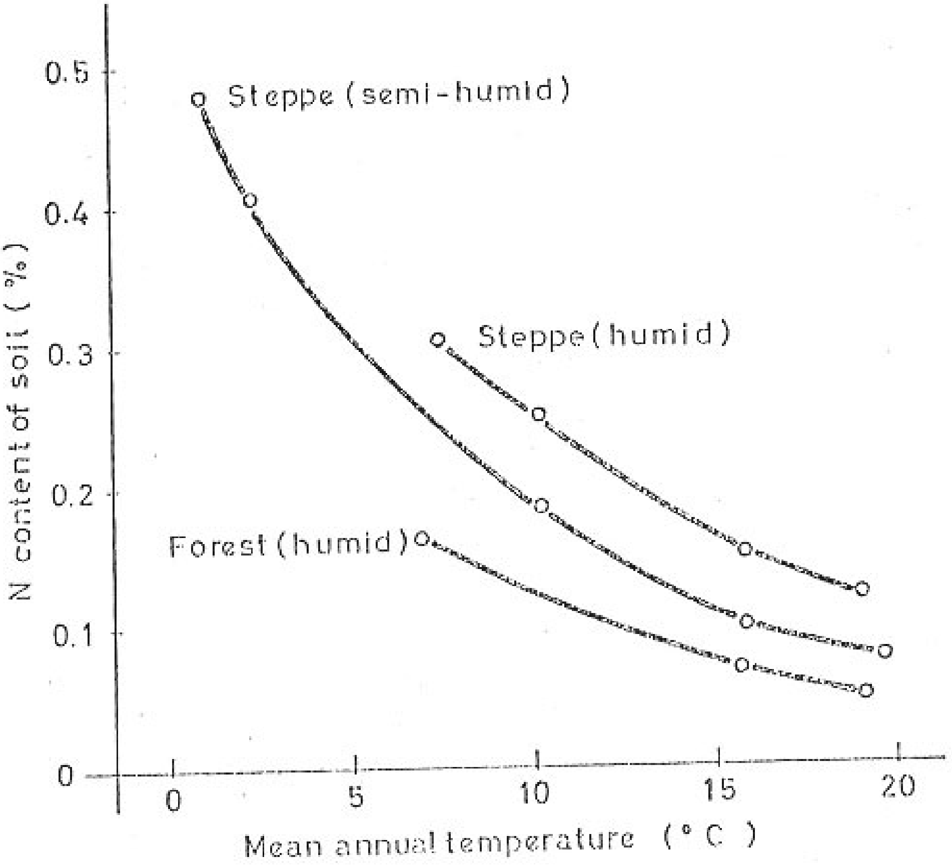
1. Nitrogen leaching from uncultivated fields (e.g. fallow) is generally the highest.

2. In cultivated fields most leaching occurs in winter, i.e. between vegetative periods.

3. The weaker and shorter the root system of a plant, and the lower the transpiration, the higher the N leaching.

Fig. 2: Relation between N content of soil and mean annual temperature in soils in the U.S.A. in different climates and types of vegetation

(Jenny, 1930)



Two examples from our lysimeter studies demonstrate these relationships. The first (table 3) shows the difference in N leaching in summer and winter. The second (table 4) gives details on the varying N losses from grassland, vineyards and fallow land.

Table 3. N leaching in summers and winters with varying amounts of rainfall

Rainfall	kg/ha N to a depth of 1 metre	
	Winter (Oct.-Mar.)	Summer (Apr.-Sept.)
Low	11	1
Moderate	16	7
Heavy	46	14

(C. Pfaff, 1963, Limburgerhof)

Table 4. Mean annual N uptake and leaching under various cropping systems

	Grassland	Vineyard	Fallow
N uptake kg/ha	190	80	-
N leaching kg/ha	10	80	160

(C. Pfaff, 1963, Limburgerhof)

By intensifying the use of the land, catch crops, particularly in winter, can appreciably reduce N leaching. In a study carried out in 1963, Pfaff recorded a relative N utilization of 63% with a potato - cereal rotation without a catch crop. With a catch crop the N utilization rose to 88%. In a further series of tests over a period of 4 years, N leaching was reduced from 69 to 24 kg/ha by the judicious cultivation of catch crops. The results of investigations carried out by A. Vömel (1970) reveal the considerable influence exerted by plant uptake and evapotranspiration on the utilization of nitrogen translocated to deeper layers of the soil. 10 - 20% of the fertilizer nitrogen that has been leached into the subsoil is withdrawn again from this layer.

Thus we can state that under the conditions we have in Europe, nitrogen leaching from uncultivated land is by far the highest, although it can appear to be relatively high under crops where the root system is not very extensive, such as in vineyards. In contrast to this, in soils under profusely growing crops, in particular grassland, there is only minimal nitrogen leaching into the subsoil (Pfaff, 1963). Studies in so-called mould (i.e. topsoil) lysimeters undertaken by Köhnlein and co-workers (1966) revealed the surprisingly high affinity for nitrogen of the vegetative cover, even following extremely high nitrogen applications. Only in the event of extraordinarily heavy rainfall at the beginning or end of the vegetation period was there any nitrate leaching in summer. The trials were carried out with six types of soil regarded as typical for Schleswig-Holstein, and the crop rotation employed was grass, oats, winter rye and beets.

Lysimeter studies in England under fallow, clover and grass revealed N leaching losses of 118, 46 and 3 kg/ha per year respectively, and this was without N fertilization (Low and Armitage, 1970).

Table 5 shows the results of comparative studies on N leaching in the economically important crops, potatoes, oats and winter rye (Pfaff, 1963).

Table 5. Annual N uptake and N leaching in three crops

	Potatoes	Winter rye	Oats
PK			
Uptake q/m^2 N	4,9	2,9	2,5
Leaching q/m^2 N	4,3	6,1	5,9
NPK			
Uptake q/m^2 N	8,2	5,5	5,5
Leaching q/m^2 N	4,7	7,4	6,0

(Pfaff, 1963)

Potatoes took up more nitrogen (both soil and fertilizer N) than cereals. Therefore N leaching under potatoes was considerably less than under rye and oats. It is remarkable that rye and oats took up less than 3 g N from the soil reserves but double that amount was leached out. This occurred mainly in winter, this season accounting for 83 and 76% of the total annual leaching in rye and oats respectively.

The extent of N percolation under wooded areas is another important point in connection with the effect of the vegetative cover on N leaching, particularly in relation to water conservation. Contrary to the popular belief that only negligible amounts of N reach the subsoil of forests, Höll (1963) obtained levels of up to 550 mg/litre NO_3 in a lysimeter study on the uncultivated soil of an oak and birch wood. Trials in pine forests also yielded mean values of 80.7 mg/litre NO_3.

It may be taken as granted that the vegetative cover affects not only the vertical translocation of nitrogen but also its runoff. Unfortunately we have as yet no definite data on this comparable to the results of studies by Kuron, Jung and Schreiber (1956) on phosphate and potassium.

To sum up what is known about the effect of the vegetative cover, we can say that all measures that promote plant growth usually decrease nitrogen leaching simultaneously. This frequently includes normal nitrogen fertilization and additional irrigation (cf. Pfaff, 1963 and Vömel, 1970).

5. Effect of N fertilization on the level of N leaching from soil

It must be borne in mind that the nitrogen found in soil can be derived from sources other than mineral fertilizers. These include farmyard manure, biological fixation of atmospheric nitrogen, and nitrogen present in rain. Leguminosae can fix as much as

400 kg atmospheric nitrogen per hectare. Under the conditions prevalent in Europe, free-living bacteria fix roughly 10 kg nitrogen per hectare and year, and about the same amount is obtained from rainfall. Fertilization with farmyard manure generally provides an annual 40 kg N/ha. The purpose of this section, however, is to deal only with the effect of mineral fertilizers on N leaching from topsoil.

Table 6 shows the increase in use of nitrogenous fertilizers in various European countries from 1948 to 1970.

Table 6. Consumption of nitrogenous fertilizers in European countries

	1000 metric tons N 1948-53 mean	1964/65	1969/70	kg N/ha 1969/70
Austria	23	73	121	31.0
Belgium	77	122	177	109.9
Czechoslovakia	48	228	400	56.3
Denmark	65	169	270	90.3
France	259	861	1243	37.7
Germany, Fed. Rep. of	365	785	1085	78.4
Germany, Eastern	194	397	487	77.7
Italy	145	404	550	27.2
Netherlands	149	294	385	174.2
Switzerland	8	22	34	15.6
Total	1333	3355.	4752	

When considering the effect of N fertilizers on the translocation of this nutrient from the soil profile, the following factors are important:

a) Application rate
b) Time of application
c) Type of N used
d) Gasesous nitrogen losses

5.1 Application rate

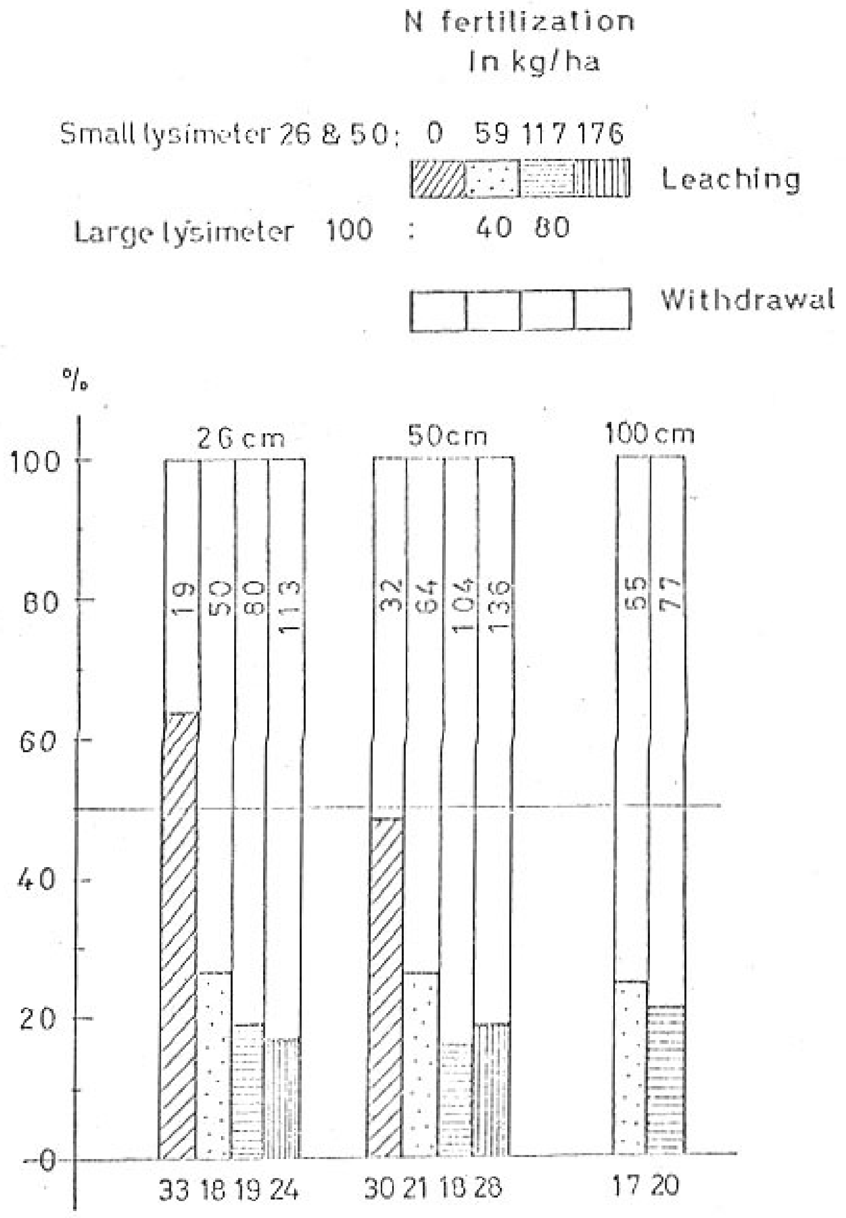
According to the extensive lysimeter studies carried out by Pfaff (1963) and Vömel (1970), fertilization with nitrogen does not necessarily cause increased percolation into the subsoil. Rather is it the case that N fertilization can lead to a decrease in leaching as a result of promoting plant growth in general, which of course includes the development of a more extensive root system.

Figure 3 presents some of the results obtained by Vömel (1970) in his trials on oats in various types of lysimeters (with depths of 26, 50 and 100 cm).

Fig. 3: Nitrogen uptake and leaching as percentage of total withdrawal

Vömel, 1970

(absolute values in kg/ha shown in columns and underneath)



Although two of the three N rates applied were excessive, only 6 -7 % of the fertilizer N percolated out of the topsoil. The proportion of fertilizer N of the total amount percolated is shown in table 7.

Table 7. N percolated from fertilization as percentage of total N percolated, 1964-65

	Added N in kg/ha		
	59	117	176
Soil depth 26 cm	6	10	16
Soil depth 50 cm	4	7	10

(Vömel, 1970)

Pfaff's investigations provide us with another example:
The results listed in table 8 are from a 7-year lysimeter study in which the crop rotation early potatoes/green maize and rye/spring rape were grown successively on sandy and loamy soil. The figures shown are the amounts of N that reached a depth of 1 metre.

Following an application of 80 or 160 kg/ha, there is practically no difference in the N leaching from these plots and the untreated controls. Percolation levels of 6 - 10% of the fertilizer N applied were found only after rates of 240 and 320 kg/ha had been used.

Table 8. N leaching following increasing N application rates.
Mean values of 7-year trial (Pfaff, 1963)

N fertilizer kg/ha	N leaching					
	Sandy soil A			Loam C		
	kg/ha N	Inc. on control	As %age of fert. N	kg/ha N	Inc. on control	As %age of fert. N
Unfertilized	39			22		
2 x 40 = 80	37			21		
2 x 80 = 160	44	5	3	24		1
2 x 120 = 240	55	16	7	36	14	6
2 x 160 = 320	72	33	10	53	31	10

If these results are applied to conditions encountered in practice, the leaching levels will be roughly half the amounts found in the lysimeter trials, since lysimeters cover extreme conditions (e.g. loosened soil, no contact with ground water etc). In arable land used for a normal crop rotation system, it can be assumed that a maximum of 5% of the N added as fertilizer will be leached out. The amount will of course deviate from this figure in crops with a limited root system that require high N application rates, e.g. grapevines, fruit and certain vegetables, and the deviation will be greatest in highly permeable soils. Fertilization carried out at the wrong time will also lead to an increase in leaching.

5.2 Time of application

As a general rule it may be said that N leaching can be reduced considerably by timing fertilization to coincide with the period when the crop needs N most, and often by dividing the required amount of N into several replications. Under European conditions, N fertilization in autumn, for instance, on fallow ground would usually result in high leaching losses. This is illustrated by the results from one of our lysimeter studies (figure 4). Gliemeroth (1958), however, reports relatively low leaching losses following an application of 360 kg/ha N in November. The nitrogen was in the form of calcium ammonium nitrate and calcium cyanamide and the soil was loess. The explanation offered for the results is that this type of soil has a high absorbency rate for NH_4 ions, and following the late fertilization there was little nitrification.

Most of the anomalous statements on the translocation of N in winter can be explained by differing climatic conditions. Van der Paauw (1962) conducted experiments in Holland to demonstrate the effect of rain in winter on N supply in the subsequent vegetation period. He reports that following rainfall of 100 - 200 mm between November and February, rye crops yielded 3 - 3.5 tons/ha, whereas after 250 mm rain in the same period the yield was only 2 tons/ha.

Geering and Schütz (1964) quote leaching losses of approximately 100 kg/ha N under fallow in winter in the Swiss climate. They also reported the results of trials in which two-thirds of the N ($NaNO_3$ and $(NH_4)_2SO_4$) applied in autumn is leached out by the following spring.

Recent investigations carried out be Dam Kofoed and Kjellerup (1970) on three sandy and three loamy soils in Denmark revealed that there is no risk of leaching from loamy soil under barley if N is applied in spring. In sandy soil, however, 30 - 40 mm rain occurring between fertilization and complete uptake can cause quite heavy losses.

5.3 Type of nitrogen

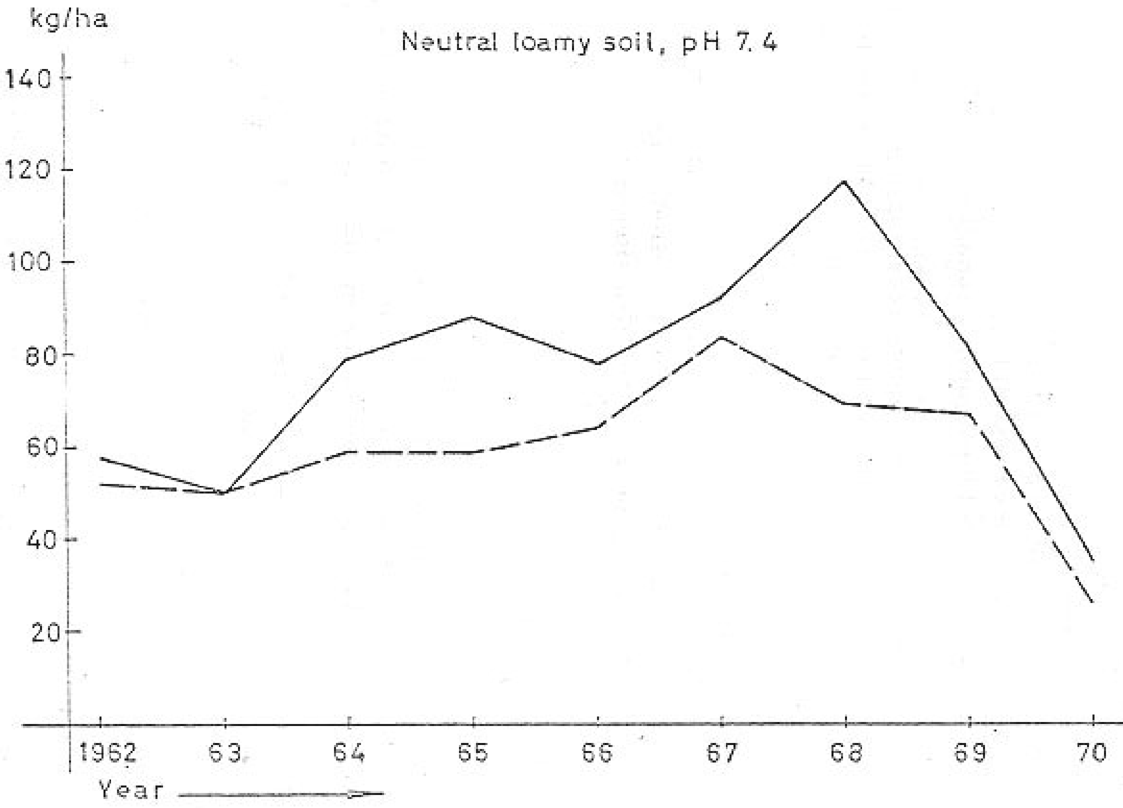
Trials covering periods of several years have proved that the average N leaching rates from soils with different types of N fertilizers are very similar. Table 9 shows an example of the figures obtained after using nitrogen in various forms. They are taken from a trial carried out in loamy soil over a period of 14 years.

Table 9. Effect of type of nitrogen on N leaching (kg/ha) from loamy soil over 14 years (Lysimeter trial, 80 kg N/ha + manure)

Without N	Ammonium sulphate	Calcium cyanamide	Ammonium sulphate nitrate	Calcium ammonium nitrate
48	56	56	55	55

Fig. 4: Nitrogen leaching following fertilization in autumn and spring

(lysimeter trial)



Average N leaching		
Fertilization 100 kg N/ha/year	kg/ha per year	Proport. of fert. N
—— autumn	68.8	27.6 %
— — spring	52.1	10.1 %

Lys.C, 8-14

A recently concluded 13-year lysimeter study (figure 5) provides results on the behaviour of ammonium sulphate (AS) and ammonium nitrate (AN) in a neutral and an acid sandy soil. Both types of N behaved in much the same manner regardless of the soil's pH. The mean annual leaching rate of the N fertilizer added was between 4 and 8%. Similar results were obtained from a 9-year trial with these two types of N in a neutral loamy soil (figure 6). However, in this case, there was a more noticable difference in the leaching of the two fertilizers, ammonium sulphate averaging 2% and ammonium nitrate 6.5%.

Since N leaching from soil is almost exclusively in the form of nitrate, and the N added in fertilizer is converted relatively quickly to nitrate, the results quoted here are only to be expected. Exceptions to this general rule can occur under conditions deviating considerably from the norm, e.g. heavy rainfall immediately following application in early spring, or on widely differing types of soil (Jung and Dressel, 1970). It is interesting to note that the N applied in manure has a similar leaching rate to that in mineral fertilizers.

5.4 Gaseous N losses and N leaching

Another factor that can affect the extent of the N leaching rate is gaseous losses of nitrogen, in particular those occurring as a result of denitrification. Various authors have mentioned a discrepancy in nitrogen balance, and recent investigations with ^{15}N-labelled nitrogen have established that between 10 and 20% of fertilizer N is given off to the atmosphere. Extensive studies in this field have been carried out by Jansson (1963), Geering and Schulz (1964) and Vömel (1970). N losses as high as 33% were detected by Owens (1960) in trials with radio-active ammonium sulphate in eight loamy soils. Therefore this must also be taken into account as a factor affecting soil nitrogen balance and thus, indirectly, N leaching. It would be interesting to establish to what extent denitrification of nitrogen leached into the subsoil is increased in depths where there is a reduced oxygen content. Attention is drawn to this point in a report by Meek and co-workers (1970).

6. Nitrogen and water quality

It emerges from the results presented here that the application of nitrogen fertilizer is only one of a number of factors that can affect the amount of N leached from the soil. In the light of the data we have at present, we can conclude that the vegetative cover or cropping system, climate, season and endogenous N normally play a more decisive role than N fertilization.

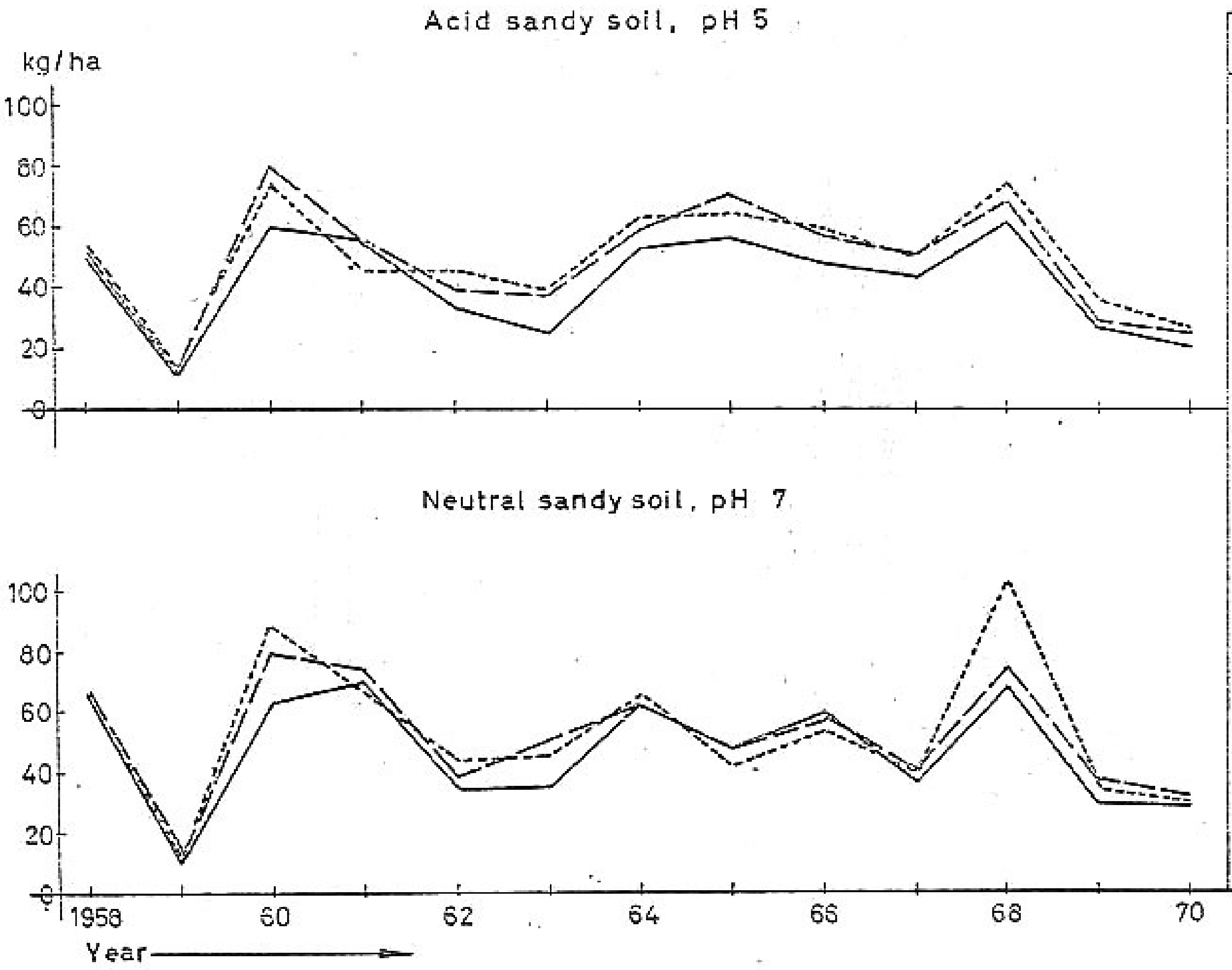
a) Ground water

The cases in which there is any effect worth mentioning on the upper ground water are exceptions. However, these are the very cases that should be investigated more fully in order to establish whether there is any real connection with mineral fertilization. In Western Germany the areas in question are some wine-growing districts from which there have been reports of raised NO_3^- levels in the water.

Sturm and Bibo (1965) tested samples of drinking water in an important wine-growing area in Germany (the Rheingau). They discovered that water from sources beneath vineyards had an NO_3 content of over 40 mg/litre; water whose source lay beneath arable land or forest yielded values of only 10 and 5 mg/litre respectively. Schwille (1969) also reports high nitrate levels in wells in the Moselle Valley that

Fig. 5: Nitrogen leaching depending on the type of fertilizer and the pH of the soil

(Ammonium sulphate = AS and ammonium nitrate = AN 100 kg N / ha / year)

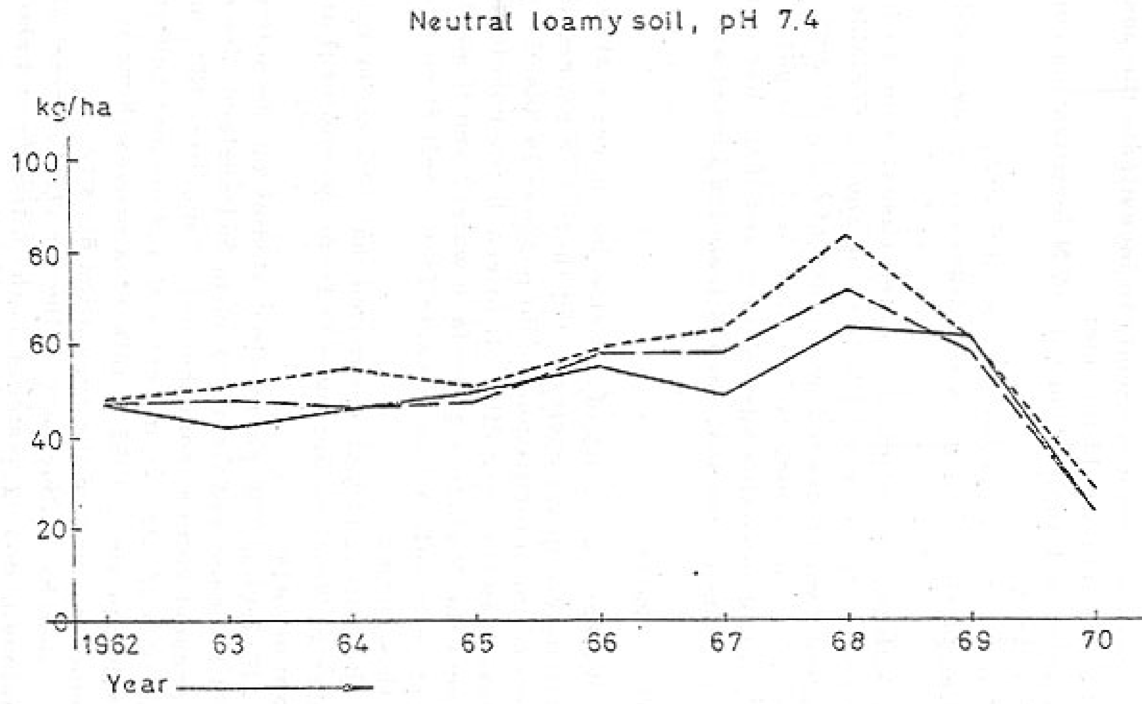


Average N leaching		
	kg/ha per year	Proportion of fert. N
——— Without N	41.3	–
— — — AS	46.1	6.8 %
------ AN	49.1	7.8 %
——— Without N	46.2	–
— — — AS	50.2	4.0 %
------ AN	52.2	6.0 %

Lys. D + E

Fig. 6: Nitrogen leaching depending on the type of fertilizer

(Ammonium sulphate = AS and ammonium nitrate = AN 100 kg N/ha/year)



Average N leaching	kg/ha per year	Proport. of fert. N
—— Without N	47.7	–
– – – AS	49.8	2.1 %
- - - - - AN	54.2	6.5 %

Lys.C, 8-14

he attributes mainly to N fertilization in the vineyards. This hypothesis can be supported by the results of lysimeter studies undertaken by Pfaff (1960) which prove that vines take up little nutrient and therefore allow a relatively high leaching rate.

Appreciable leaching, both of fertilizer and endogenous N, can be expected in very porous, gravel soil, such as can often be found in the wine-growing districts, of the Moselle. However, it is not possible to make a quantitative estimation of the effect of the NO_3 content in upper ground water, as the deciding factor is not only the amount of NO_3 leached but also the data on groundwater flow for that area. Thus it is not surprising that Schwille reported dramatic variations in the NO_3 level in well water. He states, "A swing from the lowest to the highest value, or vice versa, can occur within just a few months." Even if studies are undertaken in these isolated areas to give a quantitative estimation of the effect of the cropping system and N fertilization on the upper ground water, prophylactic measures should be put into operation simultaneously to investigate the possiblities of reducing N leaching. Such measures would include:

- Timing and application rate of N fertilization commensurate with the crop's requirements
- Cultivation of overwintering catch crops
- Use of slow-release N fertilizers (e.g. urea aldehyde condensation products)

With the exception of isolated cases, such as in the aforementioned wine-growing areas, there is not likely to be any appreciable increase in the nitrate content of ground water caused by the use of N fertilizers on normal agricultural land. In fact the reverse may be the case: If there is particularly high crop production as a result of intensive agriculture, and if the use of nutrients has been rationalized for economic reasons, then N leaching losses are likely to be very slight.

b) Surface water

We have a wealth of information on vertical translocation of N in the soil, particularly in lysimeters, but there is a regrettable lack of data on runoff, and some of the information we do possess is based on supposition rather than hard facts. It is therfore difficult to reach any conclusion on whether N fertilization affects the N content of surface water, and if so, to what extent. I should like to mention briefly a few extracts from conflicting reports to illustrate the controversy on this subject:

Bucksteeg (1966) estimates that 70% of the nitrogen discharged into surface water in Western Germany is from agricultural and wooded areas and only 30% from sewage.

Pleisch (1970) carried out studies on the nutrient content of two lakes (Pfäffikersee and Greifensee) in Switzerland. He reports that the majority of the N present comes from the soil, 7 mg/litre NO_3 being derived from wooded areas and 10 mg/ litre from peat soil and normal cultivated land. The increase in the N discharge since 1951 in this area proves there is close correlation between the N concentration and the population density.

Bernhard, Such and Wilhelms (1969) investigated the effect of population and various cropping systems on the nitrogen and phosphate discharge in four streams in the catchment areas around the Wahnbach Reservoir (table 10). There was little variation in the N inflow rates in relation to the size of the areas, but the highest concentration was found in the water of the most densely populated area, in spite of the fact that a relatively small proportion of the land was arable and a large proportion grassland.

Table 10: Vegetative cover, population and nitrogen discharge in the catchment area around the Wahnbach Reservoir (Bernhard, Such and Wilhelms, 1969)

	Bleibach	Eschbach	Heckbach	Wahnbach
a) Veget. cover/cropping system:				
Arable land	13 %	64 %	20 %	51 %
Grassland and meadow	35 %	18 %	35 %	12 %
Forest	19 %	15 %	43 %	28 %
b) Built-up areas: (Buildings, farmyards and gardens)	31 %	3 %	0 %	8 %
c) Mean nitrogen discharge (N):				
kg/ha/year	18	17	12	22
mg/litre water	3.9	2.5	1.6	2.3

In studies carried out by Schmid and Weigelt (1971) in Lakes Waging and Taching in Bavaria, it was proved that 18% of the N inflow originated from industrial and domestic waste, 73% from rainfall in the catchment area and 9% from rainfall over the lake. Neither N fertilizer from the agriculture in the area nor the soil's own N reserves contributed to the N in the lakes. The authors furnish written proof to support their assertion that N fertilization cannot play any part in the eutrophication of these waters nor in the N balance recorded for various sites and cropping systems. In all the cases they investigated, the N withdrawal was considerably greater than the N added in the form of organic and mineral fertilizers. The deficit could have been made up only by N from the soil reserves or the atmosphere. Schmid and Weigelt conclude that - apart from a few exceptions - the surface runoff of N is negligible from land with intensive agriculture.

It would be expedient to obtain further definite proof to support these observations on runoff. For this purpose special runoff studies under European conditions would be necessary, similar to those carried out on various sites by the Tennessee Valley Authority (Kilmer, 1971). The aim of such investigations is to determine the nutrient content of the runoff water before and after fertilization in watersheds with precisely defined boundaries.

7. Summary

N leaching from the topsoil, which occurs both by vertical percolation and runoff, is becoming increasingly important, not only from the point of view of crop production but also in the maintenance of water quality. N runoff from sloping fields has not yet been investigated extensively, but lysimeter studies have provided us with comprehensive data on vertical percolation of this nutrient.

Numerous investigations throughout Europe have determined the most important factors concerned with N leaching from the topsoil and their relationship to water quality. The results may be summarized as follows:

The amount and distribution of rainfall have a considerable effect on translocation of N from the topsoil. To exactly what extent is determined by the amount of water leached, which in turn depends to a large degree on the growth of the plant. Therefore the vegetative cover, as a result of its water utilization (mainly by transpiration) and its nutrient uptake, is often the most important factor in N leaching. This is borne out by the fact that by far the greatest leaching occurs in uncultivated land (fallow) and during the part of the year where little growth occurs. Under crops with a limited root system and low transpiration, such as vines, leaching will also be higher than under a profuse plant cover (e.g. grassland).

The main effect of the soil itself depends on its own N reserves and their mineralization rate. The amount of naturally occurring N in a mineral soil can vary between 600 and 12 000 kg/ha. Of this, approximately 10 - 250 kg/ha is given off anually under European climatic conditions. Thus as well as the factors already mentioned, the soil's N reserves also play an important part in the extent of N leaching. The vast majority of lysimeter studies carried out in Europe prove that the addition of N in mineral fertilizers has comparatively little influence on the amount of N leached out. An important point about N fertilizers is that they are applied when needed by the plant, which of course cannot occur in nature with the N from mineralization of the soil reserves. According to the data on hand, less than 5% of the N added in the form of mineral fertilizers will be leached out.

Although excessive rates of N in lysimeter trials led to increased translocation into the subsoil, it was also proved that as a result of increased plant growth, N leaching losses were lower in a plot fertilized with N than in the PK control.

Since N is leached out almost exclusively in the form of nitrate, and since the ammonium added as fertilizer is converted relatively quickly to nitrate, there is little difference in the leaching losses following application of the various types of N used today. The time of application, however, can be a determining factor. Gaseous N losses, in particular as a result of denitrification, can also affect N leaching indirectly.

Discussion of N leaching leads inevitably to the question of water quality maintenance and what part N leached from soil plays in the eutrophication of surface waters and the nitrate content of ground water.

The effect of agricultural land on the nitrate content of ground water depends on the cropping system: Vines, for instance, do not have a very extensive root system, and there are high leaching losses from the soil of vineyards. Under permanent grassland, on the other hand, the lowest losses have been recorded. In crops with a limited root system it is theoretically impossible to avoid an increase in the nitrate level of the ground water following high N application rates. This is however only a theory, and has not yet been fully investigated. In relation to agriculture as a whole these cases are to be regarded as exceptions, and they could possibly be improved by new agricultural techniques.

As far as eutrophication is concerned, N leaching and the factors that affect it are of minor importance, since nitrogen, in contrast to phosphate, is already present in surface-water at a concentration high enough to cause eutrophication.

To sum up, it may be said that high rates of N are applied in intensive agriculture, but they do not usually lead to an increased N content in ground water and surface water. The reason for this is that the additional N promotes plant growth, which results in a greater nutrient uptake, and rationalization of agricultural methods on economic grounds ensures an adequate utilization of nutrients by applying rates commensurate with and timed according to the crop's need.

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THE RELATIONSHIP OF SOIL AND FERTILIZER PHOSPHORUS TO WATER QUALITY

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The stimulation of algae and other aquatic plant growth by nutrients present in natural waters has been a durable problem. Assuming that all other growth factors are adequate, phosphorus can be the principal nutrient controlling water fertility. Mackenthum (1965) has stated that phosphorus concentrations in surface waters as low as 0.015 parts per million are sufficient to support a "nuisance growth" of algae if other conditions are favorable. Others have reported that concentrations of 0.05 parts per million or higher permit lush algal growth (Sawyer, 1952; Sylvester, 1961). While it is evident that exceedingly low concentrations of phosphorus and other elements can support a sizeable plant population in an aquatic environment, efforts to develop a simple and reliable technique for evaluating nutrient supplies to aquatic plants have not been successful to date (Gerloff, 1969). Adequate sampling is one problem. The agronomist is reasonably certain that a plant growing in soil absorbed most of its nutrients from the volume of soil surrounding its roots. When dealing with unrooted aquatic plant species the aquatic botanist, however, cannot be certain that the plant has not moved from its original site of growth. The picture is further complicated by exchange reactions between nutrients in sediment and the overlying water, as well as a host of other factors.

It is not the purpose of this paper to set forth the arguments as to whether or not phosphorus is a limiting factor in eutrophication as opposed to carbon dioxide, nitrogen, or any of the micronutrients, for example. It is well known that life cannot exist in the absence of phosphorus. It follows that phosphorus must be present for the growth of all flora and fauna, both terrestrial and aquatic. The concentrations of phosphorus required for accelerated eutrophication of surface waters, plus a description of conditions that permit phosphorus to be a limiting factor in aquatic plant nutrition, must be resolved by aquatic botanists and others. This paper is concerned only with the extent of contributions to the aquatic environment by soil phosphorus, including phosphorus added to the soil by fertilization practices.

I. MOVEMENT OF SOIL PHOSPHORUS

A. Geological Considerations

The classic work of McHargue and Peter (1921) in Kentucky, quoted by Thomas (1970), shows that the phosphorus in waters is directly related to the phosphorus content of the soils and the rocks from which the soils were formed. The data in Table 1 illustrate this point very well.

Table 1. Concentration of phosphorus in several streams and parent rock through which they run (McHargue and Peter, 1921).

Stream	Draining	ppm P
North Elkhorn Creek	High phosphate limestone	0.22
Green River	Low phosphate limestone	0.07
Kentucky River (upper)	Sandstone and shale	tr.
Kentucky River (lower)	High phosphate limestone	0.09
South Fork, Licking River	High phosphate limestone	0.21
Licking River at mouth	Calcareous shale	0.10
Mississippi River, Baton Rouge	Mixed	0.07
Ohio River, Pittsburgh	Mixed	0.09
Ohio River, Paducah	Mixed	0.07

From Thomas (1970)

Considerable phosphorus is lost during soil formation; such losses can approach 80-90% in Ultisols (Simonson, 1970). Syers et al. (1969) estimated that the loss during formation of soils from sand dunes in New Zealand was around 1900 kg/ha over a period of 10 000 years. The rate of loss was almost a straight line function between 500 and 10 000 years. This would amount to phosphorus losses of 0.02 kg/ha annually.

As pointed out by Simonson (1970), losses of nutrient elements has continued during the formation of soils over countless millions of years. These losses from geologic formations and soils, brought about by percolating water, occurred both before and after the appearance of man on earth. They are part of a normal, continuous cycle, the nutrients disappearing in some places only to reappear in others. This cycling of nutrients will continue as long as the earth exists.

B. Distribution in Soils

Water-soluble phosphorus applied to fine-textured mineral soils is rapidly converted to solid forms that are only sparingly soluble in water. Plants apparently do not absorb phosphorus directly from these solids, but are seemingly dependent for their phosphorus nutrition on two forms of inorganic orthophosphate ions in solution, H_2PO_4 and HPO_4^{--} (Black, 1971). Phosphorus absorbed in this manner by plant roots amounts to 15 to 20 kg per hectare annually. Perhaps half of this plant phosphorus occurs as inorganic orthophosphate and almost all the remainder as various organic forms. Plant residues thus return both inorganic and organic phosphorus to the soil. Some upward transport of soil phosphorus is thereby accomplished by plants resulting in an accumulation of phosphorus in the upper part of the soil profile. This redistribution is evident in both cultivated and uncultivated moderately weathered soils. An example of the vertical distribution of phosphorus in a soil developed on loess under grassland vegetation in Iowa is shown in Figure 1.

This accumulation of phosphorus in the upper portion of the soil profile assumes considerable importance when losses of this element by erosion occur. The movement of phosphorus with sediment is considered in a subsequent section of this paper.

C. Movement of Phosphorus in Solution

1. Fine-Textured Mineral Soils

The soil solution of well-drained heavier textured soils contains from 4 ppb phosphorus for infertile soils to over 200 ppb for fertile soils (Viets, 1971). Russel (1961) states that whether the soil is unfertilized or heavily fertilized, the concentration of phosphorus in the soil solution is normally within one order of magnitude of 0.1 ppm. Kurtz (1970) concluded that solutions in equilibrium with unfertilized soils may contain enough nutrients to support the growth of algae. This seems to be borne out by early explorers in the humid regions of the United States where names such as Green Bay. Green Lake, Green River, etc., are common. It must be remembered that these names were given to bodies of water *before* settlement took place.

The downward movement of phosphorus in most well-drained soils is very slight relative to the total amount of phosphorus present in soils. Many early workers simply reported a "trace" of phosphorus removed in drainage waters because their analytical methods were insufficiently sensitive to detect the small amounts present (Cooke and Williams, 1971). Thomas (1970) has calculated that given a soil solution concentration of 0.2 ppm phosphorus and a total annual percolation of 51 cm of water, the phosphorus loss would be about 1 kg of phosphorus per hectare, assuming complete equilibrium between soil and percolating water. That complete equilibrium would occur is doubtful and a total annual percolation of 51 cm of water would be high on well-drained upland soils in temperate regions. Nevertheless, such calculations are very useful. Generally, annual leaching losses of phosphorus on well-drained soils are less than a kg per hectare.

2. Sandy Soils

The formation of sparingly soluble phosphorus compounds in soils depends principally upon the presence of iron, aluminum, calcium, and magnesium. Low concentrations of these elements, such as are found in sandy soils, can result in an increased downward movement of phosphorus. The clay content of sandy soils is also an important factor in phosphate retention.

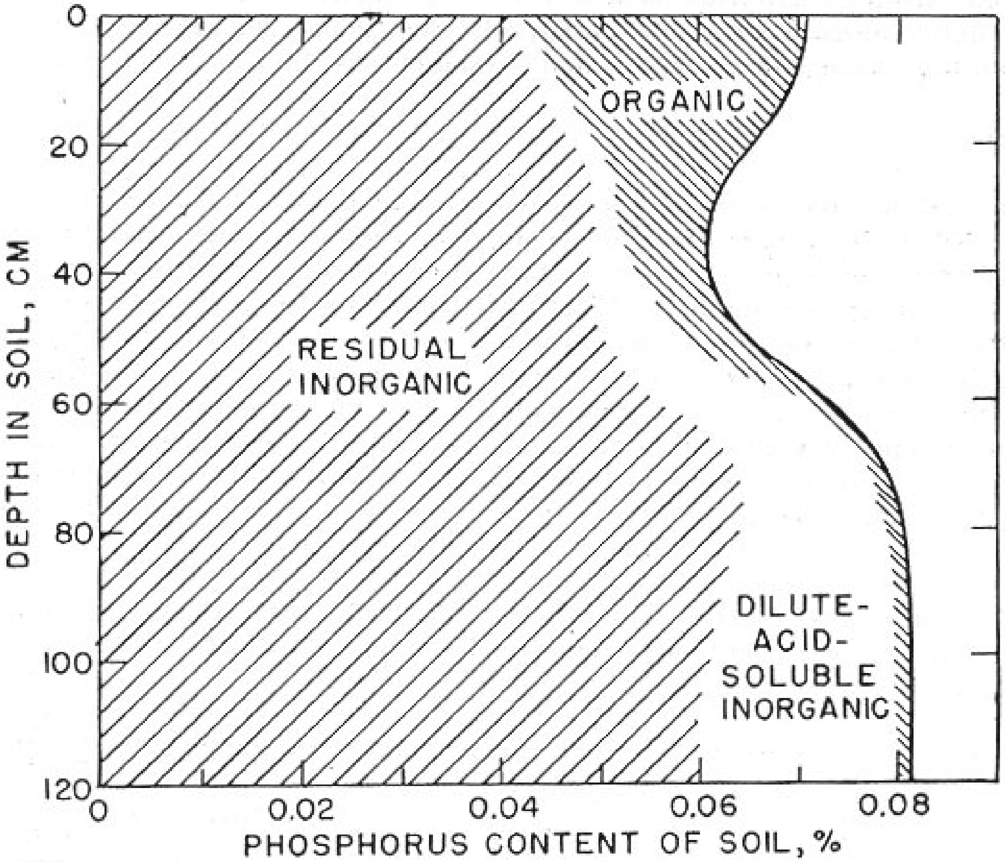

FIG. I - VERTICAL DISTRIBUTION OF PHOSPHORUS IN AN IOWA SOIL. (BLACK 1971)

Cooke and Williams (1970) found only one instance of phosphate lost by leaching in England and that was in a sandy heathland soil containing only 1-2% clay. They think it "improbable that phosphate added as fertilizer will appear in drainage water from mineral soils containing 5% or more clay that are used for agriculture". This thesis is supported by the work of Spencer (1957) who studied the distribution and availability of phosphates added to Lakeland fine sand on experimental citrus plots in Florida. Spencer describes this soils as having an A-C profile with approximately 99% siliceous sand and silt and 1% organic matter. Spencer found that a high percentage of phosphorus added as superphosphate had moved out of the surface 15 cm of soil, with greatest accumulation occurring within a 30- to 92-cm subsoil zone. However, phosphorus had leached to a depth of 210 cm in some cases.

There seems to be little question that the downward movement of phosphorus in sands may constitute a pollution hazard in localized areas. This hazard is estimated to be about eight times greater for a sandy soil than for a clay, assuming the same supply of available phosphorus (Olsen and Watanabe, 1970).

3. Organic Soils

Organic colloids also have very low capacities to absorb phosphorus. As pointed out by Wild (1950) the absorption of phosphorus by organic matter is virtually nil. The absorption that does occur is due to the cations associated with organic matter. Recent work by Fox and Kamprath (1971) illustrates this behavior very nicely. The soils studied by these workers consisted of the Ap horizon collected from a St. Johns soil, a very poorly drained soil consisting of 90% quartz sand and 10% organic matter, and the surface and subsurface of a muck soil devoid of inorganic colloids. Soluble phosphate fertilizer (monocalcium phosphate) was readily leached from these soils. The addition of aluminum chloride ($AlCl_3$) which resulted in large amounts of exchangeable aluminum caused the almost quantitative retention of added phosphorus (Table 2).

Table 2. Leaching of fertilizer P from a St. Johns soils as related to chemical treatment and chemical properties (10 mg of P as $Ca(H_2P_4)_2$ added per column).

Treatment	pH[x]	Exchangeable[x]		P leached	Fertilizer P adsorbed
		H	Al		
		- meq/100 g -		- - - mg/column - - -	
Original soil	3.4	1.92	1.63	4.6	-
Original soil + P				14.5	0.1
H soil + P	2.5	4.95	0.80	16.0	0
Al soil + P	3.9	0.35	4.65	4.7	9.9
Ca soil + P	4.0	0.40	0.40	15.8	0
Limed soil + P	4.1	0.55	0.60	13.2	1.4

[x] Soil pH and exchangeable cations were measured prior to phosphate additions and leaching.

(Fox and Kamprath, 1971)

This behavior of fertilizer phosphorus in organic soils has resulted in proposed restrictions relating to the application of phosphates to Illinois soils,containing more than 20% organic matter (Aldrich), 1971).

4. Flooded Soils

In general, the incidence of paddy rice response to phosphate fertilizer is low. When soils are flooded, the chemistry of phosphorus changes, ferric phosphates being the principal compounds involved. Ferrous phosphate, a more soluble compound than ferric phosphate, is formed through the biological reduction of iron as the oxygen content of soil is decreased by flooding. A concurrent rise in pH occurs. In addition, "free" iron oxide coatings may be reduced and solubilized, resulting in the release of occluded phosphates (Patrick and I.C. Mahaptra, 1968). An example of the effects of submergence on phosphorus in the soil solutions is shown in Table 3. These reactions are important in the phosphorus chemistry of surface waters, although relatively little is known about phosphorus exchange between bottom sediments and the overlying water. Relatively large contributions of phosphorus to streams and lakes from paddy rice production can of course occur, depending upon the hydrology of the area in question.

Table 3. The effects of submergence on phosphorus in the soil solution.

Soil	Air dry		Submerged and sucrose	
	ppm P in solution	Redox potential	ppm P in solution	Redox potential
Maury	2.00	680	3.55	- 70
Grenada	0.06	680	4.28	- 10

(S. Sookhakich, University of Kentucky, unpublished work)

5. Irrigated Soils

Information concering the phosphorus concentration in irrigation return flows is extremely limited. Our knowledge about chemical reactions of phosphorus in soils indicates that the concentration in irrigation return flows should be very low. The small amount of available data on the subject supports this contention. Johnston et al. (1965) studied the fate of nitrogen and phosphorus on four tile-drained fields in California's San Joaquin Valley. The soils drained were Panoche and Oxalis silty clays which are deep, permeable, alluvial fan and basin rim soils, respectively. These soils are calcareous and originally had slight to strong alkali accumulations. The fiels studied had been farmed for over 30 years,and large quantities of commercial fertilizer had been applied during that period. A summary of the phosphorus results for 1962 are given in Table 4.

Table 4. Phosphorus balance in tile-drained soils.

Crop	Area ha	P added* Kg/area	P lost in drainage effluent kg/area
Cotton	60	1980	11
Cotton	29	1070	1
Alfalfa	36	75	2
Rice	19	70	10

*Added in fertilizer and irrigation water.

(Johnson et al., 1965)

It is evident that some losses of phosphorus occurred, but fertilizer effects, if any, are impossible to evaluate in studies of this kind without unfertilized controls.

Carter et al. (1971) recently reported a nitrate and phosphorus study on a 200 000-acre (80 000 ha) irrigated tract in southern Idaho. The concentration of phosphorus in the irrigation water was 66 ppb; passage through the soil reduced this concentration to 12 ppb in the subsurface drainage water. Only about 30% as much phosphorus left the tract via drainage water as entered the tract in irrigation water. The authors state that "irrigation decreased the soluble PO_4-P load if the irrigation water contains more than about 0.01 to 0.02 ppm. The PO_4-P is precipitated as water passes through the soil. Of course, if the irrigation water contains less than that concentration of PO_4-P, irrigation will have no effect on the downstream soluble PO_4-P load. Under these latter conditions, PO_4-P loads are unimportant."

II. TRANSPORT OF PHOSPHORUS WITH SEDIMENTS

Viets (1971) states that nutrients contained in or absorbed on sediments are the greatest contribution of land to water. Fertilizers play important roles in this process: on the one hand fertilizers can enrich eroded materials; but fertilizers can also reduce erosion by contributing to a better plant cover and reducing the acreage of cultivated soils. Thus, more land can be returned to permanent pasture and forests and the cultivation of marginal land is kept to a minimum. A number of reviews have been published dealing wholly or in part with nutrient transport in sediments. Examples of these are Barrows and Kilmer (1963), Taylor (1967), Wadleigh (1968), and Viets (1971). Hence, only some of the more important aspects of the problem will be considered here.

A. The Enrichment Ratio

Scientists have known for a long time that eroded material frequently differs in composition from the original soil. The loss of nutrients in runoff may be expressed in terms of an enrichment ratio (E.R.). This is the ratio of that element in runoff to that in the original soil:

$$\text{E.R.} = \frac{\text{Concentration of the element in soil material in runoff}}{\text{Concentration of the element in soil from which runoff originated}}$$

The concentration of acid soluble phosphorus in runoff tends to be considerably higher than the concentration in the initial soil. The E.R. can vary from just above unity to over 3, depending upon soil and site characteristics and fertilization practices (Barrows and Kilmer, 1963).

B. Sediment-Phosphorus Relationships

About 3.6 billion tons of sediment are washed into U.S. waterways annually according to estimates by Wadleigh (1968). This is the equivalent of 1.6 million ha of surface soil. Wadleigh also estimates that 1.8 million tons of phosphorus accompany these sediments into U.S. surface waters annually. While knowledge of exchange reactions between sediment and water and the factors influencing them apprears to be extremely meager (Lee, 1970), some progress is being made toward rectifying this situation. Taylor and Kunishi (1971) have reported a study made of the availability of phosphate adsorbed on streambed sediment and soil surrounding a stream in the Mahantango watershed which encompasses 162 square miles and is located north of Harrisburg, Pennsylvania. Their data show that in this particular watershed, the contribution made to the phosphate burden of the stream by sediments, stream banks and field soils is small. The study indicated that phosphate moves from the water to the sediment, the sediment acting as a scavenger for soluble phosphate. The capacity of Minnesota lake bottom sediments to remove orthophosphate from solution was studied by Latterell et al. (1971). Their results indicate that the orthophosphate concentration in surface waters must be very low before the sediments will release orthophosphate to the water.

Gessner (1960), studying the turbid Amazon River, reported that when soluble phosphorus concentrations exceeded 0.01 ppm, phosphorus was absorbed by suspended soil. It is likely that these results are generally applicable to sediment-water systems.

The presence of sediment in an otherwise aqueous system markedly influences the pattern of phosphorus removal from solution by plants. When no solids are present, plants can deplete the solution phosphorus to a concentration approaching zero. In the presence of sediment, exchange reactions replenish solution phosphorus at varying rates. Black (1971) has depicted this schematically, as shown in Figure 2.

There appears to be little question that vast amounts of phosphates are added to surface waters via erosion. Taylor (1967), assuming that 10% of eroded fertilizer and soil is immediately available, estimates 1 to 5 pounds per acre (1.1. to 5.6 kg/ha) annually from this source, or as pointed out by others (Viets, 1971), 180 000 tons of phosphorus per year in the United States. Phosphate source contributions are difficult to assess in normal aquatic environments because of the continuous nutrient cycling that occurs.

III. QUANTITATIVE SOIL AND FERTILIZER PHOSPHORUS LOSSES IN SOLUTION UNDER FIELD CONDITIONS

Relatively few experiments have been deliberately designed to measure the effects of fertilizer use on water quality under field conditions. Workers in U.S. soils conservation experiment stations prior to about 1940 carried out considerable research on nutrient losses of surface runoff. Unfortunately, many included the total nutrient content of eroded

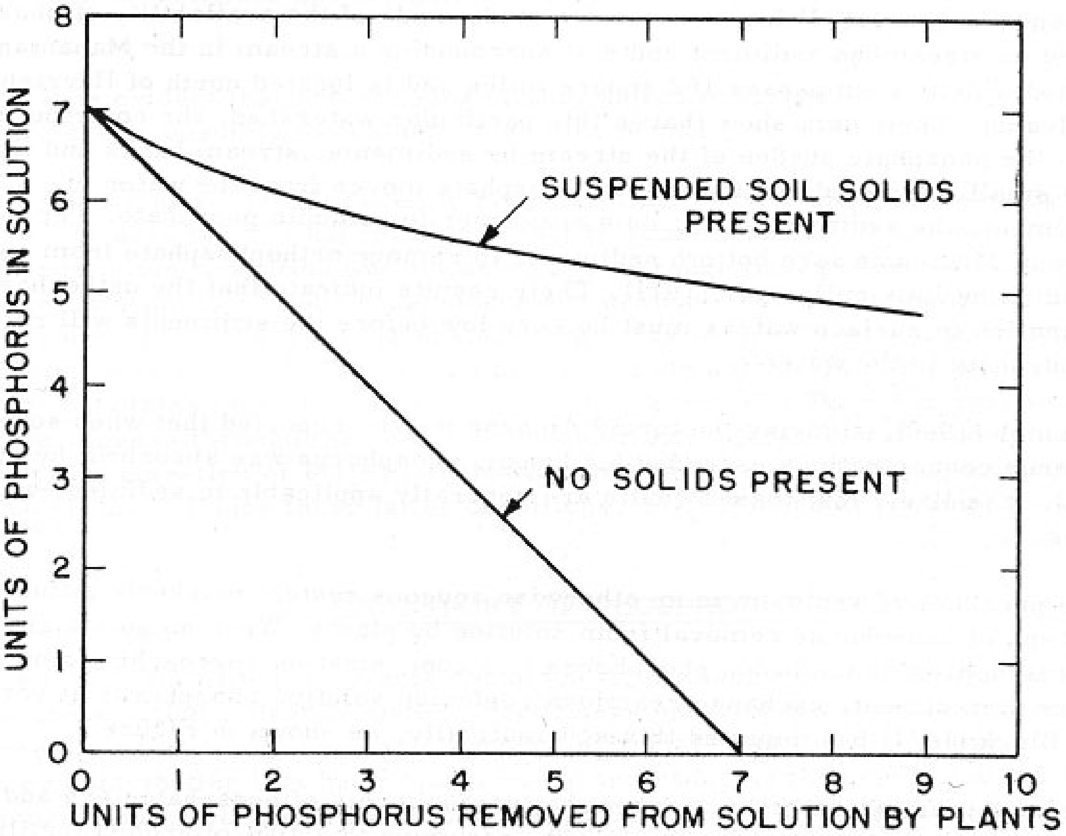

FIG. 2 - SCHEMATIC REPRESENTATION OF DECREASE IN PHOSPHORUS CONCENTRATION IN SOLUTION AFTER PLANTS HAVE REMOVED DIFFERENT QUANTITIES OF PHOSPHORUS FROM A SOLUTION WITH NO SUSPENDED SOLIDS AND FROM A SOLUTION WITH SUSPENDED SOIL SOLIDS. (BLACK 1971)

material in their calculations which detracts from the usefulness of the data in attempting to solve present day problems (Barrows and Kilmer, 1963). Such studies grossly overestimated losses of <u>available</u> phosphorus. Typical data from an early experiment are shown in Table 5.

Table 5. Annual phosphorus content of runoff and eroded material from Shelby loam, 3.6% slope.

Cropping System	Total P kg/ha
Not cultivated	22
Spaded 8 in. deep	15
Bluegrass sod	< 0.1
Wheat annually	5
Rotation: corn, wheat, clover	1
Corn annually	4

Duley and Miller (1923)

Current field studies vary widely in design and complexity. Ideally, field experiments designed to study nutrient contributions to water from soils and fertilizers should have the following attributes:

- A drainage system permitting the quantitative measurement of water discharge volumes (both surface and base flow) from an area whose dimensions are accurately shown.

  A continuous water sampling system that takes samples proportional to flow volume.

- Monitoring instruments for measuring nutrient inputs in precipitation and dry fallout.

- Provisions for obtaining nutrient transport data under unfertilized conditions.

- Facilities for preserving water samples during the period following collection and chemical analysis.

It is difficult to include all of the foregoing in a single experiment, due to difficulties frequently encountered in locating ideal measuring sites. For a more complete discussion of the subject, the reader is referred to Kilmer and Joyce (1971).

A. <u>Condensed and Orthophosphate Sources</u>

The question is often asked as to whether condensed phosphates in fertilizers may enter surface and groundwater more readily than the orthophosphates, the thought being that condensed phosphates move through soils in solution at a more rapid rate. The reactions of condensed and orthophosphates with soils has been thoroughly discussed by Huffman (1968). He states that the behavior of polyphosphate in soils is even more complicated than that of orthophosphates, since rates of hydrolysis of polyphosphate to orthophosphate are influenced by various soil factors, principally biological activity. Under field conditions suitable for crop growth, the hydrolysis of pyrophosphate to orthophosphate is often rapid, being essentially completed in 3 or 4 weeks. It is principally for this reason, plus the fact that pyrophosphate is assimilated by plants less readily than orthophosphate, that the two phosphorus sources usually behave identically from an agronomic standpoint when properly evaluated. For purposes of the present discussion, the unpublished work of E.C. Sample and F.E. Khasawneh of TVA can be cited. Their exhaustive laboratory studies utilizing P^{32} and 10 different soils indicate essentially no difference in the rate or the extent of movement of ortho and pyrophosphates. Thus, as far as these two forms of phosphorus are concerned, one is no more readily lost from the soil by leaching than the other.

B. Phosphorus Losses from Cultivated Soils

Timmons et al. (1968) investigated the phosphorus content in runoff as influenced by different cropping practices in Minnesota. The results are summarized in Table 6.

Table 6. Dissolved inorganic phosphorus in runoff water for various crops in Minnesota.

Crop	P added kg/ha	kg/ha/yr[x]
Fallow	0	0.04
Corn--continuous	29	0.05
Corn rotation	29	0.05
Oats rotation	N.A. †	0.01
Hay rotation	0	0.23

[x] Average of 2 years' data.

† Not available.

(Timmons et al., 1968)

It is interesting to note that unfertilized hay plots lost several times as much phosphorus as the fertilized corn plots. Haylands may thus contribute appreciable amounts of dissolved phosphorus to surface waters. Studies of nitrate and phosphorus losses from tile-drained fields under various cropping systems were carried out by Bolton et al. (1970) in Ontario, Canada. A portion of this data is presented in Table 7.

Recent studies were conducted in Indiana to determine the amounts of nitrogen and phosphorus removed in surface runoff from fallow silt loam plots with 5.8% slope after applying 6.25 cm of artificial rain in 1 hour. Superphosphate was disked into the soil at 0, 56 and 112 kg rates of phosphorus per hectare. Analyses revealed that 0.008, 0.047 and 0.127 kg of soluble phosphate were lost per hectare at the 0, 56, and 112 kg rates, respectively (Nelson, 1971). Plowdown or other deep incorporation of fertilizer to reduce losses of soluble nitrogen and phosphorus in runoff was recommended by Nelson.

Table 7. Average annual P composition of tile drainage from non-fertilized (NF) and fertilized (F) continuous corn, continuous bleugrass and a 4-year rotation on Brookston clay for 1961-67, inclusive, in southwestern Ontario, Canada.

System	P applied	P loss NF	P loss F	P Concentration NF	P Concentration F
	----- kg/ha/yr -----			--- ppm ---	
Rotation					
Corn (1)	29.6	0.13	0.24	0.20	0.22
Oats & Alfalfa (2)	29.6	0.13	0.13	0.20	0.19
Alfalfa (3)	0	0.13	0.15	0.18	0.21
Alfalfa (4)	0	0.08	0.22	0.17	0.27
Continuous					
Corn	29.6	0.26	0.29	0.17	0.19
Bluegrass	29.6	0.01	0.12	0.17	0.19

Bolton et al. (1970)

C. Phosphorus Losses from Forested and Pastured Soils

The transport of phosphorus in drainage from forest ecosystems is typically very low. In some studies phosphorus may not be mentioned, in others phosphorus has been sought but not found (Cooper, 1969). Even spectrographic analyses failed to detect phosphorus in streams draining grazed, but otherwise unmodified forests in New Mexico (Miller, 1961). Lysimeter studies in the forest-steppe zone near Moscow, USSR, showed that loss of phosphorus beyond the root zone was insignificant (Remezov et al., 1964). Cole and Gessel (1965) measured phosphorus and other nutrients in drainage waters in the Douglas fir region of Washington state. Clear-cutting and nitrogen fertilization accelerated phosphorus losses to a slight extent, even though no phosphorus was added in fertilizer (Table 8).

Table 8. Output of mineral nutrients beneath the root zone in untreated, fertilized and clear-cut Douglas fir forests.

Treatment	N	P
	--- kg/ha ----	
Control	0.21	0.01
Clear-cut	0.39	0.05
Fertilized (200 lb/acre)		
Urea	0.28	0.03
Ammonium sulfate	0.43	0.07

Cole and Gessel (1965)

Clear-cutting and burning of forested areas appear to be the most important practices involved in accelerated release of nutrients. Phosphorus carried in rivers draining forested landscapes in Finland ranged from 0.17 to 0.27 kg/ha/year (Viro, 1953). Other examples could be cited, but the foregoing sufficiently illustrates the typically low transport of phosphorus in drainage waters from forested soils.

Forest fertilization may present problems, particularly if fertilizers are applies directly in or too near streams. However, Cooper (1969) considers that properly applied applied fertilizers are probably not an important threat to water quality.

Losses of phosphorus from pastured and grassland soils are also apt to be low because of reduced surface runoff and minimum erosion. Unpublished data by Kilmer et al. of the Tennessee Valley Authority showed virtually no fertilizer effect in the phosphorus load of water draining a 5-hectare pastured watershed in western North Carolina. Discharge waters carried only 0.03 kg/ha of phosphorus during a 6-month period when no fertilizer was applied. Application of 45 kg of P resulted in an escape of only 0.04 kg/ha during a similar period of time. Thomas (1971) reported that the phosphorus transport was highest in waters draining unfertilized bluegrass pastures in Kentucky compared with other land use areas of the state. He attributed this to geological formations relatively high in phosphorus.

IV. NONAGRICULTURAL CONTRIBUTIONS OF PHOSPHORUS TO SURFACE AND GROUNDWATERS

The huge inputs of phosphorus and other elements to surface waters via sewage effluent and industrial wastes have received much attention in nearly all developed countries of the world. While quantitative data on this score are not voluminous, sufficient figures are available to put the problem in perspective.

A. Phosphorus in Human Wastes

On the average, humans excrete around 540 grams of phosphorus annually (Vollenweider, 1970). In the United States, about 70% of the 214 million population are served by municipal sewers (Anonymous, 1963). Unless treated, the potential soluble phosphorus contribution in sewage effluent from this source alone would amount to over 116 thousand metric tons annually. Vollenweider (1970) in a report prepared for the OECD[1/] gives estimates of amounts of nitrogen and phosphorus arising from animal and human wastes in Europe and great Britain. The figures for phosphorus are given in Table 9.

Note that the amounts of phosphorus produced in animal wastes average 11 times that excreted by humans. The figures are similar for the United States. However, if handled properly, the phosphorus produced in animal wastes need not find its way into surface and groundwater.

1/ Organization for Economic Cooperation and Development.

Table 9. Approximat arisings of phosphorus from livestock and human wastes in selected European countries. Figures in 10^3 tons per year.

	From livestock	From population	A/B
Switzerland	25	3	8
Austria	50	4	13
Germany	240	29	8
France	270	25.5	11
Italy	140	26.5	5.5
Netherlands	55	6.5	9
Belgium	40	5	8
Denmark	65	2.5	26
Sweden	45	4	11
Norway	20	2	10
United Kingdom	210	28	8
			Mean 11

Vollenweider (1970)

B. Detergents

Most of the phosphates contained in detergents are disposed of through sewage systems. About 225 000 metric tons of elemental phosphorus are thus used annually in the United States [2/]. Figures of this nature are not at hand for other countries. About 60% of the phosphorus in sewage effluent was estimated to derive from phosphate based detergents (Anonymous, 1970). Thus, the combination of detergent and human waste phosphorus in U.S. sewage effluent totals around 315 000 tons of elemental P annually, compared with the estimated 180,000 tons of available phosphorus contained in sediments.

Figures for phosphorus released in industrial wastes are not available. For the Lake Erie region of the U.S., however, industrial inputs of phosphorus to surface waters are estimated to be about 7% of the total (Anonymous, 1970). Possible the 7% figure represents a maximum for all but very highly industrialized areas.

[2/] The accelerated eutrophication of U.S. lakes and rivers is in part attributed to phosphorus. Government hearings were held (Anonymous, 1970) and deadlines set for the substitution of other builders in detergents for phosphates. The favored substitute was nitrilotriacetic acid (NTA). Several soap companies spent huge sums of money converting from phosphates to NTA. Subsequent research turned up some unfavorable facts about NTA, including a possible link with cancer. As a result, Washington officials recently announced that phosphates are at present approved for detergent use (see Nature, Vol. 233, Oct. 8, 1971, pp 362-363).

SUMMARY

It is evident that soil erosion contributes huge amounts of potentially available phosphorus to streams and lakes. The control of soil erosion is of paramount importance in this regard.

Natural losses of phosphorus from soils and phosphate-bearing rocks seem sufficient in many cases to support algal growth in surface waters. A feasible means of mitigating the transport of phosphorus from these sources is not apparent to the writer.

Fertilizer phosphorus seems not to be significantly involved in raising the phosphate levels of surface waters. Indeed, there is substantial evidence that fertilizer phosphorus contributes positively to water quality by aiding and maintaining strong erosion-resistant vegetative cover on soils and minimizing the cultivation of marginal lands. While some soluble phosphorus is lost from nearly all soil-plant systems, the amounts are small and rarely exceed a fraction of a kg/ha annually. Noted exceptions are sandy and organic soils.

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MAN'S PHOSPHORUS REQUIREMENTS
AND THEIR EFFECTS ON THE ENVIRONMENT

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I - INTRODUCTION

1) The purpose of this note is to examine the extent of man's phosphorus requirements from the angle of food requirements. The West European area has been chosen for this study because of:

- its great population density;
- its generally very intensive agriculture;
- the eutrophication found there;
- the statistics available from OECD sources.

The magnitude of phosphorated food requirements could be estimated in this area; in particular, the supply of P furnished by meat and milk products has been the object of 2 distinct approaches leading to the same results.

It is thus possible to show how much man's phosphorus requirements are characterized by their great dimension, with inevitable repercussions on our environment. This dimension is all the more considerable as the supply of P in the human diet involves plant and animal production which itself generates waste and by-products (crop residues, manure, semi-liquid manure, bones, etc.) containing large quantities of P and necessarily returning to the natural environment.

2) It is evident that man's phosphorus requirements cannot be met without contributing to spreading this element in the environment.

Food phosphorus required by man is subject to variable development; in the highly urbanized West European area, the major part enters surface water through sewers.

3) Man is the point of passage for a quantity of P which:

a) calls for the use of much bigger quantities of the element to permit the production of food of plant and, especially, animal origin;

b) then returns to the natural environment, mainly in water, with a local pressure that rises with population density and the degree of urbanization.

4) In conclusion, recommendations are made to restrict the polluting effects of activities before and after human consumption, which are responsible for the growing propagation of P in our environment. It will be absolutely necessary to remedy this situation.

II- SCOPE OF THE STUDY

The study concerns a group of countries with about 320 million people on slightly more than 3 million square kilometres, with an average density of 105 inhabitants per square kilometre. The agricultural area (A.A.) covers 115,740,000 hectares, or 38 per cent of the total area.

The annual use of phosphatic fertilizers at present involves some 5 million tons of P_2O_5, or more than 2 million tons of P. Doses are small in Spain and Portugal and, to a lesser extent, in Italy, where the climate hampers general intensification of soil development (see Table I).

III - USE OF PHOSPHATE FERTILIZER IN WEST EUROPEAN COUNTRIES

Phosphate fertilization is examined under two aspects - in terms of the doses of P_2O_5 employed per hectare of A.A. per year and according to annual phosphate fertilizer consumption expressed in kg of P/inhabitant/year.

First graph - The doses of P_2O_5 used in each country (kg/ha A.A.) are listed in the ordinate and population density (inhabitants/km^2) in the abscissa. For most countries (with the exception of three - Portugal, Spain and Italy), the points obtained are situated around a slightly rising line. The three Mediterranean countries are at lower levels, about half the values for the countries of the first group which have a population density of the same order.

This graph shows that in appropriately watered countries with a temperate climate the present supply of P_2O_5/ha A.A. is close to the annual maintenance generally assumed in the matter of phosphate fertilization.

The Mediterranean countries show how much the handicap of insufficient or badly distributed rainfall hampers the advent of intensive agriculture on the territory as a whole (see chart with breakdown of P_2O_5/ha A.A.).

It may be concluded that phosphate fertilization characterizes mainly a type of agriculture and increases slightly with population density. In the group of intensively cultivated West European countries, this fertilization is at two levels:

- 40 to 60 kg of P_2O_5/ha/year in the central and northern areas,
- 15 to 30 kg of P_2O_5/ha/year in the Mediterranean area.

Second graph - Annual use of P/inhabitant, in the form of mineral fertilizers is listed in the ordinate, while the abscissa remains unchanged.

The West European countries fall into several distinct groups:

a) Sparsely populated Scandinavia (Finland has been included in the graph);

b) Atlantic countries grouped along a hyperbolic curve with, on the one hand, the countries where agriculture exports products and is an important sector of the economy, and, on the other hand, the highly industrialized countries;

c) Mediterranean countries grouped along a hyperbolic arc where, population density being equal, the ordinates are clearly below those of the Atlantic agricultural countries;

d) central mountainous countries (Switzerland and Austria) which have isolated positions.

IV - DIETARY PHOSPHORUS REQUIREMENTS

Recent studies have established that in Western Europe man's phosphorus requirements are well matched by supplies in the diet.

The value which appears to be most in line with present habits is 1.5 g of P per day and person.

Supply of P/day, in g

Plant products	
Bread	0.41
Potatoes	0.20
Vegetables	0.10
Fruit	0.04
	0.75

Animal products		
Meat	0.28	Fish: 0.04
Milk	0.29	
Cheese	0.07	
Eggs	0.06	
Butter	0.01	
	0.71	

Total .... 1.5 g of P/day

In 1966, the suggested global proportion was 0.81 g of P from plant products and 0.66 g of P from animal products. It is certain that a shift has since occurred in favour of meat and milk products.

For 320 million consumers, this represents about 175,000 tons of P in one year, of which:

- half comes directly from plants,
- 82,500 tons from animal products, and
- about 5,000 tons from fisheries.

V - PLANT AND ANIMAL PRODUCTION

a) Plant Production

Taking into account waste and by-products of plant production intended for human consumption which are lost or used as animal feed (bran, middlings, miscellaneous fodder, etc.), the quantity of P mobilized annually by plant production has to be estimated at a minimum of 150,000 tons. About one-third of this serves to feed animals.

b) Animal Production

Milk products and eggs correspond to an annual supply of:

0.43 g x 365 x 320 millions = 50,000 tons of P,

and meat:

0.28 g x 365 x 320 millions = 33,000 tons of P.

OECD statistics for 1969 on Milk and Milk Products give the following breakdown of European dairy production:

Livestock feed	13.9 million tons
Butter	43.08
Cheese	17.3
Condensed and powdered milk	5.66
Fluid milk	31.9
Cream	3.92
Miscellaneous	1.11
	116.87 million tons

If we deduct the share of eggs (7,000 tons of P) from the first tonnage (50,000 tons) and if we include only cheese, fluid milk, cream and one-third of processed milk in human consumption (based on a content of 0.9 g of P/kg of milk), the quantities of P furnished and used are in equilibrium, at about 5 %.

The OECD meat statistics for 1969 lead to the same conclusion.

Thirty-three thousand tons of P, with an average content of 0.15 % of P, correspond to the utilization of 22 million tons of meat. The OECD statistics give a total consumption of 21,718,660 tons (for a production of 20,720,000 tons).

VI - PHOSPHORUS REQUIREMENTS OF ANIMALS

Dairy and egg production poses the principle of a transformation of vegetable feed phosphorus into animal product phosphorus. While excellent methods of animal husbandry permit a coefficient of phosphorus utilization close to 2, it would seem preferable to take 2.5 as the average coefficient, that is, 125,000 tons of P were distributed to animals (female dairy animals and laying hens) to meet their production requirements; maintenance rations have to be added to this figure.

The annual consumption of about 22 million tons of dressed carcasses furnishes about 33,000 tons of food phosphorus; but to obtain this quantity, the animals require much more considerable supplies during their life.

1) Poultry production: 2,970,000 tons

- weight of P of live animals .... 35,000 tons
- weight of alimentary P required: 4,200,000 tons (yield 70 %)
  x 2.5 x 0.007 (P content of feed) .... 73,000 tons

This means that a chicken fixes about half of its P intake in its body; the major part - more than 30,000 tons - is to be found in the bone tissue and waste products.

2) Meat production (see Table II)

To simplify estimates, beef and veal are included in one figure - 7,220,000 tons - and average slaughter weight has been fixed at 500 kg with a yield of 60 %.

Such an ox or cow concentrates about 4 kg of P in its skeleton and has about 1 kg in the other parts of its body. On the West European scale, this means 96,000 tons of P in the bones and 25,000 tons of P in the other tissues, of which more than half serves human consumption (meat + offal).

But 6,600,000 tons of carcasses call for a utilization of P which may be put at

12.5 kg up to a weight of 400 kg
and 2.5 kg to increase the weight from 400 to 500 kg
total 15.- kg,
or 330,000 tons of P for 22 million head.

3) Pig production

Estimates made on a comparable basis show that a 100 kg pig receives 1,200 to 1,300 g of P in its feed during its life; it assimilates about half of it, and 450 g are in its body when slaughtered.

Applied to Europe as a whole, this gives a minimum of 150,000 tons of P involved in pig feed, of which 50,000 tons are later found, about three-quarters in the bones and waste products and one-quarter in the edible parts.

A considerable percentage of bones from meat for human consumption is used by various industries. In France, it may be estimated that more than one-third of the bones is collected in this way - 175,000 tons, out of a production of 1,600,000 tons of carcasses with about 500,000 tons of bones. Phosphorus recovered in this way totals 4,000 tons and is used mainly in the manufacture of animal feed.

The same proportion applied to Europe gives 21,000 tons of P, that is to say two-thirds of the bones of slaughtered cattle cannot be recovered, and one-third of the remaining third is also lost:

$$\frac{96{,}000}{3} \times \frac{2}{3} = 21{,}000 \text{ tons of P.}$$

VII - PHOSPHORUS CARRIED AWAY IN SURFACE WATER AND OTHER LOSSES

We still have only very incomplete information on the subject. According to old estimates and on the basis of some seasonal data on P content in rivers, the quantity of P from French soil swept toward the sea in solution may be put at 7,000 to 10,000 tons a year. This tonnage would indicate 0.045 to 0.067 ppm of P in surface water while its content in rural areas generally ranges from 0.07 to 0.1 ppm. This would mean that two-thirds of the P content in surface water are due to runoff and drainage, in areas free from pollution by agglomerations and industries.

For the whole of Europe, which is 5.5 times the size of France, this would amount to a loss of 38,000 to 55,000 tons of P per year.

Estimates will be on firmer ground when all analytical results for 1971 are known.

If we put the average duration of human life at 60 years, 5,000 tons are concentrated annually in cemeteries and necropolises.

But the biggest losses of P are undoubtedly due to the following two factors:

1) Non-recovery of bones, their dispersion and that of the waste materials of human nutrition in our environment: discharge, garbage, direct-to-sewer drainage, etc. This involves about 180,000 tons of P a year, over which no control is possible at present. We can express this tonnage in a figure but we know nothing about its subsequent activities except that they doubtless act as various causes of pollution.

2) It is impossible to return to the soil the entire quantity of P contained in animal excrements. It is very difficult to make a division between phosphorus actually reused in organic manure and phosphorus lost. It has already been established that strong animal concentrations are responsible for abnormally enriching underground water with nitrates, and one can even now put forward the principle of a policy of hygiene in view of the fact that the phosphorus of animal production forms a much bigger quantity than of urban agglomerations.

VIII. OVERALL PHOSPHORUS BALANCE-SHEET (Table III and Diagram of phosphorus circuits)

We are going to omit the quantities of P used for non-food crops (tobacco, timber, textiles, oilseeds, flowers, ornamental trees, etc.). Nor has it been possible to consider the result of the grain import-export balance-sheet or imported food produce.

Plant production for human consumption corresponds to an exportation of 150,000 tons of P a year, or an absorption of 200,000 tons; it may be estimated that the supply of P to meet this requirement must be close to 250,000 tons.

Animal production represents annual requirements of some 805,000 tons of P: [875,000 - (50,000 + 20,000)].

If this tonnage is to be present in the plant products feeding animals, a minimum of 1,000,000 tons of P must cover absorption by plants, that is, the supply of P to the soil must be 1,250,000 tons, in view of the dynamic of phosphorus in the soil.

Total annual supplies therefore should be of the order of 1,500,000 tons, from which we may deduct the quantity of P returning to the soil through animal dejecta (200,000 to 300,000 tons).

A purely static examination of the quantities supplied (2,000,000 tons) and required (1,200,000 to 1,300,000 tons) might lead to the conclusion that phosphorus supplies are adequate at present.

In actual fact, phosphate fertilizer has to be considered mainly under another two aspects:

1) P is an element indispensable to life, and one necessarily has to put supplies somewhat above the strict level of requirements. This is particularly true of animal production; the maintenance of productive and fertile livestock necessitates an excellent level of phosphate fertilization. The 1939-45 period showed the grievous consequences of inadequate phosphate fertilization.

2) The supplies of P established according to exportation by crops could not meet the requirements of plant production. The periods in which plants draw phosphorus do not coincide with those in which this element is easily available in the soil (use in winter and at the beginning of spring). At no time should phosphorus supplies in the soil be a limiting factor of production. Moreover, adequate supplies of P in the soil make for faster development of plants, for better resistance to cold, and for better defence against parasites, especially those attacking the root system.

Attention should also be paid to the particular levels phosphate fertilization must reach in soils poor in P_2O_5 (fertilizer for recovery) and in soils that rapidly insolubilize P_2O_5 (calcareous soils, highly acid soils, soils rich in Fe and Al).

Under these conditions, it would be out of the question to limit phosphate fertilization in Europe to the theoretical requirements of 1,300,000 tons of P per year. Besides, there are other types of non-food production which account for 100,000 tons of P a year.

IX - CONCLUSIONS

Man has increased the biomass of the ecosphere, especially in Western Europe.

The movement of P has been intensified and speeded up, above all owing to the importance of animal production in our nutrition.

In the area under review, 175 000 tons of P per year are necessary for the existence of 320 million people. The share of food phosphorus directly from plant production meets half of these requirements; it corresponds to the mobilization of 200 000 tons of P which call for 250 000 tons of P a year in the soil.

Vegetable foods involve excellent utilization of P: of 3 parts of P employed,

- 1 goes into human food
- 1 returns to the soil
- 1 is lost or is fed to animals.

But animal production is another matter. It is mainly responsible for the circulating tonnage of P and for the dispersion of considerable quantities in the natural environment. Of 10 parts of P employed,

- 1 goes into human food
- 3 return into the soil
- 6 are lost in the environment.

The few data available to us seem to show no direct influence of very slight direct influence of phosphate fertilization on the P content of surface water.

In France, 7 000 to 10 000 tons of P are carried from the cultivated areas to the sea. This is a very small quantity compared with the hundreds of thousands of tons supplied by fertilizers. Cultivation techniques might be suggested to reduce losses by drainage and runoff. They would result in a saving of only a few thousand tons at most, which is very little in relation to the other agricultural factors in the spread of phosphorus (about 2%).

Despite imperfections and inaccuracies (of which the author is well aware), this note finally intends to point up the considerable import of animal production in the various processes spreading P in our environment - probably more than 700 000 tons of P per year (see diagram "P circuit"). New studies might provide recommendations or solutions to prevent the development of animal production from progressively soiling our environment.

Man is using rivers to dispose of the waste products of his biological, domestic and industrial activities which contain phosphorus. As this pollution is very frequently due to point sources, it should be possible to provide remedies by intervening where necessary.

But the character of animal production is another matter. Production is highly dispersed over a very large area and should be subjected to rules on:

Animal husbandry

1) Regulation of strong and stable concentrations of animals in small areas (open housing, feedlots) because penetration of P in depth must inevitably cause abnormal enrichment of underground water;

2) the need of treating the wastewater of industrial stock-raising before it reaches surface water;

3) trying to spread the dejecta of livestock on areas of sufficient size for reuse of P by plant production, without miscalculation;

4) use of concentrated dejecta (poultry droppings and litter, dried mixture of liquid and solid manure) to produce organic fertilizer for marketing.

Slaughter-houses and canneries

Recovery of all bones and waste products for use as a source of mineral elements (animal feed and fertilization).

Consumption

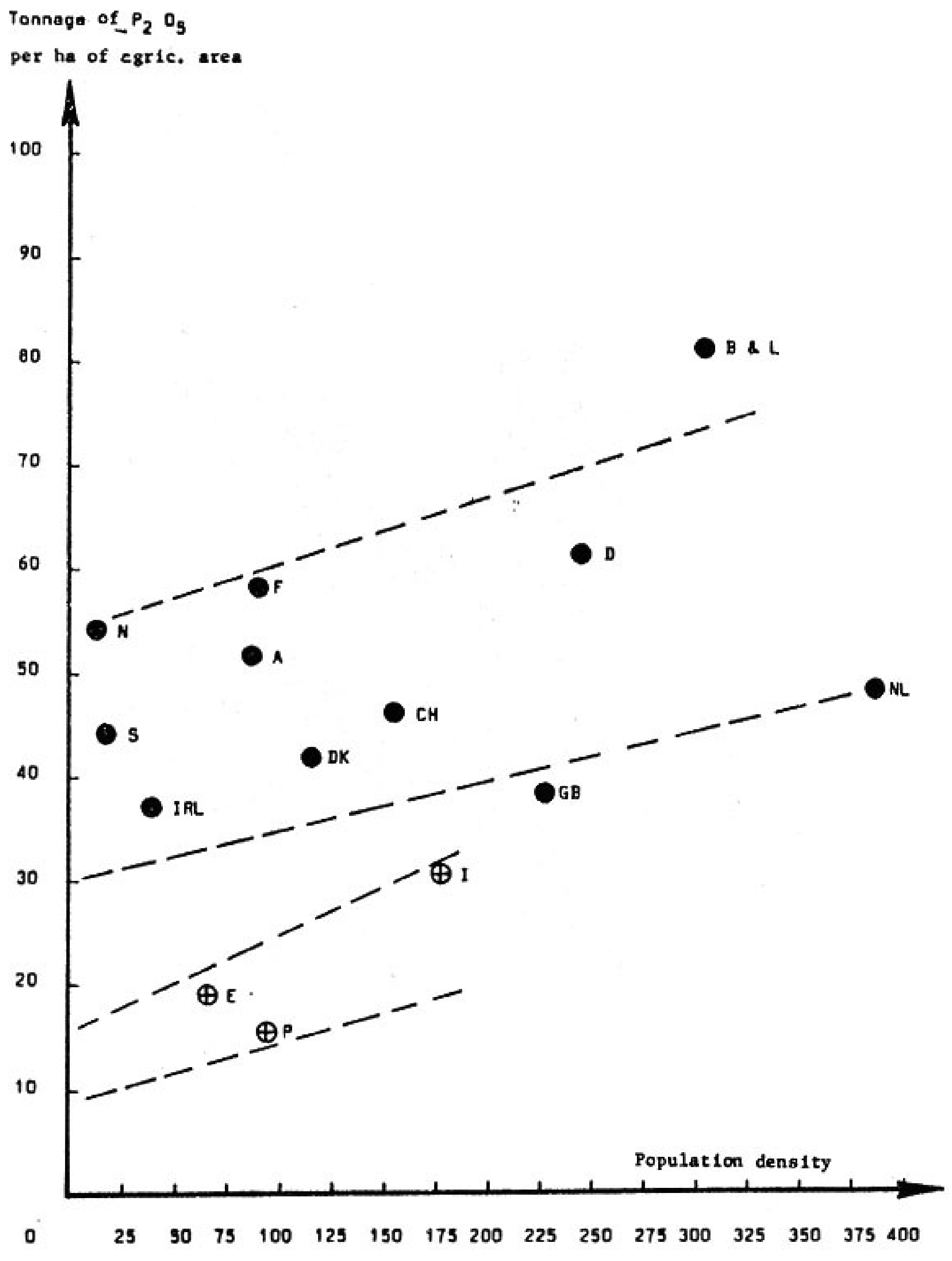
1) Separation of bones and food waste to prevent them from reaching surface water;

2) likewise, the ashes of incinerated household garbage must not be left to chance; precautions must be taken so that they will not become a source of pollution replacing the pollution that was to be avoided.

1969 and 1969-1970

Country	Number of inhabitants	Area km^2	Inhabitants per km^2	Agricultural Area (1000 ha)	P_2O_5	P	P_2O_5/ha	P per inhab.
AUSTRIA	7 375 000	84 000	88	2 779 ha	144 500 t	62 800 t	52 kg	8,3 kg
BELGIUM AND LUXEMBOURG	9 990 000	33 100	302	1 834	148 100	64 400	81	6,45
DENMARK	4 910 000	43 000	114	3 023	126 900	55 200	42	11,20
IRELAND	2 900 000	70 300	41	4 585	169 100	73 500	37	25,50
FRANCE	50 300 000	551 500	91	29 234	1 710 200	743 600	58	14,80
FED. REP. OF GERMANY	60 800 000	248 000	245	13 996	856 600	372 400	61	6,20
ITALY	53 200 000	301 000	177	15 557	486 200	211 400	31	4
NETHERLANDS	12 900 000	33 500	385	2 239	107 500	46 700	46	3,6
NORWAY	3 850 000	324 000	12	1 000	54 000	23 500	54	6,2
PORTUGAL	8 860 000	92 000	96	4 130	60 900	26 500	15	2,8
SPAIN	33 000 000	507 000	65	20 725	395 000	171 700	19	5,3
SWEDEN	7 800 000	450 000	17	3 138	139 200	60 500	44	7,7
SWITZERLAND	6 400 000	41 300	155	1 100	50 900	22 100	46	3,6
UNITED KINGDOM	55 500 000	244 000	227	12 405	469 600	204 200	38	3,7
TOTAL OF AVERAGE	317 785 000	3 022 700	105	115 740	4 918 700	2 138 500	42,5	6,7

GRAPH -I-


Tonnage of P_2O_5
per ha of agric. area
100
90
80
70
60
50
40
30
20
10
0
B & L
D
F
N
A
NL
CH
S
DK
GB
IRL
I
E
P
Population density
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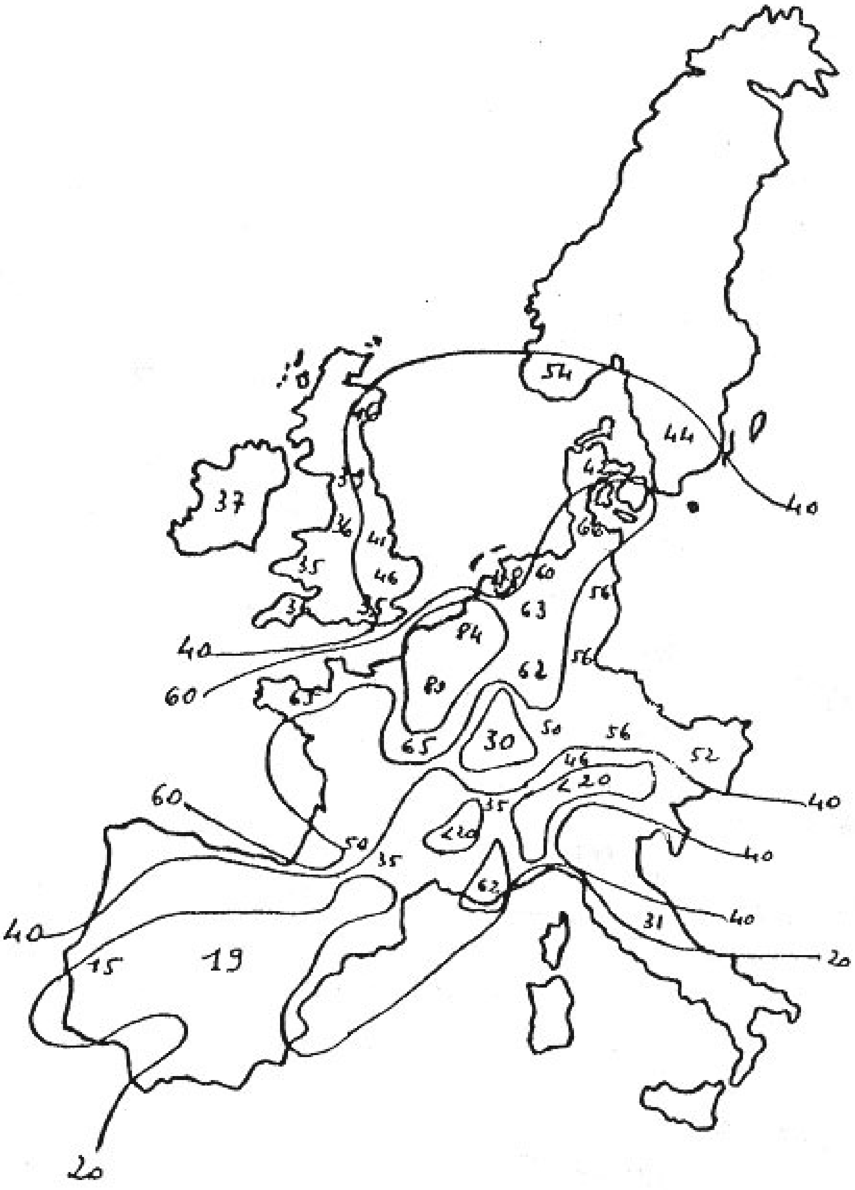
100
125
150
175
200
225
250
275
300
325
350
375
400



AVERAGE ANNUAL CONSUMPTION OF P_2O_5 per ha of agric. area

GRAPH - II -

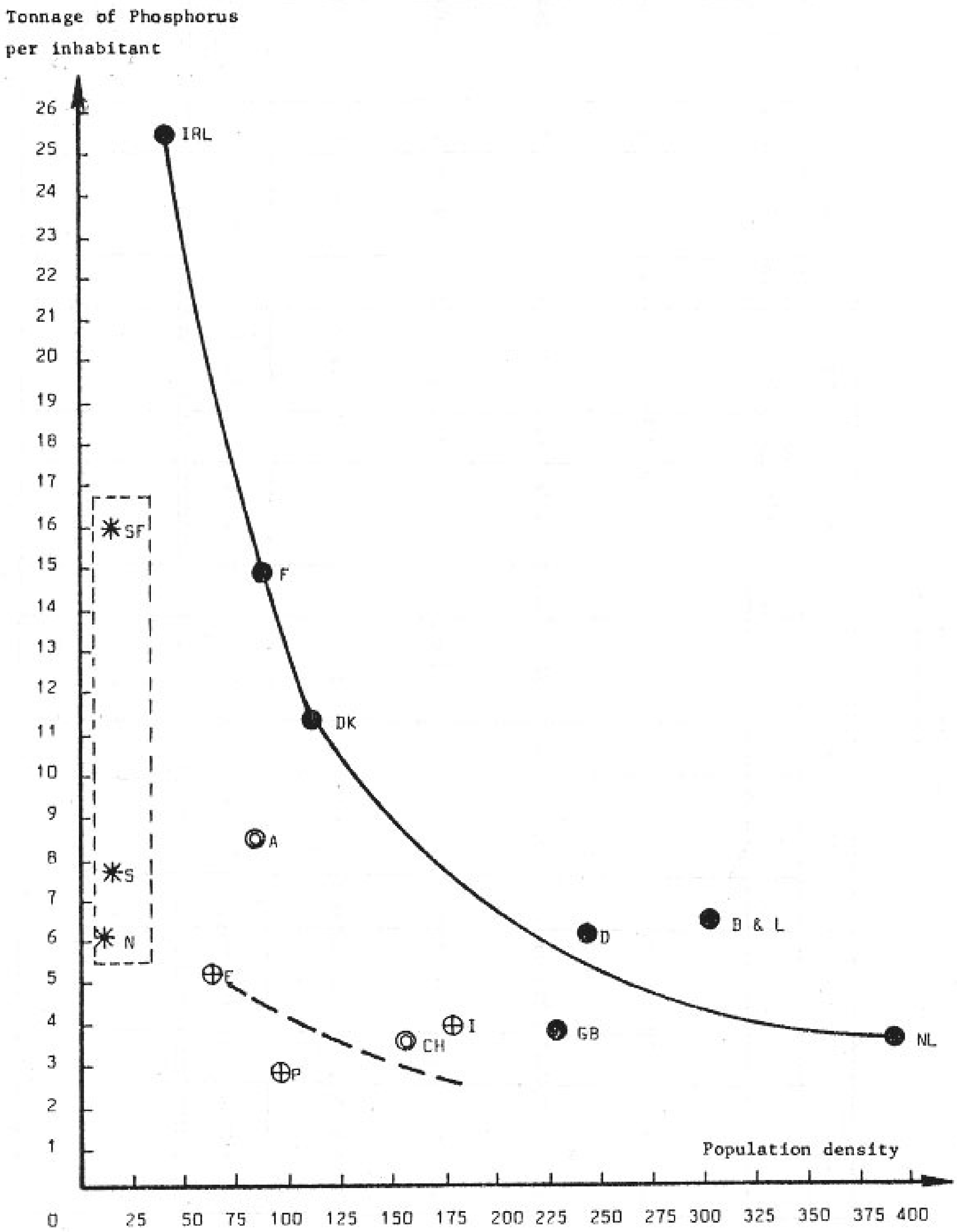

Tonnage of Phosphorus per inhabitant
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
IRL
F
DK
SF
S
N
A
E
P
CH
I
GB
D
B & L
NL
Population density
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400

Table II

MEAT
(tons)

OECD Statistics - 1969

1) CONSUMPTION	POPULATION	PORK		BEEF-VEAL		MUTTON-GOAT		HORSE		POULTRY		OTHER		OFFAL		TOTAL
		per inhab.	total	per inhab.	total	per inhab.	total	per inhab.	total	per inhab.	total	per inhab.	total	per inhab.	total	
EEC	187 190 000	28,9	5 409 800	24,2	4 530 000	1,2	224 600	0,7	131 030	10,1	1 890 620	2,3	450 540	4,9	917 230	13 553 820
EFTA	94 635 000	24,5	2 318 560	20,4	2 271 120	6,7	634 050	0,2	18 925	7,3	690 840	2,6	246 050	4,4	416 395	6 595 940
Spain	33 000 000	13,3	438 900	11,1	366 300	4,0	132 000	0,4	13 200	9,1	300 300	0,7	23 100	2,0	66 000	1 339 800
Ireland	2 900 000	29,0	84 100	18,0	52 200	10,8	31 320	-	-	9,2	26 680	-	-	12,0	34 800	229 100
Total	317 725 000		8 251 360		7 219 620		1 021 970		163 155		2 908 440		719 690		1 434 425	21 718 660
2) TOTAL PRODUCTION			8 500 000		6 600 000	-	810 000		130 000		2 970 000		460 000		1 250 000	20 720 000

Table III

QUANTITIES OF P EMPLOYED FOR HUMAN FOOD (tons)

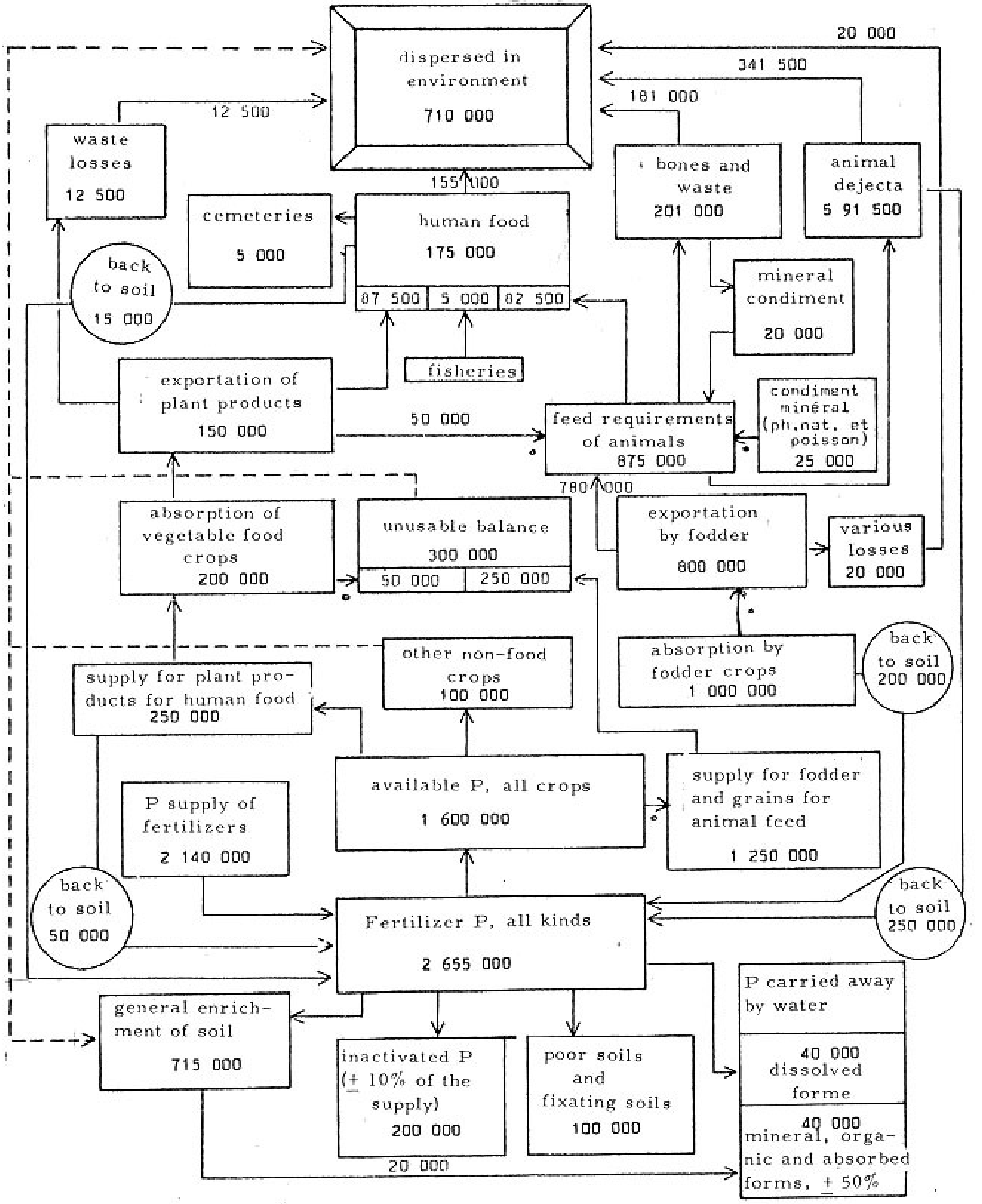
(320 million inhabitants)

PLANTS		collected	human food	animal feed	waste and losses
to be supplied to soil	drawn by plants				
250 000	200.000	150 000	87 500	50 000 (1)	12 500

Animals	Present in livestock feed	Human food	waste and bones	dejecta
Poultry	73 000	4 500	30 500	38 000
Cattle	330 000	11 000	96 000 (2) 11 500 (- offal 2 500)	209 000
Pigs	150 000	12 000	39 000	100 000
Miscellaneous and Offal	67 500	5 000 (3)	25 000	40 000
Feed for laying hens	75 000	7 000		68 000
Feed for milch cows (13 kg/day)	180 000	43 000		137 000
TOTAL	875 000 (1) (2)	82 500	201 000	592 000

1) 50,000 tons of P found in animal feed
2) 20,000 tons of P found in animal feed
3) whereof 2,500 tons of P in offal

QUANTITES ANNUELLES de PHOSPHORE qui CIRCULENT dans l'OUEST-EUROPEEN pour COUVRIR les BESOINS ALIMENTAIRES de l'HOMME (en tonnes de P)



SORPTION AND MOBILITY OF POTASSIUM IN SOILS

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Introduction

There is a close correlation between sorption properties of soils and the mobility of K in soils. A soil that adsorbs K very tenaciously has a low K concentration in the soil solution. K mobility is therefore also low, as the translocation of ions over longer distances in a soil takes place in the aqueous phase. This is true for both diffusion and convection.

Only convection appears to be involved in the long-range transport of K, as for instance in the translocation down a profile, whereas diffusion plays an important part in the supply of K to plant roots under conditions of rapid uptake.

K bonding sites in soils

Soils are ion exchangers, as they carry a net negative charge (there are exceptions, however). The soil minerals and organic matter both contribute negative charges, which are balanced by inorganic cations, among them K.

The greater part of the inorganic negative charge residas at the clay minerals in the clay fraction. The contribution of the silt fraction is comparatively small because of its low surface area and low charge per unit weight (fine silt ∾ 1/3, medium silt ∾ 1/10 of the C.E.C. of the clay fraction).

Except in sandy soils, organic matter plays only a negligible role in the sorption of K because of its low K selectivity and its preference for H^+ and multivalent cations (NEMETH et al. 1970, NEMETH a.GRIMME 1972). In most of our arable soils the clay fraction is made up of mica-derived illite and its weathering products: expanded illite, vermiculite, montmorillonite and pedogenic chlorite. These different clay minerals do not exist as separate entities in the soil but as a result of the weathering process the properties of all the above mentioned clay minerals can be found in one clay particle (Figure 2). During weathering the illite particle looses some of its interlattice K which is replaced by other cations which because of the higher hydration energy of these cations leads to an expansion of the clay lattice. The interlayer space now takes part in ion exchange reactions . On addition of K ions to the soil the lattice collapses again and the added K is fixed in a rather immobile form. If the soil solution contains A1-ions, these too, will occupy exchange positions in the interlayer space and eventually they polymerize to A1-hydroxo-polymer cations which are no longer exchangeable and act as props preventing the collapse of the clay sheets on addition of K. But these polymer interlayers are imperfectly built so that holes and channels remain through which cations of appropriate size can diffuse into the interlayer space (Figure 2). Such a soil clay has exchanged positions of very different quality especially as far as K is concerned. The planar sites are accessible to any cation and show, if at all, only a slight preference of K over other cations. The interstitial positions show already some K selectivity. The edge and wedge sites have a high K selectivity because only K fits snugly into the hexagonal holes of the tetrahedral layer and because the hydration energy of K is low enough to be overcome by the electro-static forces between cation and negatively charged clay layers.

K saturation as a factor of K mobility

The K selectivity of a clay mineral can be expressed in quantitative terms as selectivity coefficient. Gapon's equation is mostly used to calculate the selectivity coefficient:

$$\frac{K_a}{Ca_a + Mg_a} = k \frac{K_1}{Ca_1 + Mg_1} \qquad 1/$$

Figure 3 shows that the K selectivity is dependent on the K saturation of the clay. Obviously a certain K saturation of the exchange capacity is required to have all K selective sites occupied with K ioms. Below a certain K saturation the selectivity coefficient increases rapidly indicating a high preference for K over Ca + Mg and correspondingly a low K concentration in solution, which is of practical consequence if one wants to estimate K availability to plants or K mobility in the soil.

It is interesting to note that montmorillonite does not show a significant change in K selectivity with changing K saturation and that over the whole range the selectivity coefficient is significantly less than for illite. This is due to the fact that montmorillonite has only planar exchange sites (Figure 1) and does not collapse on addition of K, because of its low surface charge density. In contrast to montmorillonite chlorite clay exhibits a very high selectivity which is probably the result of an unusually high proportion of wedge sites. At a given K saturation a montmorillonite soil has therefore a higher K concentration in the soil solution than an illite soil and hence K mobility is higher, whereas the reverse is true for soils with chlorite as dominant clay mineral. Figure 4 demonstrates that the same relationship holds for soils, which usually contain a mixture of clay minerals. 2/

From the foregoing it appears that K saturation is an important factor determining the behaviour of K in soils. The lower the K saturation the more tightly K is held by the soil, so that the K concentration in the soil solution is low and hence the K mobility in the soil is low too. This would mean that at a given content of exchageable K a sandy soil (low inorganic exchange capacity) has a higher K concentration in the soil solution than a loam or clay soil. Figure 5 demonstrates that this is indeed the case. Therefore, in heavy soils there is much less K loss through leaching (Tab. 3), and a substantial downward movement of fertilizer K would occur in a loam soil only at much higher doses than in a sandy soil.

It is rather inconvenient to have separate regressions for each textural class of soils. We therefore prefer to plot K saturation of the inorganic exchange capacity instead of exchangeable K content. Then only one regression line is obtained and it is possible to estimate the K concentration in the soil solution if the K saturation is known (Figure 6).

Vertical K movement in soils

Unfortunately it is not as easy to calculate the K movement down a profile even if the amount of water moving downwards were known, because at a given K saturation the K concentration varies also with water content (Figure 8). Under conditions of unsaturated flow the concentration will be higher than given in Figure 6, however, the amount of water

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1/ K_a, Ca_a, Mg_a = exchangeable cations (me/100 g)
K_1, Ca_1, Mg_1 = cations in solution (mole/1)

2/ It should be stressed that only the inorganic exchange capacity has to be taken into account when calculating the K saturation of a soil.

percolating through the profile will also be appreciably lower, so that the overall vertical K movement might still be lower than at or above field capacity. However, the fact still remains that mobility depends on the K concentration in the soil solution because transport will take place in the aqueous phase. In moving downwards the soil solution will pass through horizons with K saturations different from those of the top soil so that a continuous equilibration process will take place during the downward movement and the K concentration will continuously change. The composition of the leachate will correspond to the K saturation of the last layer of soil through which it passes. As the K saturation in the subsoil is nearly always lower than in the surface layers the soil solution is gradually depleted of K so that the drain water has usually a rather low K concentration.

In Figure 7 the K concentration at different depths of 3 profiles (one unfertilized) is given. In the highly fertilized as well as in the K deficient soil the K concentration becomes more or less the same below the depth of 1 m, which means that in three of the profiles about the same amount of K would be leached, if the same amount of water would percolate through each profile irrespective of fertilizing practice, only the sand would suffer significant leaching losses. Assuming field capacity and knowing the amount of percolating water and K concentration of the soil solution one can make an approximate estimate of how much K will move out of a soil layer (Tab. 1). It is obvious that more K will be leached out of a fertilized plough layer than out of a subsoil. High applications of K fertilizer will result in a gradual increase in K saturation of the subsoil. From the point of view of plant nutrition this is rather a desirable process as an enrichment of the subsoil would ensure a sufficient nutrient supply during times of drought when uptake from the dry top layer is severely restricted (GRIMME et al. 1971). This is, however, also a very slow process as after 50 years of fertilizing practice the subsoils of our arable soils have still a considerably lower K saturation than their plough layers.

This theoretical reasoning is confirmed by lysimeter experiments, which show leaching of K out of the plough layer, but this K is retained in the subsoil which looses only small amounts of K corresponding with its lower K saturation (Table 2, VOMEL 1970).

A further interesting fact emerges from Tab. 2: leaching into the subsoil is less when the soil is fertilized. Even with 240 kg K_2O/ha K movement into the subsoil was nearly 30% less than without K fertilizer, if there was an adequate N-supply. Similar results have been obtained by JUNG et al. (1970) who also found in their long term lysimeter trials that fertilizing practice has an important influence on the downward movement of K in soils (Tab.3). Especially N supply is of importance here. On well fertilized soils higher yields are obtained, more nutrients are taken up and more water is consumed, so that as a result less nutrients are translocated to deeper layers. The pH of soils exerts a considerable influence on K mobility, because at a given K saturation the K concentration increases with decreasing pH (NEMETH a. GRIMME 1972). As a consequence leaching losses increase substantially with decreasing pH (KRAUSE, 1965, Tab. 4). Under arid conditions there are of course no leaching losses,unless irrigation is practiced and a surplus of water over the actual consumption is applied but salt accumulation in the top soil. Here the same principles apply as for the downward movement. However, there is an accumulation of the more mobile ions, especially Na.

K concentration in surface and groundwater

There is only little information available on the K concentration of surface and groundwater. But from our knowledge of the behaviour of K in soils one would conclude that with the exception of sandy soils there is no influence of K fertilization on water composition. The K content of ground and surface is dependent on the chemical and mineralogical properties of the soil and their parent material (TOTH A., 1969). The K content of water from land drains is usually in the order of 0.1 me/l or less (WILLIAMS 1970, KLETT 1965).

Because of K enrichment in the top layer from fertilizer substantial amounts of K may be exported from the fields by erosion. But most of this K will be bound within the soil particles or in exchangeable form. On dilution the K concentration in the aqueous phase

of a suspension will decrease rapidly and the initial difference between soils of different K saturation becomes negligible (Figure 8), so that no important increase of the K concentration of ditches and rivers by erosion is to be expected, because of this dilution factor.

Conclusions

There is little danger of fertilizer K being carried into groundwater and surface water from arable fields with the exception of heavily fertilized sandy soils.

Although there is so far no indication that K contributes to entrophication avoidable exports from the agricultural land should be avoided. This can be done by adopting soil and crop management practices that avoid unnecessary losses: erosion control by cover crops, balanced fertilization for high yields, deepending of the plough later to increase water capacity (less drain water), pH control, spring application of fertilizers on sandy soils (leaching losses occur during winter and early spring).

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Table 1

Calculated K loss (kg/ha) through leaching at different K concentrations in the soil solution and different amounts of drain water

drain water (mm)	100	200	300	400
K-conc.me/l				
0.05	2	4	6	8
0.1	4	8	12	16
0.5	20	40	60	80
1.0	40	80	120	160

Table 2

Leaching of K from different depth of a profile under oats with different N and K applications (Vömel, 1970)

	Treatment		K leached, kg K_2O/ha	
	kg N/ha	kg K_2 O/ha	from 26 cm	from 50 cm
fallow	0	0	57	3
oats	0	0	55	4
oats	59	123	45	13
oats	117	182	51	2
oats	176	240	41	2

Table 3

K leaching in two soils with different fertilizer applications (Jung a. Dressel 1970)

Treatment		Leaching kg K_2O/ha
Sand		
0		6
PK	100/250 kg/ha	40
NPK	100/100/250 kg/ha	18
Loam		
0		3.9
NPK	80/80/120 kg/ha	5.0
NPK	160/160/254 kg/ha	5.5

Table 4

Influence of pH on leaching losses of K (Krause 1965)
mg / lysimeter)

	3.8	7.5	15	K application mg/100 g
pH				
4.3	54	224	650	
5.1	24	100	400	
6.4	15	61	250	

Figure legends

Figure 1.	Model of illite and its principal weathering products
Figure 2.	Model of typical clay mineral in an illitic soil
Figure 3.	Relationship between K saturation and selectivity coefficient of different clay minerals
Figure 4.	Relationship between K saturation and selectivity coefficient of soils
Figure 5.	Correlation between exchangeable K and K concentration in soil solution
Figure 6.	Correlation between K saturation and K concentration in soil solution
Figure 7.	Variation of K concentration with depth in 4 profiles
Figure 8.	Effect of dilution on K concentration.

Fig.1 Different types of 3 layer clay minerals

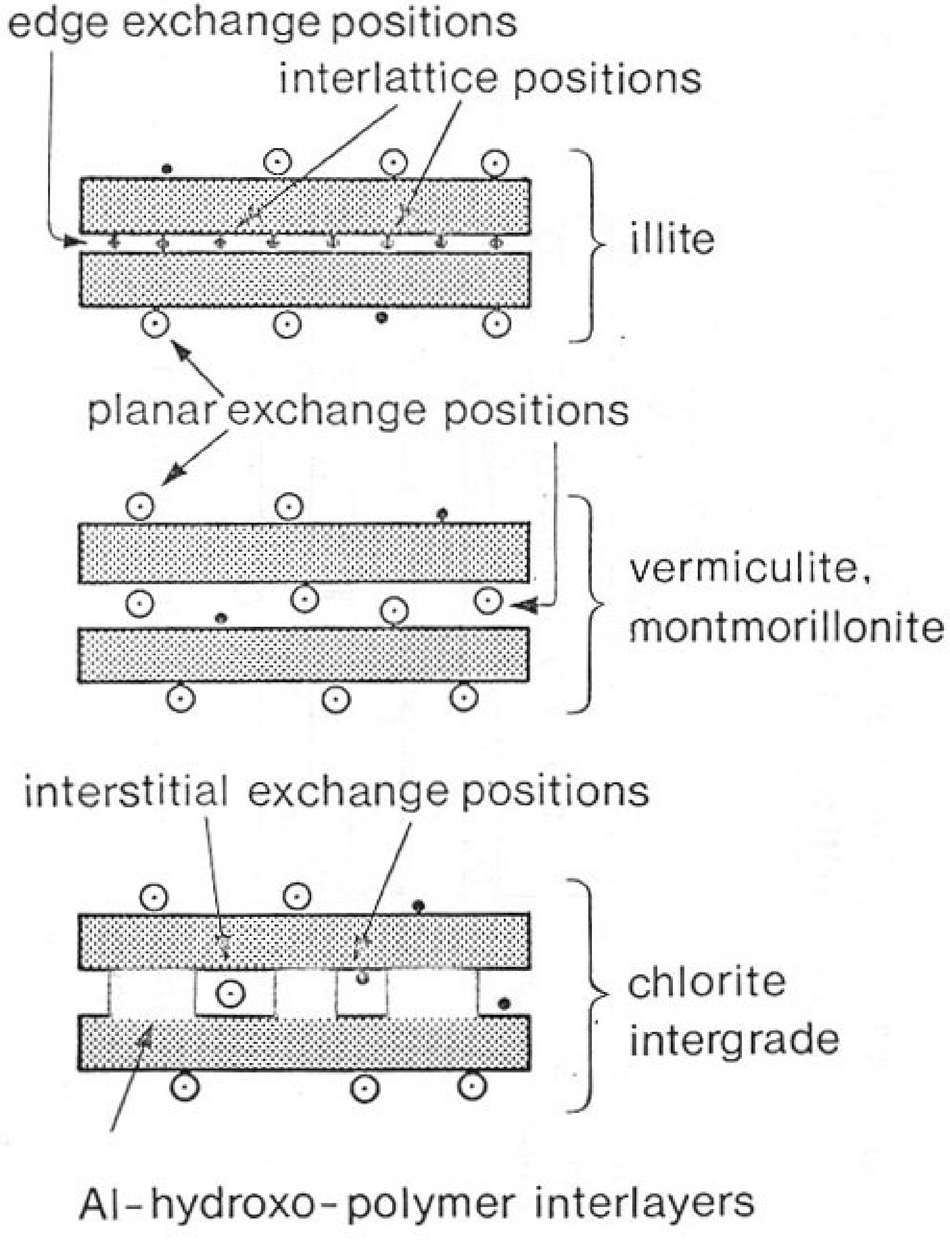
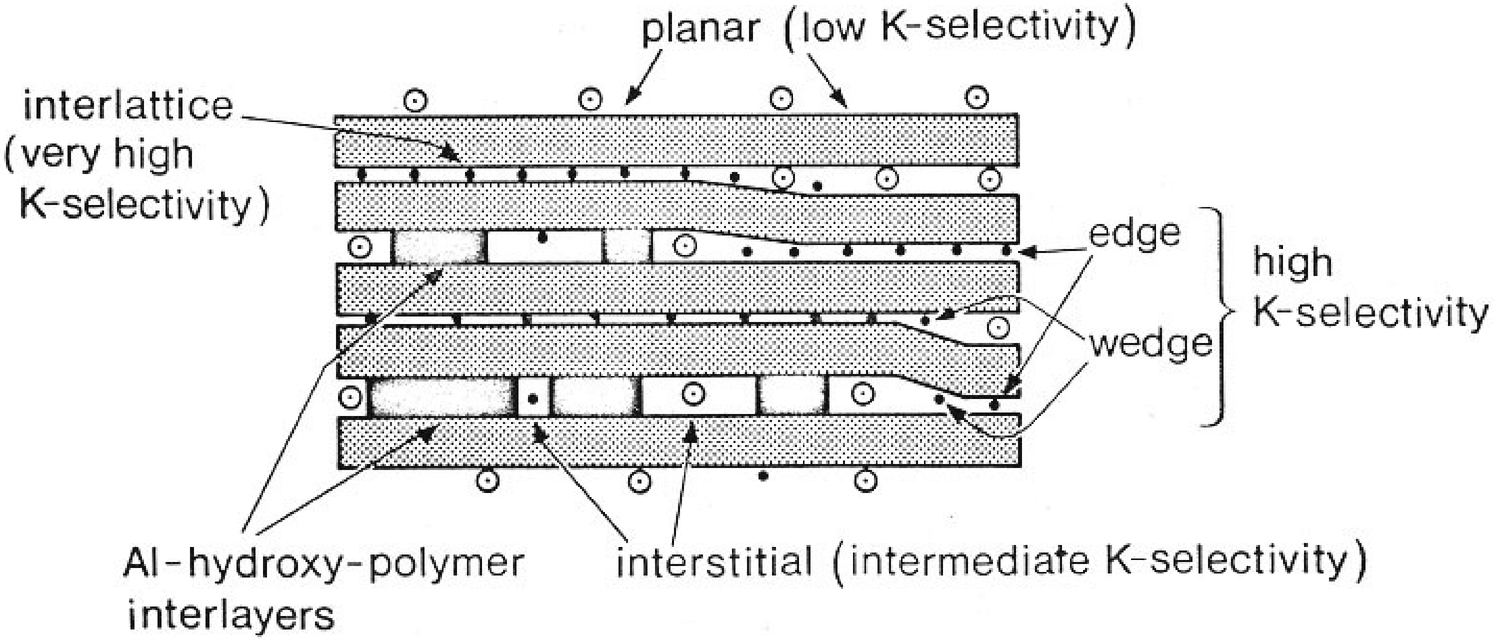


Fig.2 Exchange positions on a clay mineral (partly expanded and chloritised illite)



• = K   ⊙ = cations other than K

Fig. 3

(after Schwertmann and Schouwenbourg et al. resp.)

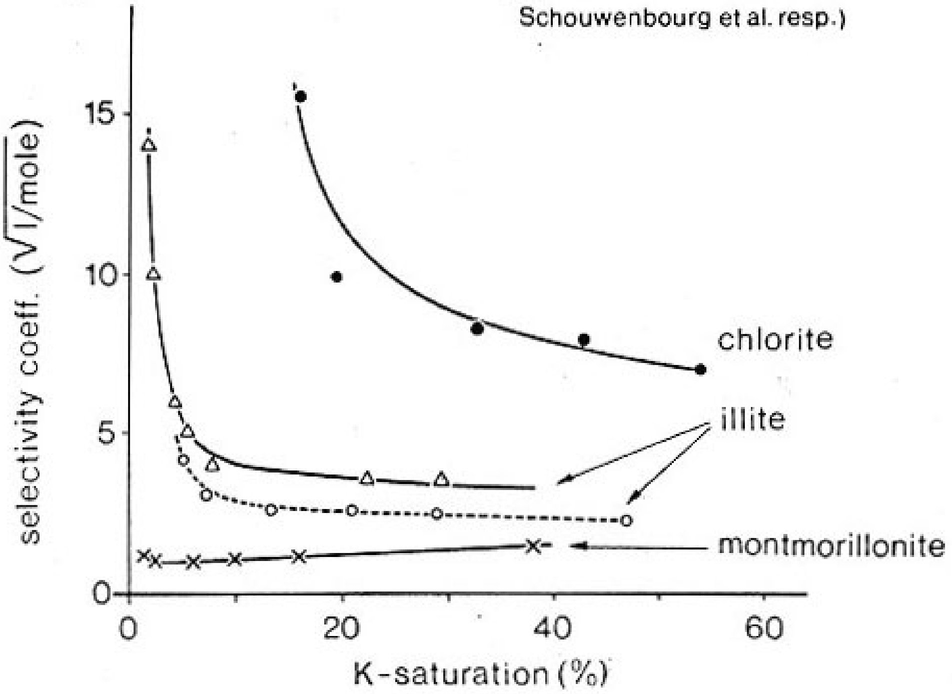


Fig.4

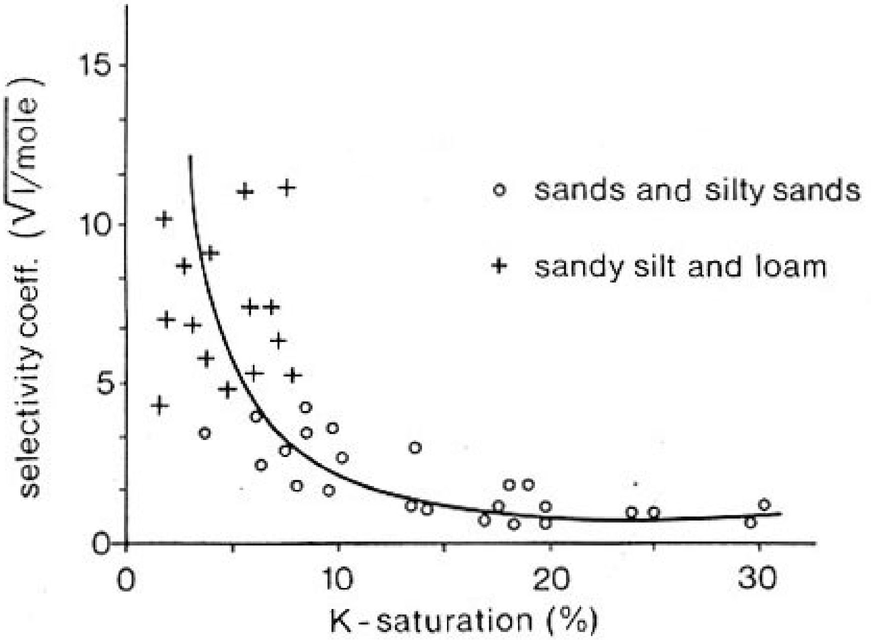
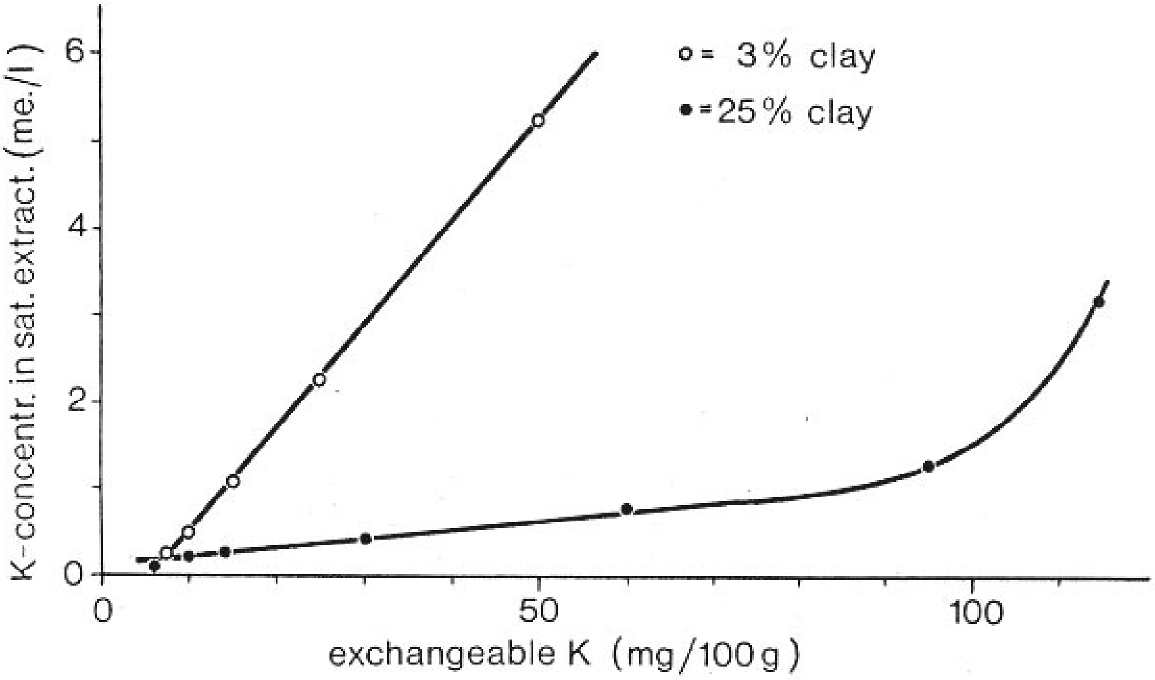
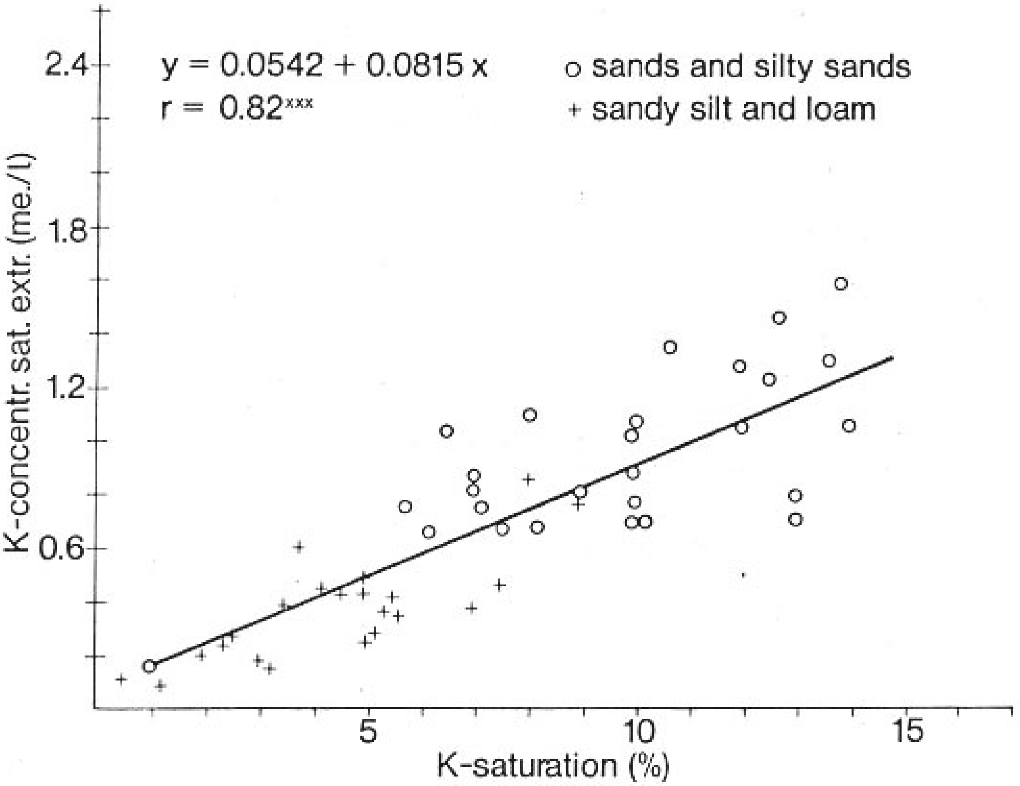


Fig. 5



K-concentr. in sat. extract. (me./l)
6
4
2
0
0
50
100
exchangeable K (mg/100 g)
○ = 3 % clay
● = 25 % clay

Fig. 6



y = 0.0542 + 0.0815 x
r = 0.82xxx
○ sands and silty sands
+ sandy silt and loam
K-concentr. sat. extr. (me./l)
2.4
1.8
1.2
0.6
5
10
15
K-saturation (%)

Fig. 7

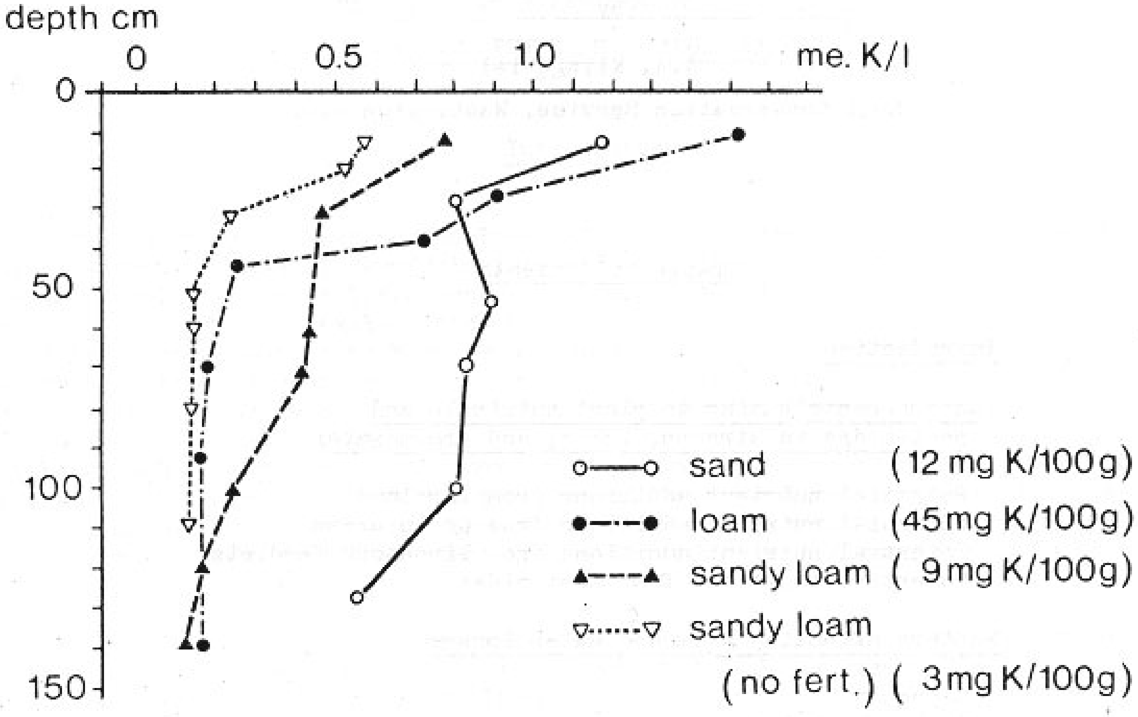
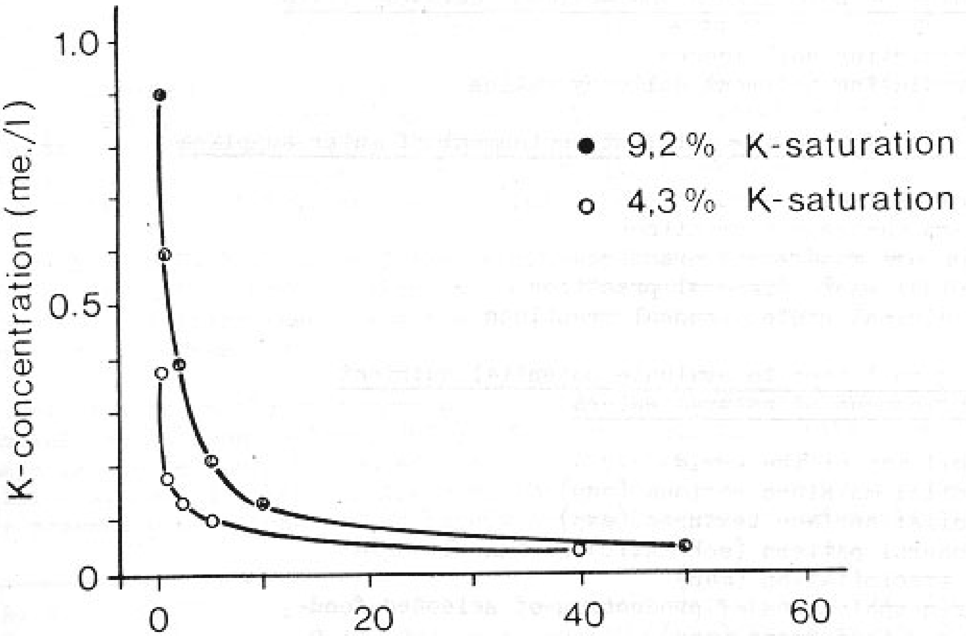


Fig. 8 Effect of dilution on K-concentration



SOIL AND WATER MANAGEMENT TO CONTROL PLANT NUTRIENTS IN NATURAL WATERS

by

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Summary

SOIL AND WATER MANAGEMENT TO CONTROL PLANT NUTRIENTS IN NATURAL WATERS[1]

Introduction

The present concern about our environment is only a new chapter in a story that goes back many hundreds of years. Archeologists and historians have recorded data that show that man has exploited natural resources for centuries. Some authors have related the downfall of nations to the exploitation of the soil, water, and plant resources. In spite of all of these statements that have been made in the past, advances in science and technology have allowed us to produce more food and fibre and enjoy a higher standard of living today than at any other time in the history of civilization.

We have much to learn about the nature of environmental constraints. We often disagree about the permissible levels of nutrient concentration in water and about the effects on the environment of some forms of production and consumption (Gratto, 1971). This uncertainty forces us to make decisions without having a clear idea as to the outcome of our actions.

Evidence is available to show that excessive use of plant nutrients can be one of the sources of nutrient enrichment of natural waters. This is especially true if poor soil and water management practices are followed and if fertilizers are applied without regard for the hazard of water pollution. But there is no doubt about the technical feasibility of preventing serious degradation of our water supplies. In fact, the prospect of being able to improve our environment is good.

Methods are available that can be used to keep plant nutrient losses due to runoff and erosion from rural and urban areas at an acceptable level. By applying what we know, we can make great strides in reducing pollutants in water supplies.

Agriculture is facing a formidable challenge. We must produce more food and fibre to feed, clothe, and provide shelter to millions of additional people in the years ahead and at the same time keep agriculture's contribution to water pollution to a minimum. We must, and we can, maintain a standard of quality of our soil, water, and plant resources that will be beneficial to present and future generations.

Dr. Norman E. Borlaug told the opening meeting of the 16th Governing Conference of the Food and Agriculture Organization in Rome a few months ago that if agriculture is denied its use of fertilizer then the world will be doomed, not from chemical poisoning but from starvation (FAO News, 1971).

Unfertilized soils no longer can provide the food necessary to meet the needs of expanding populations (Nelson, 1972). Today's populations have so expanded that food demands can be met only by use of chemical fertilizers. Without continued use of fertilizers, most developed nations of the world probably would be unable to feed even their present populations and certainly not at the accustomed dietary standards that are

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1/ A. A. Klingebiel, Director, Soil Survey Interpretations, USDA, Soil Conservation Service, Washington, D.C. Prepared for FAO Conference on the Effects of Intensive Fertilizer Use on the Human Environment, Rome, Italy, January 25-28, 1972.

heavily dependent on protein. Developing countries are even more dependent on use of chemical fertilizers since food supplies in these countries already are nutritionally inadequate and populations are increasing much faster than in the developed regions. To use larger amounts of plant nutrients without some nutrient enrichment of natural waters, especially where a high potential for pollution exists, will require proper soil selection and the use of good soil and water management practices.

High-yielding crop varieties much more than native varieties require large amounts of plant nutrients, along with pesticide control, adequate water, and improved management. In developing countries, a rough rule of thumb is that 1 ton of plant nutrients will produce about 10 tons of cereals or enough to provide 2400 calories daily to 40 people for 1 year (Nelson, 1972). The increased yields ascribed to fertilizers, however, have been made possible only through combining fertilizer use with a complex set of other inputs and improved farming practices (Kellogg, 1960).

Each dollar spent on fertilizer in the U.S. brings a return of about $2.50. This is relatively large in relation to returns achieved from most other inputs (Nelson, 1972). As a substitute for land, 1 ton of plant nutrients on the average is equivalent in production to about 3.8 hectares (Ibach, 1966). Fertilizer substitutes for labour also since higher yielding crops increase labour requirements only a small amount per hectare. Fertilizers, as a result, have had a major influence on American agriculture and on the American economy.

What would be the effect if fertilizers were not used on selected crops in certain states in the U.S.; for example, say cotton in Texas, wheat in Kansas, or corn in Iowa (Viets, 1971)? Eliminating fertilizer on cotton in Texas in 1964 would have required an acreage increase of 28.7% to sustain production. Eliminating fertilizer on wheat in Kansas in 1964 would have required a 20.3% increase in acreage the first year to maintain production. To have prohibited fertilizer use on corn in Iowa in 1964 would have required a 29% acreage expansion to maintain production. Fertilizers substantially reduce our land needs for crop production. The use of fertilizer on the better soils where erosion hazards are minimal permits leaving the poorer soils in permanent grass or tree cover.

Great concern has been expressed over nutrient buildup in streams, lakes, rivers, and reservoirs, not so much because of the increased nutrient concentration per se, but because of its possible promotion of undesirable growth of algae and other aquatic plants (Stanford, England, and Taylor, 1970). In this connection nitrogen and phosphorus are commonly regarded as being of primary importance.

Returning all cultivated land to grass or trees would not eliminate erosion or nutrient runoff. Natural geologic erosion and eutrophication took place on virgin lands long before they were disturbed by man (Wadleigh and Britt, 1969). Soils developed from alluvium and also large deposits of lowland peat are evidence of the direction and power of these natural forces.

The belief that nitrogen and phosphorus are the nutrients that control or limit the growth of algae and other aquatic life including fish has focused much attention on these elements (Stanford, England, and Taylor, 1970). Other nutrients are generally considered to be present naturally in sufficient quantities for optimum growth, although molybdenum may be an exception. However, not enough is known of the nutritional requirements of algae or phytoplankton and how these requirements are influenced by factors such as temperature, light levels, carbon dioxide and oxygen supply, and acidity. Over 40 species of algae fix nitrogen. Furthermore, nutritional and environmental requirements of algae may vary even among species. We know little about molybdenum levels in water, but it is known that molybdenum is essential in the normal life processes of micro-organisms, higher plants and animals (Sauchelli, 1969). Recent studies indicate that nitrate absorption is hampered by the absence of molybdenum (Viets and Hageman, 1971).

An evaluation of the conflicting evidence on the sources and role of fertilizer nutrients in water pollution requires an understanding of the balance between nutrient additions from soil and fertilizer and withdrawals as affected by cropping systems, soil conditions, and management and climatic factors, especially water (Stanford, England, and Taylor 1970). The chemical composition and biological properties of water in a flowing stream or lake are influenced by various soil and geologic materials. Runoff from adjacent land, seepage from underground strata, runoff from feedlots and barnyards, domestic sewage, and waste water from industrial and food processing plants are all potential sources of nutrients that affect the quality of water.

Because nitrogen compounds are highly soluble, many people have associated the rapid expansion of fertilizer use with suspected increases in nitrates in water; but they are not necessarily related. Besides the nitrogen added to soil in the form of fertilizers, one must consider the organic matter in the soil and the rate at which this organic matter is mineralized. Atmospheric nitrogen is fixed either symbiotically or non-symbiotically. The nitrogen involved in crop utilization and leaching, the nitrogen fixed by algae and by micro-organisms, the nitrogen assimilated by micro-organisms, and the nitrogen returned to the atmosphere must all be accounted for if a record is to be made of the source of the nitrate in water.

When plant nutrients are applied in proper amounts and there is ample moisture for crop growth, there should be very little, if any, nitrate or other nutrient losses from the root zone by leaching (Garman, 1969). It is reasonable to expect that where crops are harvested and good conservation practices are followed the nitrate loss from farming should be no greater than the amount lost from forests or grassland.

Although some concern has been expressed about possible increases in the phosphorus content of waters because of greater phosphorus fertilizer use, other phosphorus sources, particularly detergents and effluent from sewage disposal systems, may be far more significant (Stanford, England, and Taylor, 1970).

When phosphorus is added to the soil in the form of fertilizer, it is rapidly immobilized on clays or precipitated as calcium, iron, or aluminum phosphates (Stanford, England, and Taylor, 1970). Because of low solubility the loss of fertilizer phosphates in water is not significant, especially in relation to the quantities released from municipal and industrial wastes. Phosphorus additions to water bodies from agricultural lands are almost wholly associated with erosion. Thus erosion control practices, with use of fertilizers to provide good plant cover, may reduce rather than increase water pollution from phosphorus.

There has been little concern about the increased use of potassium fertilizers because there are no indications that potassium enrichment of waters enhances algae growth (Stanford, England, and Taylor, 1970). The influence of calcium, magnesium, and sulphur additions on chemical composition of water is negligible in comparison to the effects of soils and their parent materials on water quality. Micro-nutrients, excepting boron applied as fertilizer, have little tendency to migrate in the soil and can be ignored in consideration of water quality.

To solve some of the environmental problems facing us today we need to know more about what is happening. We need to be able to identify the source of nutrients that get into water supplies. We need to know more about those factors that influence the growth of algae and other undesirable plants. We need to know the tolerable levels of concentration for all kinds of matter and energy that are relevant to managing the environment, and at what levels of concentration the pollutants are harmful to humans and to animals. Research can provide the answers.

To summarize briefly some of the data presented in this paper: it is evident that rural sources of pollution are sediment, plant nutrients, and animal wastes. Nitrates dissolve in water and are carried by surface flow to streams and lakes and by percolating water to underground aquifers. Contamination of water can result if soil enrichment by nitrogen greatly exceeds the crop demand. It is evident that phosphorus and pesticides are removed in surface water by soil erosion and that erosion control measures on farmland will minimize this potential source of pollution. Erosion from well-managed grass and wooded areas is negligible. Therefore, in farm areas the greatest attention needs to be given to reducing runoff and erosion from soils in row crops.

Non-rural sources of nutrients are recognized as major water pollutants.

Factors Contributing to Plant Nutrients and Pesticides in Streams, Lakes, and Groundwater

Potential nutrient additions from farmland: In determining the source and amount of plant nutrients that may reach surface and underground water supplies, it is necessary that the potential sources of pollution be identified and carefully evaluated.

There are numerous recognized sources of water pollution by the nutrients nitrogen and phosphorus. Under selected circumstances any one of these sources could be a significant contributor to water pollution.

In trying to find answers to the water pollution problem, some writers and speakers have placed the major blame on increased use of chemical fertilizers and have overlooked the numerous other sources of pollution. As stated earlier, a certain amount of recycling of nutrients takes place every day in nature regardless of what we do or don't do. The decomposition of plant and animal wastes is a part of nature's way if we are to have plants, animals, and marine life on earth. This has taken place since the beginning of life, as can be seen in the fossil fuel and peat deposits. Of course, when man started to cultivate the soil he speeded up the decomposition of the organic matter and the removal of nutrients from the soil.

Rainfall itself contains nutrients. Numerous researchers (Taylor, Edwards, and Simpson, 1971; Gratto, 1971; and Boyle, 1971) have reported that lesser quantities of nutrients run off from both farmed and unfarmed watersheds than fall with the rain or snow. The soil and the plant cover act to retain nutrients. Plant nutrients in rainwater vary a great deal depending on numerous factors such as prevailing winds, nearness to oceans, and kinds of soil and vegetation (Attiwill, 1966).

Runoff and soil erosion are major factors that carry pollutants to water supplies. From a review of a number of articles on nitrogen losses from soils, the following statements were selected to summarize the articles reviewed.

1. Nitrate losses have been measured in runoff from sloping soil where a surface application of fertilizer was made before an intensive rain, or where the application was made on frozen ground or melting snow (Nelson, 1972). Sloping soils not properly protected by residues or plant cover or mechanical conservation measures are subject to severe runoff and erosion. Most nitrogen losses measured in runoff and erosion from cultivated fields are in the form of organic material and probably come mostly from decaying plant residues as well as from the soil itself.

2. More fertilizer nutrients are lost by soil erosion than by leaching (Smith, 1967).

3. Percolation of water through a soil profile is exaggerated in Lysimeter studies when runoff is prevented (Kilmer, 1971).

4. Leaching loss of nitrates appearsto be small in the presence of a growing crop (Kilmer and Barber, 1971). Two main reasons for this are (a) the rapid uptake of nitrate ions by plants and (b) less free water in the soil due to removal by plants. However, in situations involving excessive applications of nitrogen to porous soils in areas of high rainfall,leaching losses of nitrogen can occur.

5. Nitrate nitrogen can be leached only when water in excess of soil retention capacity moves through the soil profile (Anonymous, 1969). If the soil is near saturation, the water and nitrate are displaced to lower depths by incoming water. If the soil is dry and water input is less than retention capacity, the nitrate may be redistributed within the root zone.

6. Situations most conducive to nitrate leaching are (a) when rainfall exceeds evapotranspiration, (b) where over-irrigation is practiced, (c) where soils are devoted to shallow-rooted crops, (d) where soils have a low water-retention capacity and high infiltration rates, and (e) where fertilizers are applied in amounts and ways that result in the presence of excess amounts of nitrates in the soil (Nelson, 1972; and Linville and Smith, 1970).

7. Leachates from highly fertile unfertilized farmlands have a higher concentration of nitrates than percolates from fertilized cropland low in natural fertility (Smith, 1967). More nutrients are being removed from soils by cropping than are added in fertilizers.

8. The total amount of nitrogen lost by leaching increases with the amount of water percolating through the soil. The percentage of total soil nitrogen leached per inch of leachate is greater in coarse than in fine-textured soils (Brown, 1965).

9. The amount of nitrogen leached from a soil in fallow is considerably greater than from a soil with growing plants and varies with the crop grown (Brown, 1965). Crops vary in their effect on evapotranspiration and in their ability to extract nitrates from the soil solution.

10. Leaching losses of nitrogen are considerably smaller than formerly thought; however, with the increased use of chemical fertilizers, there has been a growing tendency for nitrate to accumulate deeper in the root zone (Brown, 1965).

11. Main sources of nitrogen in water supplies beyond that amount normally contributed by rainfall and other natural sources appear to be largely from human, livestock, and industrial wastes (Smith, 1967).

12. Nitrogen fertilizers are undoubtedly contributing to nitrates in groundwater in some localities (Viets, 1971).

The following research data were selected to provide the reader with some specific information about nitrogen losses from soils.

Some studies in Colorado showed that in irrigated cropland 25 to 30 pounds (11 to 13 kgs.) of nitrate per acre moved to the groundwater table annually (Stewart, et al., 1967). Summarizing studies in Illinois, it was found that the highest nitrate concentrations in surface waters are more consistently found in areas of intensive farming on fertile, well-drained soils naturally rich in organic nitrogen (Harmeson, Sollo, and Larson, 1971).

In South Carolina (Garman, 1969), lysimeters below fields which were fallowed and received no nitrogen fertilizer released 154 pounds of nitrogen per acre to the leachate over a 5-year period, whereas lysimeters receiving high levels of nitrogen fertilizer, but where crops were kept growing, released very little nitrogen to the leachate over this same 5-year period.

The analysis of data from a water study in a number of watersheds in Illinois over a 25-year period (Bergstrom, 1971; U.S. Department of Agriculture, Soil Conservation Service, 1971; and Harmeson, Sollo, and Larson, 1971) show that each watershed or part of a watershed has a unique combination of nitrate sources. Although the nitrate content of some streams has increased during this period, the trend has been erratic. For example, recent data from the Kaskaskia River near Shelbyville shows that the nitrate content was less in 1971 than it was in 1961 even though the amount of fertilizer used has increased fourfold during this period (Aldrich, S. R., University of Illinois - personal communications, 1971).

The effect of fertilizer nitrogen on the nitrogen content of a stream cannot be estimated without a full analysis of the nitrogen budget of the whole watershed, including the amount removed in the harvested crops and that returned to the area as byproducts of denitrification. It is, however, clear that the loss in the stream is a small fraction of the whole turnover. The problem is too complex to draw any generalizations as to the source of the nitrate. There is need for careful study to identify the nitrate source.

Studies in Missouri over a period of years on four different soils show no evidence of nitrate movement beyond a depth of 244 centimeters when ammonium nitrate fertilizer was applied to continuous corn plots at rates of 112 and 134 kilograms of nitrogen per hectare annually (Linville and Smith, 1970). When 168 and 224 kilograms of nitrogen per hectare were applied annually, leaching below 244 centimeters was very slight on very slowly permeable soils but appeared to be substantial on the more permeable soils.

Bower and Wilcox, 1969 (Kilmer, 1971), studied the nitrate contribution from irrigated fertilized land to the upper Rio Grande River. Over a 30-year period, when the application of nitrogen fertilizer increased from a very low to a very high level, the overall nitrate concentration of the river did not increase. This indicates no significant contribution of nitrate to the river from nitrogen fertilizer.

The citrus industry in southern California seems to have adjusted its fertilizer input according to these studies to a level that, high yielding trees can be maintained with good water management and not leave a high nitrate load in the drainage water (Pratt, Jones, and Hunsaker, 1972).

California scientists Scott and Burau as quoted by Garman, 1969, say that "tillage of native soils is probably one of the most significant factors in releasing nitrates to underground waters because of the enormous store of nitrogen in the organic matter of most soils and the speed with which nitrate is released from organic matter when oxidation is increased by tillage." They also say that some Mollisols in the U.S. may contain as much as 32,000 pounds of nitrogen in the top acre-foot (36,362 kg per ha/30 cm). Converting this over to its nitrate equivalent, the figure is 140,000 pounds of nitrate per acre-foot (159,090 kg/ha/30 cm). If only one-half of this is lost over a 100-year period, the average annual loss could amount to 360 pounds of nitrates per acre per year (400 kg/ha).

It is estimated that a legume cover can fix 100 pounds of nitrogen per acre (113.5 kg/ha) per year (Garman, 1969). When this plant material decomposes, the nitrates can contribute to percolating waters, at least in a climate where growth is dormant part of the year.

It is not the intent of the author to go into the many details affecting the accumulation of nitrate in soil and water. Readers are referred to Agriculture Handbook 413 (Viets and Hageman, 1971) recently published by the USDA for greater in-depth discussion of this topic.

Many lysimeter and soil drainage studies have been carried out on different kinds of soil and cropping systems in the U.S. to determine movement of plant nutrients in the soil. A summary of some of these studies follows:

Studies at Coshocton, Ohio, on unglaciated soils from sandstone and shale showed that phosphorus movement downward beyond the plant roots was measurable and averaged less than 5 pounds per acre per year (Edwards and Harrold, 1970; and Harrold and Dreibelbis, 1958). Leaching of nitrates to the 8-foot depth was less on the lysimeter receiving the larger amounts of nitrogen fertilizer because the more vigorous plants used more water and reduced the amount available for percolation and nitrate leaching.

The amount and the composition of tile drainage was measured on fertilized and unfertilized Brookston Clay in Ontario, Canada. The average nitrogen loss as nitrate from all unfertilized plots was 4.4 kilograms per hectare per year; and from the fertilized plots, 8.1. Phosphorus loss was .12 and .19 kilograms per hectare per year, respectively (Viets, 1971).

Phosphorus does not leach except from extremely sandy soils. It is lost mostly through surface erosion of soil particles and soil organic matter (Nelson, 1972; and Taylor, 1967). Thus soils that have received large amounts of phosphate under conditions susceptible to surface erosion are most apt to contribute phosphorus to the surface waters.

There is much speculation that increased use of phosphorus fertilizers has greatly increased the phosphorus concentration in surface waters, and that this concentration increase is the key to algal blooms and stimulated growth of aquatic plants (Carter, Bondurant, and Robbins, 1971; Taylor, 1967; and Wadleigh, 1968). Phosphorus (PO_4-P) concentrations ranging from 0.02 to 0.05 ppm have been reported as minimal for supporting algal blooms. Algae do require phosphorus for growth and reproduction, but many people have considered phosphorus as the only key to water pollution and have ignored other possible factors.

The following studies show that the loss of phosphorus from farmlands are minimal:

Numerous studies (Stanford, England, and Taylor, 1970; and Nelson and Romkens, 1971), have shown that phosphorus losses from cropland are caused almost entirely by erosion. Phosphorus supplied to a soil becomes water insoluble within a few hours. Up to 30% of fertilizer phosphorus added to a soil is recovered by the first crop. The remainder is rendered insoluble or is fixed by the formation of insoluble iron, aluminum, or calcium compounds.

Experiments with cotton and corn in Virginia showed a loss of 10 pounds of phosphorus per acre per year. Under high erosion the loss may reach 30 to 50 pounds. Of the phosphorus adsorbed on the soil colloids, only a fraction will be available for growth of aquatic plants, perhaps no more than 10%. The available phosphorus in lakes and rivers from fertilizer and the soil phosphorus seldom exceed 1 to 5 pounds per acre per year.

Data from woodland and farmland watersheds at Coshocton, Ohio, 1966-1969 (Taylor, Edwards, and Simpson, 1971), show that total nutrient losses cannot be calculated meaningfully unless both hydrologic and chemical data are available because of the high concentrations of nutrients found in periods of slight runoff.

Information on the phosphorus concentration in irrigation return flows is extremely limited (Carter, Bondurant, and Robbins, 1971). Chemical reactions of phosphorus in the soil indicate that phosphorus (PO_4-P) concentration in subsurface drainage waters should be very low (Carter, Bondurant, and Robbins, 1971). These concentrations should not exceed the solubility of the various phosphorus compounds found in the soil. Johnston and others reported that the amount of phosphorus removed from an irrigated area through the subsurface drainage water was insignificant (Johnson et al., 1965).

Carter and coworkers found that only 30 percent of the phosphate entering a 200,000 - acre irrigated tract near Twin Falls, Idaho, in irrigation water (66 parts per billion of phosphorus) left the tract in drainage water (12 parts per billion). An average of 27 pounds of phosphorus per acre was used on crops during the water measurement year (Carter, Bondurant, and Robbins, 1971).

The foregoing statements are among the many factors related to farming that contribute to plant nutrient losses.

Potential nutrient additions from urban areas: More than 1 million acres of land in the U.S. are being reshaped each year as a result of roadway and reservoir construction, housing and business developments, surface mining, and similar operations (Meyer, Wischmeier, and Daniel, 1971). Sediment yield from areas undergoing intensive development are often many times greater than that from comparable areas of farmland, and they are creating serious problems in intensively developing urban areas (Anderson, 1965; Anderson and McCall, 1968; Wadleigh, 1967; and Ringler and Humphrys, 1971). Annual sediment yields from land under active urban development range from several hundred to 100,000 tons per square mile. On highway cuts, annual losses up to several hundred tons per exposed acre have been measured (Diseker and Richardson 1962). Barnett et al., 1967, measured 97 tons per acre erosion and 62 percent runoff from 2-7/10 inches of intense rainfall on a bare 2-1/2 (horizontal) to 1 (vertical) highway cut while adjacent mulched area lost only about 10 tons and 40 percent runoff (Barnett, Diseker, and Richardson, 1967).

An evaluation was made of the amount of erosion in Scott Run Basin, Fairfax County, Virginia, where highway construction covered 11 percent of the basin area (Vice, Guy, and Ferguson, 1969). The sediment yield per acre for an average storm event in construction areas was about 10 times greater than for cultivated land, 200 times greater than for grassland, and 2,000 times greater than for forest areas.

Another source of water pollution from urban areas is the effluent discharged in streams from sewage disposal plants. The following are examples:

There has been very rapid growth in the use of soluble pyrophosphates in detergents in the U.S. (Stanford, England, and Taylor, 1970). The annual consumption of detergents now represents a per capita phosphorus use of about 4 pounds in the U.S. Unless sewage treatments specially designed to remove phosphates are applied, urban areas can contribute available phosphorus to the environment at an annual rate of 2 tons per 1,000 persons in sewage effluents containing concentrations up to 5 parts per million of phosphorus.

Effluent from a sewage disposal facility in Washington, D.C., for example, contributes 8 million pounds of phosphorus and 24 million pounds of nitrogen to the Potomac River each year. Average flow in the river over a year's time is about 7.3 billion gallons per day, but the daily summer flow is about 1/4 this average. The nitrogen and phosphorus from this facility is sufficient to cause eutrophication in a stream having 10 times the average summer flow of this river (Wadleigh and Britt, 1968).

Potential nutrient additions from livestock feedlots: Another source of nutrient enrichment of water supplies is large livestock feedlots. Feedlots for finishing livestock have undergone a rapid transition from 100-head farm feedlot systems to commercial operations enclosing 25,000 or more animals within a space of a few acres (Cross, Mazurak, and Chesnin, 1971). A herd of 50,000 cattle would require a sewage treatment facility equal to one for a human population of 300,000. Since dumping waste into natural waterways is no longer acceptable, alternative methods of waste disposal must be developed.

Evaluation of pollutants in runoff from feedlots presents problems not met in describing conventional wastes (Miner et al., 1966). Cattle feedlot runoff was found to be high in organic wastes containing considerable quantities of nitrogen. Concentrations of organic matter and nitrogen in runoff increased with low rainfall intensities, warm weather, and moist lot conditions. Runoff from a concrete lot was approximately twice as heavily polluted as runoff from unsurfaced lots.

Quantity and quality of runoff from experimental feedlots in Nebraska seem to depend more on rainfall than on feedlot slope or cattle density (Gilbertson et al., 1971). High density lots yielded 103 to 170 percent more winter runoff than low density lots. Concentrations of solids in winter runoff were about 10 times greater than that from spring and summer runoff. The movement of pollutants in the soil under feedlots in a one-year period was minimal. There is strong evidence that livestock feedlots are major sources of nutrients that pollute surface waters.

Contrary to the results obtained in the Nebraska study, nitrate nitrogen as high as 4,600 pounds per acre were found within depths of 20 feet or more under some commercial feedlots in Missouri (Smith, 1968). An evaluation of over 6,000 water samples showed that areas with the largest livestock production showed the highest nitrate concentration. Preliminary research data show that numerous factors influence the hazard of pollution from feedlots. Some of the major items are kind of soil (especially permeability and slope), climate,method of collection and disposal of runoff from feedlots, livestock population per acre and per year, and method of disposal of manure from feedlots.

Yet another source of water pollution is wildlife. Studies of Lake Chautauqua in Illinois indicate that ducks add 5.6 pounds of phosphorus and 12.8 pounds of nitrogen per acre of lake per year (Wadleigh and Britt, 1969). This alone is sufficient plant nutrition to induce eutrophication.

As stated earlier, there are many potential sources of nutrient enrichment to water supplies. Each situation needs to be carefully evaluated, the major source of pollution identified, and corrective action taken.

Potential additions from pesticides: Pesticides are used in agriculture as purposeful environmental contaminants to increase cost-benefit ratio in favour of the farmer and the citizen as consumers of food and fibre. However, their use has become a focal point in public concern for the preservation of environmental quality. They have become an essential part of farm technology, and their use is the inevitable consequence of the monoculture approach to modern high production agriculture.

Numerous studies have been made on the hazards of water pollution by use of pesticides on farmland (Harrold and Edwards, 1970; White et al., 1967; Metcalf, 1972; Barnett et al., 1967; and Stewart and Chisholm, 1971). These materials have been measured in washoff from soils where they have been applied. No evidence was found where significant amounts of pesticides percolated to any significant depth in the soil.

The basic principles that apply to the safe use of chemical fertilizers also apply to pesticides. If sound conservation practices including erosion control are followed and if good judgment and management are used, the hazard of water pollution from agricultural applications of pesticides is minimal.

Factors Affecting Soil and Water Losses

Soil erosion and runoff are major sources of nutrient enrichment of surface water supplies. To reduce this hazard of water pollution, there is need to understand the factors that influence erosion and runoff. This will help us to avoid the use of critical erosion areas as well as to manage suitable areas for the conservation of soil, water, and plant resources resulting in a minimum of water pollution.

Numerous investigators (Smith, 1957; Wischmeier and Smith, 1958; Wischmeier and Smith, 1965; Wischmeier, Johnson, and Cross, 1971; and Wischmeier and Mannering, 1968) have found that the four basic factors affecting runoff and erosion are (1) climate, especially rainfall intensity and amount, and the season of year that rainfall occurs; (2) kind of soil; (3) length and percent of slope; and (4) cover. In addition, soil and water management practices also affect losses and often modify one or more of these four factors. Practices such as terracing and contouring modify slope whereas tillage, mulching, and crop rotation modify soils and cover. Only climate has been considered as unalterable.

Climate: Soil erosion is a mechanical process that requires energy. Much of this energy is supplied by falling raindrops. The magnitude of the kinetic energy of rainfall is readily apparent from a very simple calculation (Wischmeier and Smith, 1958). The weight of the water falling in 30 minutes of a common thunderstorn in northcentral United States may exceed 100 tons on each acre. The billions of drops which comprise this 100-ton volume of water strike unprotected soil at an average velocity of nearly 20 miles per hour. The rainfall energy to be expended during the 30 minutes may well exceed 2 million-foot pounds per acre. Water flowing over the land surface, coupled with raindrop action, produces sheet erosion. The concentrated scouring action on the channelized flow causes rill-and-gully erosion.

Sheet erosion is a function of rainfall characteristics, although the magnitude of the effects vary with soil conditions, slope cover, and management practices. It involves detachment of soil particles and transportation of the detached particles (Wischmeier and Smith, 1958). The soil-carrying capacity of runoff water increases exponentially with increasing velocity. Not only soil detached by raindrops but also additional soil detached by flowing water is carried from the field in increasing amounts as a depth of flow increases.

Studies show the best single variable found for predicting soil losses from cultivated fallow soils is a product of the total rainfall energy of a storm and its maximum 30-minute intensity (Wischmeier and Smith, 1958). This product term measures the inner action effect of the two rainfall characteristics (known as the EI variable). Soil moisture, soil compaction, and the effects of freezing and thawing also influence the amount of runoff and erosion from an area. Runoff from melting snow is another factor that influences runoff and erosion.

Soil erodibility: The erodibility of a soil is a function of complex interactions of a number of its physical and chemical properties (Wischmeier, Johnson, and Cross, 1971; and Wischmeier and Mannering, 1968). Those that affect surface seal and crust formation are, of course, highly important, but characteristics of the soil beneath the surface layer are also relevant to erodibility. The behaviour of individual soil properties are highly interrelated, and the coefficient of a single term taken out of context may not reflect the overall relation of one parameter to erodibility.

Several research workers have found five soil parameters to be especially important in predicting the erodibility of soil in the U.S. (Wischmeier, Johnson, and Cross, 1971; and Wischmeier and Mannering, 1968). These are percent silt (0.002 to 0.05 mm) plus very fine sand (0.05 to 0.1 mm), percent sand greater than .10 millimeter, organic matter content, soil structure, and permeability of the least permeable layer in the soil profile.

Analyses of rainulator and natural rain, soil erodibility data, show conclusively that very fine sand (0.05 to 0.10 mm) behaves more like silt than like larger sand (0.1 to 2.0 mm).

Generally speaking, soils that are high in silt, low in clay, and low in organic matter are the most erodible. Usually a soil becomes less erodible with decrease in silt fraction; however, percentages of silt, clay, and sand must be considered in relation to existing levels of other physical and chemical properties of the soil.

Organic matter content in soils ranked next to particle size distribution as an indicator of erodibility. Both the rainfall energy needed to start runoff and the final infiltration rates increased directly with organic matter increases, whereas soil content of the runoff was inversely related to organic matter content. There was an important but complex interrelation between organic matter and clay. On silts, silt loams, loams, and sandy loams, the inverse relation of erodibility to both aggregration index and organic matter level was strong, but it significantly declined as the clay fraction became larger and may be insignificant on clay soils.

Studies (Wischmeier, Johnson, and Cross, 1971; and Wischmeier and Mannering, 1968), show that soil structure grade (strength) did not significantly affect erodibility; however, influences of type and size of structure apparently were great enough to be of practical importance. There were indications that a relationship exists between structure type and size and structure, grade, and soil pH, but these interaction effects could not be quantitatively evaluated from the data.

A soil layer, below the soil surface, that is slowly or very slowly permeable can influence the erodibility of a soil, depending on the moisture content of the soil. For example, a soil with a fragipan or a clay pan 25 centimeters below a permeable surface layer probably has little, if any, effect on the amount of runoff or erosion from a moderate storm on relatively dry soil. Conversely, if the same soil is saturated when a rainstorm comes, the effect is apparent in data from long-time erosion studies. Thus, a soil with a slowly permeable subsoil may be very erosive during those periods of the year when the upper soil layers are saturated.

Length and percent of slope: The relationship of length of slope and steepness of slope to soil loss has been worked out mathematically by research workers and, through the use of formulas, predictions can be made about soil losses that occur on slopes of different lengths and gradients (Smith, 1957).

The capacity of runoff to transport soil particles increases approximately as the fifth power of its velocity; and its detachement capability, as the square of its velocity (Wischmeier, Johnson, and Cross, 1971; and Wischmeier and Mannering, 1968). The flow velocity of runoff increases as the amount increases, as the flow concentrates, or as the slope steepens. Therefore, the erosive potential of runoff increases substantially either as slope lengthens or as steepness increases. The shape of slope may also influence erosion losses.

Soil cover: Many controllable variables influence water intake by the soil, help protect the soil from raindrop impact, or increase the soils ability to resist detachment by the erosive agents (Wischmeier and Smith, 1965). Among them are cover, crop sequence, seeding method, soil tillage, disposition of residues, and general management level. Vegetal cover, amount of residues on the surface, and effects of tillage and other management practices change as a growing season progesses. Therefore, the amount of erosion that occurs for an annual or multi-year cropping system depends on how well the period of greatest soil protection coincides with occurrence of the erosive rains. The following table, developed from data in U.S. Agriculture Handbook 282, shows the effectiveness of plant cover in reducing soil losses in percent by comparing different cropping systems with fallow (bare ground).

Soil Loss Reduction in Percent 1/	
Continuous corn (maize), conventional plant and till, harvest for silage	57
Rotation corn (maize), spring plow, conventional plant, residues left, corn, corn, grain, (small grain)	27
Rotation corn (maize), spring plow, conventional plant, residues left, corn, corn, grain, 1-year meadow	12
Continuous corn (maize), no plow, no cultivation (minimum tillage), plant in corn residue, 3 tons of residue	7
Grass and legume meadow, good quality	.04

1/ Based on fallow (bare soil) as being 100%.

Erosion control practices: When sloping soil is cultivated and exposed to erosive rains, the protection offered by the plants in the cropping system needs to be supported by practices that slow the runoff water and thus reduce the amount of soil it carries (Wischmeier and Smith, 1965). The more important supporting practices for cropland are contour tillage, strip cropping on the contour, terrace systems, stabilized waterways, and minimum tillage practices. Improved tillage practices, sod-base rotations, fertilizer treatment, and greater quantities of crop residues left on the surface of the soil contribute materially to erosion control.

Tillage and planting on the contour have been effective in reducing erosion from individual storms of moderate to low intensity but provide little protection against severe storms that cause extensive breakovers of the contoured rows. Contouring appears to be most effective on slopes of less than 7 percent.

Contour strip cropping is a practice in which contour strips of sod are alternated with strips of row crop or small grain. This practice has proved to be a more effective practice than contouring alone. As a rule of thumb, it can be stated that soil losses from contour strip crop fields will be about 50 percent as great as those from contour tillage for the same kinds of crops and management.

Terracing with contour farming is more effective as an erosion control practice than strip cropping because it divides the slope into segments equal to the horizontal terrace spacing. Soil losses from contoured and terraced fields are about the same as those from a contoured field having the same slope length as that of the terrace interval.

Numerous research workers (Meyer, Wischmeier, and Foster, 1970; and Van Doren and Stauffer, 1944) have found that crop residues and other forms of surface mulches are very effective in reducing soil erosion and the velocity of runoff.

The erosion-reducing effectiveness of six different rates of straw mulch was tested on slopes averaging 15 percent (Meyer, Wischmeier, and Foster, 1970). Mulch rates of only .56 and 1.12 metric tons per hectare reduced soil losses to less than one-third of those from unmulched areas during a series of intense simulated rainstorms. A rate of 2.24 metric tons per hectare decreased soil loss to 18 percent of that with no mulch, and rates of 4.48 or 8.96 metric tons per hectare reduced it to less than 5 percent. Runoff velocity for the .56 metric tons per hectare rate was one-half that without mulch, but heavier rates decreased velocity only slightly more. The reduced velocity due to mulching accounted for much of the resulting decrease in soil erosion. Although the small mulch rates greatly reduced erosion, more mulch was required to fully control erosion than was required on the less steep, more permeable soil conditions tested in earlier studies.

Minimum tillage is a general term that may be applied to any of the numerous practices that require fewer trips across the field than are required by conventional methods of preparing a seedbed. A plowed surface left rough and containing appreciable plant residue allows water to infiltrate more rapidly, has greater surface and plow-layer storage, and is less easily eroded than a pulverized soil surface.

The average annual soil loss from natural rainfall over a 5-year period at LaCrosse, Wisconsin, on a Fayette silt loam, 15 percent slope, was .7 of a ton per acre for plots that received minimum tillage compared with 2.94 tons for conventionally tilled plots when both methods were contoured (Mannering and Burwell, 1968).

Another study on minimum tillage at Coshocton, Ohio, showed that annual soil loss over a 3-year period averaged .50 of a ton per acre per minimum tillage compared with 4.86 tons for conventional tillage.

Another erosion control practice was evaluated at LaCrosse, Wisconsin, on a 16 percent slope (Mannering and Burwell, 1968). The annual soil loss was 2.6 tons per acre for interseeding in 60-inch corn rows compared with 5 tons from 40-inch rows with no interseeding.

Predicting Soil Losses and Sediment Delivery Rates

Predicting soil losses: Scientific planning for soil and water conservation requires knowledge of the relation between those factors that cause loss of soil and water and those that help to reduce such losses. To aid in predicting rates of erosion and measures needed to reduce those losses, an empirical soil loss equation has been developed (Wischmeier and Smith, 1965). Many of the factors used were discussed in the preceding section of this paper.

To predict the amount of soil erosion by water on any particular field or construction site, it is necessary to know (1) the capability of the expected rainfall and runoff to detach and transport soil particles, (2) the natural susceptibility of the soil to erosion, and (3) the effectiveness of cover and management variables for reducing the forces of erosion. Charts and graphs from which this information can be obtained for any particular site have been developed from the analyses of erosion research on 48 research stations in 26 states in the U.S. and published in Agriculture Handbook 282 (Wischmeier and Smith, 1965). The following discussion on the soil loss equation contains pertinent information from this handbook for predicting soil losses.

The erosion equation is: $A = RLSKCP$. It expresses soil loss per unit area (A) as a product of factors for: rainfall (R), slope length (L), slope steepness (S), soil erodibility (K), cropping and management (C), and conservation practices (P). The soil loss prediction (A) is usually obtained in terms of tons per acre per year. However, it can be easily obtained in inches of soil or in metric units and for a given month or season by selecting the values of K and R in corresponding units.

Numerical values for each of the six factors in the formula have been determined from research data. These values differ from one area to another. The approximate numerical values for any particular field have been developed.

Rainfall factor (R). When factors other than rainfall are held constant, storm soil losses from cultivated fields are directly proportional to the product value of two rainstorm characteristics; total kinetic energy of the storm times its maximum 30-minute intensity (EI). This product variate is an interaction term that reflects the combined potential of raindrop impact and turbulence of runoff to transport dislodged soil particles from the field.

An Iso-erodent map was computed from rainfall data for each of about 2,000 locations farily evenly distributed over 37 states of the eastern U.S. The Iso-erodents were then plotted as indicated by these values.

Factors for slope length and gradient (LS). The rate of soil erosion by water is affected by both slope length and gradient (percent slope). The two effects have been evaluated separately and are represented in the erosion equation by capital L and capital S, respectively. In field application of the equation, however, it is convenient to consider the two as a single factor LS. This ratio for specific combinations of slope length and gradient are taken directly from a chart.

Soil erodibility factor (K). The soil erodibility factor K in the soil loss equation is a quantitative value experimentally determined. The criteria used for developing this value were discussed earlier. For a particular soil it is a rate of erosion per unit of erosion index from unit plots on that soil. These values are determined for each kind of soil and are used in the equation.

A unit plot is 72.6 feet long with a uniform lengthwise slope of 9 percent in continuous fallow tilled up and down the slope. To evaluate K for soils that do not usually occur on a 9 percent slope, soil loss data from plots that meet all the other specified conditions are adjusted to 9 percent slope by means of the slope factor.

Factor for cropping and management (C). The factor C in the soil loss equation is the ratio of soil loss from land cropped under specific conditions to the corresponding loss from continuous tilled fallow. About 10,000 plot-years of runoff and soil loss data assembled from 47 research stations and 24 states (Wischmeier and Smith, 1965) were analyzed to obtain empirical measurements of the effect of the cropping system and management on soil loss within each crop stage period.

The erosion control practice factor (P). This factor is similar to the factor C, except that P accounts for the erosion control effectiveness of superimposed practices, such as contouring, terracing, and strip cropping. The factor P in the erosion equation is the ratio of soil loss with the supporting practice to the soil loss with up-and downhill culture. Values of P for various percent slope groups have been developed.

The empirical soil loss equation underlying this technique is applicable in any location where numerical values of the equation factors are known or can be determined. It can be a useful tool in helping to select alternative methods for reducing soil loss and erosion. The tables and charts that have been developed make this information readily available for field use.

Predicting sediment delivery ratios: Many factors influence sediment delivery ratios. Some of these factors are the types of sediment sources, the magnitude of the sediment sources, climate, kind of soil, factors affecting deposition, and watershed characteristics.

Considerable success has been achieved through use of empirical soil loss equations to obtain values for sheet erosion (Roehl, 1962). Similar values for channel-type erosion are obtained from volumetric measurements in the field or by use of erosion rates developed in the course of research studies.

Sediment delivery ratios are a means of using computed erosion data to predict sediment yields at desired points within a watershed. A sediment delivery ratio is a percentage relationship between the sediment yield at a specified measuring point in a watershed and the gross or total erosion occurring in the watershed upstream from that point. If realistic estimates of both the erosion and the sediment delivery ratios can be made, sediment yields can be predicted with reasonable accuracy (Roehl, 1962).

It is estimated that sheet erosion generally produces most of the sediment load of rivers in areas that are primarily agricultural and have more than 20 inches of precipitation annually (U.S. Department of Agriculture, Soil Conservation Service, 1970). In most forest and range areas where the precipitation is less than 20 inches, channel-type erosion usually produces most of the sediment. An analysis of 157 watershed work plans having a total combined drainage area of 9.7 million acres indicates that, in general, 73 percent of the sediment was from sheet erosion, 10 percent from gully erosion, and 17 percent from other sources such as roadsides, streambanks and flood plain. Of the total sediment yield in the U.S., it is estimated that 50 percent is from farmland, 10 percent from forest and rangeland, 10 percent from construction sites, and 30 percent from land relatively undisturbed by man (geologic erosion). A sediment delivery ratio of 40 percent has been used by SCS to calculate national sediment yields from estimated soil losses from cropland (U.S. Department of Agriculture, Soil Conservation Service, 1971).

A study of 113 watersheds (Roehl, 1962; and Glymph and Holtan, 1968), located in humid areas of the U.S., showed that sheet and rill erosion accounted for 90 percent or more of the sediment yield in half of the watersheds. In about 20 percent of the cases studied, however, 50 percent or more of the sediment was derived from gullies. In most instances of relatively large sediment production from gullies, watersheds of less than one square mile were involved. In three instances, stream channel erosion contributed more than 40 percent of the sediment yield.

Thus, measurements indicate that extreme variations in sediment yield may occur in a region having different kinds of land use, topography, climate, and soil. The relatively flat area of northcentral Iowa, for example, has sediment yields of about 50 tons per square mile per year for a 100-square-mile watershed, whereas in the rolling hills of western Iowa, sediment rates of about 6,000 tons per square mile per year are estimated for 100-square-mile watersheds (U.S. Corps of Engineers, 1968).

Langbein and Schumm, 1958 (Holeman, 1968), found that the maximum sediment yield in the U.S. occurs when annual effective precipitation is between 10 and 14 inches. The sediment yield dropped sharply as annual rainfall decreased from 10 inches because of the deficiency of runoff. On the other hand, sediment yield decreased generally with rainfall above 14 inches because the increased rainfall produced a greater density of vegetative cover and, therefore, less erosion. This generalization may or may not apply to other environments of the world, but the relation between rainfall and vegetative cover seems universal. The vegetation reflects rather closely the annual rainfall patterns, and the rate of runoff is tied closely with precipitation.

Studies on eight small experimental watersheds at Coshocton, Ohio, showed that conservation farming practices resulted in smaller average rates of runoff and more water absorption (Glymph and Holtan, 1968). Here the average annual peak rate of runoff from land in corn was 47 percent greater without conservation practices than it was with improved practices, 55 percent greater from land in wheat, and 14 percent greater from land in meadow. In terms of total runoff amount, land in corn without treatment produced 53 percent more runoff from May to October than that with improved practices; wheat without treatment practices produced 34 percent more runoff from October to July; and runoff from untreated meadow for 33 consecutive months was 31 percent greater than from meadow with improved practices.

From these data and experiences it is apparent that the universal soil loss equation can be a valuable tool in estimating sediment delivery ratios. The use of erosion control practices on both farm and nonfarm land will reduce runoff and erosion from these areas and in turn reduce the amount of sediment delivered to surface water areas.

Methods for Reducing Nutrient Enrichment of Water Supplies

Soil surveys: One of the first and most important steps in the development of a plan to reduce water pollution through soil erosion and runoff is to make a soil survey. Soil maps and needed interpretations prepared by pedologists provide the basic data needed to determine the location and extent of each kind of soil and its potentials and limitations for various uses. With a soil map, plans can be developed to minimize soil and water losses through proper soil selection and the application of conservation practices for each use.

The use of soil surveys is the best method we have for evaluating the land resources available to people (Klingebiel, 1967). Soil surveys can be interpreted to show the various alternatives for safe use and the potential for the production of plants. Accurate predictions can be made about soil behaviour and crop potential from areas for which soil surveys have been completed. Where soil surveys are not available, samples areas can be mapped and the data projected to similar soil areas for broad general planning.

By rating the soils according to their suitability for a particular use, one can determine the areas that are well suited or poorly suited for that use. Such information is useful to those who are evaluating areas for farmers, for food processors, and for others who are searching for soils that are suitable for growing certain crops. Soil maps can also be useful for those seeking sites for residential, industrial, or recreational development (Steele, 1967).

Soil surveys can be especially helpful in making predictions about the hazards of runoff and erosion. Erosion is a serious problem on many sloping soils, especially in places where farmers and contractors have left the soil bare for long periods of time.

Soil maps provide a base for land use planning by showing the areas that have the greatest potential for each kind of use. In addition, predictions can be made about the soil hazards involved in each kind of use. Most cultivators can benefit from some direct assistance in developing a plan for their operations and for carrying out the plan that will provide maximum benefits from their investment and at the same time keep soil erosion and runoff to a minimum.

Such technical assistance is based on a detailed soil map that is interpreted to show the alternative uses and combinations of practices for which the different kinds of soil are suited. The plan must be arranged to take advantage of the effects of the different practices on each kind of soil and between fields within the farm unit having different kinds of soil.

If we are to use our soils efficiently and effectively in the years to come, we must develop plans that will encourage the public to use soil resources carefully and efficiently for the benefit of present and future generations. The use and interpretation of a soil survey is the key to this kind of planning.

Despite the urgent need, improved technology is not easily transferred from temperate regions to tropical ones (Kellogg and Orvedal, 1969). But the principles developed from scientific research in the sciences basic to soil use and the scholarly method for both basic and adaptive research can be transferred. The basic task of the scientist or small group of scientists in technical assistance is connecting the basic principles of the sciences relevant to farming and the other sectors of agriculture to the specific natural, social, economic, political, and religious environment where the work is to be done. Success requires scholars with knowledge of the basic principles and with the skills to work in various social and natural environments and to communicate with the local people.

Farm management practices: There is every reason to believe that plant nutrient losses due to runoff and erosion from rural and urban areas can be kept at an acceptable level by applying presently known methods. These include (1) proper soil selection for each use, (2) selection of a combination of management practices including the use of acceptable erosion that will give favourable results, and (3) prudent use of fertilizer, pesticides, and irrigation water.

With the use of a soil map, cultivators can select and manage intensively those soil areas offering the lowest potential for erosion and runoff and the highest potential for crop production. Management practices can be selected that are best adapted for each of the different kinds of soil. In this way, marginal soils and those having high hazards for erosion and runoff can be avoided. Each kind of soil has a potential for some use. A soil survey can serve as a blueprint in showing the potentials and limitations of each kind of soil for many different uses.

The importance of interactions must be emphasized (Kellogg, 1960). It is wasteful to use fertilizers without water control, adapted plants, and measures for plant protection. The proper selection of soil and water management practices for a particular use can best be achieved through a review of available research data and local experience. In areas where little is known about the soils and their response to management, simple field trials can be established to determine the best combination of practices to use.

The effectiveness of the various erosion control practices was discussed earlier in this paper. Losses of nitrogen and phosphates can be minimized through more careful and thorough application of selected soil conservation and water control practices. These include terracing and contour cropping, adequate plant cover, returning crop residues to the soil, and use of forages and other close-growing crops on steeper lands.

There are a number of ways to minimize nutrient enrichment of surface waters without sacrificing the important benefits of fertilizers and productive agriculture (Nelson, 1972). One is to more carefully tailor the rates and times of nitrogen application to better fit the needs of the growing crops. The main consideration here is to limit the buildup of nitrates during the periods when leaching is likely. This can be accomplished by delaying large nitrogen applications until the growing crop can utilize it, by using smaller and more frequent applications, and by being careful not to apply amounts highly in excess of that needed by the crop during its growing season. On irrigated crops, additional care is needed not to overirrigate or leach excess salts from the soil during the periods when large amounts of nitrates are present.

The kinds and amounts of fertilizer to use depend on the soil, the crop to be grown, the other practices followed, and the expected costs and returns. The time and amount of fertilizer applied is especially critical in areas of high rainfall and leaching, including both the cool temperate regions and the humid tropics. Fertilizers are economically effective only if the correct kinds and amounts are used for the kinds of soil and the crops to be grown and if the practices needed to meet the other requirements for a good harvest are adopted at the same time.

Progress is being made in the development of slow-release nitrogen fertilizers (Kellogg and Orvedal, 1969). If these can be improved to the point where nitrogen is released at a rate that approximates plant removal, potential nitrogen contribution from this source to the environment could be reduced even further. Management practices such as timing and rate of fertilization and control of water and erosion are of course equally important in reducing nitrogen transport. For the most part fertilizers should be added to the soil only when plants are available to utilize the nutrients. Surface application should not be made when the plants are dormant or when the ground is frozen or covered with snow. Fertilizers should be incorporated into the surface of the soil and not placed on the surface where they can be washed away with the first rain. This is especially important with nitrogen fertilizers.

The use of pesticides has become a focal point in public concern for the preservation of environmental quality (Metcalf, 1972). They are an essential part of farm technology, and their use is essential for modern low-cost, high-production agriculture. Pesticides will be used in the foreseeable future. It is the judgment of the U.S. National Academy of Sciences' Committee on Persistent Pesticides (Metcalf, 1972), that, for most purposes, nonchemical methods of control are not expected to supplant the use of chemicals in the foreseeable future.

There is every reason to believe that man can control the pests of crops and animals without serious jeopardy to the environment (McNew, 1972). Once we settle down to intelligent reasoning about the broad spectrum of opportunities before us, we can find sensible solutions to the problems as they arise. There are tremendous opportunities for design of better and safer chemicals for the future. Factors of environmental safety must be considered along with pesticidal efficiency, and this imposes a great burden on research ingenuity as well as industrial economics.

An intensive search must be initiated for new pesticides that are highly pest specific, safe to apply, and biodegradable in individual organisms and the environment (Metcalf, 1972). Many leads exist: the hormone mimics of insects, juvenile, and moulting hormones; various phytohormones; and viral and bacterial toxins. From these and other potential discoveries about sites of actions and modes of degradation, will come the pesticides of the future.

As an example of new research, a team led by Dr. Robert L. Metcalf at the University of Illinois (Freund, 1970–1971) devised and recently patented a new form of nonpolluting DDT. In addition to being able to be broken down by higher organisms into products that are safe to the organism and to the environment, the new DDT can be produced in many forms, each of which is an analogue related to the old form of DDT, thus insects that become resistant to one form can be destroyed by another.

The hazard of water pollution of pesticides through runoff and erosion can be reduced by following the same basic management practices followed in the use of chemical fertilizers.

Nonfarm management practices: Evidence has been presented that shows that sloping soils under construction for roads and buildings can be a major source of pollution to surface water.

Erosion and sedimentation can be controlled in these areas by the application of practical combinations of the following technical principles (Ringler and Humphrys, 1971). To reduce erosion potential; fit development plans to the kinds of soil, landscape features, and vegetative cover; to retard runoff and erosion; retain and protect natural vegetation wherever feasible during development; protect structural measures to accommodate the increased runoff caused by damage of soil and surface conditions; install permanent vegetative and structural erosion control and water disposal methods as soon as practical in the development stage; maintain planned vegetative and structural improvement to insure their effectiveness.

An alternative method to the use of vegetation is the application of mulch for immediate protection where final grading is not completed (Meyer, Wischmeier, And Daniel, 1971). Two tons of straw per acre afford ample protection. If final grading is completed in late fall or winter, the area should be mulched immediately and then seeded at the proper time with grass and legume species adapted to the area. Mulch can either be removed or worked into the soil after it is no longer needed for protection. The application of asphalt mulches and other agents may assist in stabilization, particularly during periods of high intensity rainfall. The hydro method of applying fertilizer, seed, and mulch, is effective during the growing season.

Animal waste disposal practices: In our concern about polluting the environment, we have not taken full advantage of the great capacity of our soils to absorb waste materials (Carlson and Menzies, 1970). Soil can absorb organic wastes and biologically break them into compounds that can reenter the natural cycle of plant and animal life. The soil can also act as a living filter for many of the inorganic pollutants. Caution must be taken to avoid damaging soils by applying amounts that exceed the soils' capacity to absorb these effluents. Properly planned land areas used for waste disposal can serve useful purposes as greenbelts or for agricultural production (Webber, 1971).

Evidence shows that runoff from concentrated livestock feedlots can be a major source of pollution to surface waters. These and other related problems can be prevented if animal feedlots are located in areas less prone to runoff that releases wastes directly to streams or to air movements that carry the odours to residential areas.

The most satisfactory solution for animal waste includes some type of initial treatment followed by disposal on land (Loehr, 1972). Possible initial treatment methods include aerated liquid systems, natural drying systems, runoff control measures, and waste-holding units. In overall animal waste management all aspects of the production scheme should be evaluated for interactions and tradeoffs in order to get an acceptable environment for the public and an adequate profit for the producer.

The design of a runoff control facility for a livestock feedlot must include some means of handling the solid as well as the liquid waste (Gilbertson et al., 1971). Settleable solids should be removed from runoff before it reaches a liquid detention pond to avoid overloaded anaerobic conditions and to prevent loss of liquid storage capacity. The design volume of liquid detention ponds will depend on the climate, area available, and method of disposal. If the effluent is to be used for crop irrigation, the type of plant must be carefully selected because of the salt content of the effluent.

Soil scientist A. Earl Erickson (1971) of Michigan State University developed a simple waste treatment system that removes 99.8% of the phosphate and 99.5% of the nitrogen from animal wastes. The system is basically a mound of soil 4 feet high, 25 feet wide, and of any length topped with limestone and set on a barrier that is impermeable to water. Liquid wastes are spread on top of the mound with a sprinkler system.

The soil in the mound decomposes organic materials into carbon dioxide and water. This layer also converts all nitrogen in the waste to nitrate, which is then carried with the water to the bottom layer. At the bottom the nitrates are changed into nitrogen gas, which is released back into the atmosphere. Waste material added to the system had an average nitrogen concentration of 340 parts per million. Water coming out of the system had only two parts per million nitrogen, which means that 99.8% of the nitrogen had been removed.

Erickson says this system is about 40 times more efficient than spreading liquid manure on cultivated fields, pastures, or woods and depending on the plants to harvest the nutrients.

Although a great deal is now known and much can be done to reduce water pollution from livestock feedlots, there is need for additional research. More needs to be known about methods and safe rates of application of wastes to the soil and its influence on growing plants. In addition, new methods for the disposal of large quantities of wastes need to be investigated.

Municipal waste disposal practices: Evidence presented earlier showed that many municipal waste disposal plants dump large quantities of nutrients into streams and lakes. Studies have been under way in several places in the U.S. to evaluate methods of applying sewage effluent from municipal plants to woodland areas and to cultivated fields.

A good example of how treated sewage effluents can be used on the land is the system developed by Kardos and associates (1970) at Pennsylvania State University (Carlson and Menzies, 1970). The objectives of these studies were to return sewage nutrients to the land, restore groundwater, avoid stream pollution, and eliminate the need for adding chemical fertilizer to cropland. The system involves using the water and nutrients in sewage effluent on forest and cultivated crops. Yields of treated cultivated and forest crops were about double those not receiving the effluent. The data indicate that the system, modified to suit local conditions, holds real promise for solving waste disposal problems, especially in small cities and villages.

Sewage effluents have been applied to land in Europe for up to 100 years, and at several sites in the U.S. applications have been in progress for over 50 years (Carlson and Menzies, 1970). The composition of the effluents has been variable, and the application rates on a dry weight basis have ranged from less than 900 kilograms per hectare to over 90,000 kilograms per hectare. In general, there has been very little evidence of harmful effects on crops or soils.

One of the dangers in the use of municipal wastes that needs to be evaluated more carefully is the effect of toxic metals on soils and plant growth.

In review of the importance of toxic metals in soils, Lagerwerff, 1967 (Carlson and Menzies, 1970), warns that it is possible for a number of these metals to enter the food cycle by way of the soil. Copper, zinc, and nickel can be a problem through toxicity to crop plants. Cadmium and lead, on the other hand, may be hazardous to man and animals eating the crop. Cadmium is of concern because it is absorbed readily by many species of plants. Cadmium can be absorbed in the body and has been related to cardiovascular disturbances and degradation of certain body tissues.

Lead accumulates in the surface soil (Carlson and Menzies, 1970). Most research data suggest that plant contamination occurs by lead deposition from the atmosphere.

However, there is some evidence that lead translocates from root to shoot. Unfavourable effects of toxic metals on plants generally can be alleviated by keeping the soil pH above 6.5. Also the organic matter in soil or in the sludge tends to reduce the toxicity of metals to plants. There has been concern also about methylated mercury in the environment. Therefore the mercury content of these sludges needs to be evaluated.

The soil can serve as a good media for recycling wastes, but care must be taken that runoff or soil percolation does not contaminate water supplies.

Using Soil Maps to Evaluate Potential Nutrient Enrichment of Natural Waters

The materials discussed this far have dealt largely with factors affecting nutrient enrichment of natural water and methods that can be used to reduce this problem. The intent in this section is to show how research data and experience can be projected from one area to another through the use of soil maps and to show some general relationships of broad soil regions of the world to hazards of water pollution.

Soil maps with appropriate interpretations can be very useful in predicting areas of potential soil and plant nutrient losses, some of which may contribute to water pollution. In addition, they provide a basis for selecting alternative measures for avoiding or for overcoming those hazards related to water pollution.

Six small-scale maps (approximately 1-50,000,000) have been prepared by the Soil Geography Unit of the Soil Conservation Service, USDA, 1971. These maps are too small and too general for planning purposes but can serve as examples to show some of the kinds of interpretations that can be made from more detailed soil maps that are available locally.

Soil map of the world: This map shows the general distribution of soils classified at the higher categorical levels (order, suborder, great group) of the new classification system recently developed by the Soil Conservation Service, USDA (Soil Geography Unit, 1972; and Soil Survey Staff, 1972). Only the most extensive areas of soil orders, and the dominant suborders and great groups within them, are shown.

For this discussion, an abbreviated legend identifying orders and dominant suborders is provided on the map. Accordingly, the legend explains only the first two characters of the three-character symbols. However, the complete legend for the published map will provide explanations of the three-character symbols and brief definitions of the orders and suborders appearing as mapping units on this map. For more complete definitions of the components of mapping units, the reader should refer to Soil Taxonomy—A Basic System of Soil Classification for Use in Making and Interpreting Soil Surveys, now in press (Soil Survey Staff, 1972).

Information about the orders and suborders provided in the complete legend includes a variety of data, such as soil moisture regimes, soil temperature regimes, base supply, and soil texture. More specific information about soil properties can be obtained from information inferred from mapping units identifying soils at the great group level.

This soil map, as with all basic soil maps made in the United States by the National Cooperative Soil Survey, provides the basic soils data needed for making meaningful interpretations. Individual soil properties or interpretations of combinations of soil properties taken from a basic map can be assembled in a legend and a map prepared that can be useful for specific purposes. From the basic soil map many different kinds of interpretations can be made, such a soil wetness, soil texture, soil temperature, organic soils, high shrink-swell soils, soil permeability, and the potential productivity of different plants.

One example of how a soil map can be used to project research data and experience is demonstrated by a study made in Missouri (Linville and Smith, 1971). This study shows that nitrate did not move down as deep or as fast in soils with slowly permeable subsurface layers (Aquic Arguidolls and Udollic Albaqualfs) as it did in permeable soils (Typic Haplundolls). Thus, the potential for groundwater contamination is much greater on permeable soils than on slowly permeable soils. The data obtained from this study apply equally well to other areas having similar soil and climatic conditions.

Soils: moisture regimes (map): By evaluating the different moisture regimes expressed in the new soil classification system (Soil Survey Staff, 1972), it is possible to combine the 120 different kinds of soil shown on the basic soil map into six soil moisture categories. These categories are shown on the soil legend as (1) soils that are wet all, or nearly all year, (2) soils that are moist all year, (3) soils that are usually moist but dry for periods amounting to less than 3 months per year, (4) soils that are moist part of the year and dry for periods amounting to more than 3 months per year, (5) soils that are moist during winter and dry during summer, and (6) soils that are dry all year and are seldom moist.

This kind of a map alone or in combination with other data can show potential for different kinds of plant production, need for irrigation, trafficability, dust hazard, potential groundwater contamination through leaching, and hazard of soil erosion and runoff. Many applications can be made of this kind of map. Several are quite obvious as they relate to nutrient losses and water pollution. Soils that are dry all or most of the year are not likely to be potential sources of high plant nutrient losses except possibly if the soils are irrigated and the management practices are poor. This in general would include items shown in the legend as mapping units 5 and 6. Over 25 percent of the soil surface of the world is in this grouping.

Soils in category 4 that are moist part of the year and dry for more than 90 days may present problems, especially in hot climates where high intensity rains occur over short periods of time, resulting in much erosion and runoff. Also, during the dry season plants die or are dormant and do not use up nitrate accumulated in the soil.

Arable soils in category 2 and 3 are potential sources of plant nutrient losses if good soil management practices are not followed.

Some of the arable soils in categories 1, 2, and 3 are potential for groundwater contamination through percolation if good management is not used.

Soils: surface textures (map): Surface soil texture can be an important soil property when evaluating such items as trafficability, infiltration, workability of soil, plant selection, and wind and water erosion hazards. Research results reported earlier by Wischmeier et al., 1971, show a very close relationship between surface soil texture and soil erodibility. A potential erosion index map could be prepared by relating soil texture and other important soil properties (organic matter, soil structure, soil permeability, soil mineralogy) with total energy exerted by rainfall.

General pattern (schematic) of annual world precipitation (map): This map shows annual precipitation superimposed on a map showing surface soil textures. The composite map relates to factors that are especially important in evaluating the potential erosion hazard of bare soil. Although rainfall intensity is a better index for evaluating the total energy expended during a rainstorm (Wischmeier and Smith, 1965), there is a relationship between total precipitation and total energy expended.

It would be reasonable to assume from the evidence presented earlier in this paper that, by keeping all other factors constant, the greatest erosion potential would occur in those areas having the highest rainfall and with soils with a silt or silt loam surface texture. Sandy soils with very slowly permeable subsurface layers also have a high erosion potential. The least erosive soils are those with less than 10 inches of precipitation and a sandy or clayey surface.

By obtaining climatic data from local stations to show total energy from rainfall and relating these data to kinds of soil, a map could be prepared showing those soil areas having a slight, moderate, or severe erosion hazard.

Erosion index (EI) values shown in table 1 were estimated for selected locations in the world in an attempt to show, in a very general way, values for the five rainfall regimes shown on the schematic world precipitation map. These were estimated from normal monthly precipitation and normal monthly number of days with measurable precipitation (Newhall, Franklin, U.S. Department of Agriculture, Soil Conservation Service—personal communications, 1972).

Table 1. Estimated Erosion Index (E.I.) Values[1]

Rainfall Regime	Est. E.I.	Location
Over 80" PPT	651	Bombay, India
	861	Belem, Brazil
40–80" PPT	354[2]	Birmingham, Alabama (USA)
	331	Corrientes, Argentina
20–40" PPT	136[2]	Des Moines, Iowa (USA)
	252	Kano, Nigeria
10–20" PPT	81	Malaga, Spain
	89	Janin, Jordan
Less 10" PPT	65	Ngumi, Niger
	24	Ciudad Lerdo, Mexico

[1] For location outside of the United States the postulated within-month distribution of storm rainfall amounts was calculated using the gamma distribution for storm rainfall. The kinetic energy E was computed using the storm total and twice storm average rainfall. The short interval intensity was a function (1/2) of storm size. The separate products of EI value for each postulated storm were summed over the year to get the EI index.

[2] Taken from Agriculture Handbook 282.

The limted data in Table 1 show that a relationship exists between total precipitation and the erosion index. Recognizing the limitations of these data (Wischmeier and Smith, 1958), one can classify the potential erosion areas of the world in five broad classes: high (over 80"), moderately high (40–80"), moderate (20–40"), moderately low (10–20"), and low (less than 10").

Areas of high potential erosion hazard that are being cultivated are also most likely to be areas with a high potential for nutrient enrichment of natural waters. Many meaningful interpretations and projections about soil erosion and nutrient enrichment of waters in an area can be made from specific soil and climatic data.

Principal areas of production of selected food and feed crops (map): This map shows where most of the world's principal food and feed crops are grown in relation to the major kinds of soil. Data presented earlier in this paper show that with the exception of paddy rice, most of the sediment originating in rural areas comes from cultivated soils. By relating land in cultivation to climate and to kinds of soil, it is possible to locate those areas where potential losses of soil, water, and plant nutrients needed by plants are high as well as show potential sources of soil and nutrient enrichment of surface waters. Areas of moderate to high rainfall with soils that are moderate to rapid in permeability are potential sources of nutrient losses through percolation. The soil areas now in cultivation that have moderate to severe erosion hazards are the ones that need special conservation practices to prevent soil and runoff rich in nutrients from entering surface waters and becoming pollutants.

Distribution and density of population (map): This map shows three classes of population density (low, moderate, and high) per square mile and per square kilometer superimposed on a general soil map. High population density areas present major water pollution hazards because of (1) high runoff and erosion from construction and builtup areas, (2) wastes from municipal sewage disposal systems and from food-processing, chemical and other industrial plants are usually dumped in nearby streams, and (3) arable soils near large cities are usually farmed intensively. Safe disposal of wastes in high population density areas is especially difficult in areas of high rainfall. More attention needs to be given to the use of soils as a medium for the disposal and recycling of wastes. Soil areas that are safe for this use can be selected through the use of a detailed soil map. Soil maps can also be used as a guide in selecting sites for homes, buildings, and roads. In this way, soils ill suited for these uses can be avoided thereby saving large sums of money in maintenance costs.

Summary

One of the first and most important steps in the development of a plan to improve the environment by reducing soil erosion and runoff is to have an inventory of the soil resources. Soil maps prepared by pedologists with needed interpretations provide basic soils data needed to determine the location and extent of each different kind of soil and and its potential for various uses.

Plans can be developed to minimize soil and water losses through proper soil selection, and conservation practices can then be applied. Nutrient losses can be held to very low levels by using known conservation practices. Although the application of presently known methods can reduce greatly the present rate of water pollution, new research is needed to develop better methods for the disposal of the greater quantities of human, animal, and industrial wastes that will be produced in the years ahead.

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THE EXTENT AND EFFECTS OF ATMOSPHERIC POLLUTION ON SOILS

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Man's activities take place mainly in a thin layer of air near the ground, and both direct and indirect emissions into the air give rise to local, regional or even global distribution of man-made products. Radioactive substances, insecticides, hydrocarbons, heavy metals and exhaust products from industries and urban areas are thus emitted into the atmosphere and they may be distributed all over the Globe. This widespread distribution is now a well-known fact for some compounds such as radioactive isotopes, chlorinated hydrocarbons (DDT) and lead. For other substances the distribution pattern is more local - or seems to be more local due to lack of information. In the long run, however, all emissions will be globally distributed.

All elements and compounds in the atmosphere are cycling between the air and the ground (soil and water). If the cycling speed is high, the residence time in the atmosphere must be low and the distribution area from the source will be small. On the other hand, the amount of fallout will be high and effects (if any) will show up in a short time. Since the residence time for different air pollutants varies from hours to years, we have a corresponding variability with respect to the amount of fallout and the distributional patterns. The situation is complicated not only due to the spectrum of meteorological factors but also to the variation of the sink processes, e.g. rain out and wash out, soil conditions, type of vegetation etc. To some extent the problems of air pollution and related effects on soils and waters can be treated theoretically. To be on safe ground in a specific case, however, we still have to handle the problem experimentally, e.g. by data from sampling networks. In Europe and more specifically in Sweden different networks have been continuously operating since 1952. The following is of interest for this conference:

1. The European network for the chemistry of air and precipitation.
2. The Scandinavian network for the chemistry of lakes and river water.
3. The Swedish network for the determination of pesticides in natural soils.
4. The Swedish network for the determination of heavy metals and the chemistry of natural soils.

In addition to these networks, which have the purpose of checking the chemical quality of our environment and its changes with time, other studies are coordinated such as detailed synoptic studies, local studies around a single point source, studies of artificially polluted soils etc. One of the greatest air pollution problems in Europe at present - SULPHUR IN AIR AND PRECIPITATION - has been treated along all these lines and the result will be presented by Sweden at the UN Conference on the human environment as a Case Study.

1. THE CHEMICAL CLIMATE

The atmosphere contains not only a number of gases that are chemically more or less inert but also a large number of substances (normally at low concentrations) which are highly reactive both within the atmosphere and with soil, water and vegetation. Everything related to these chemically active substances is incorporated into the term "The chemical climate". Before the industrial period the chemical climate was more or less constant and the rate of change of any chemical parameter with time was probably in the order of less than 10^{-1} % per year. Since the cyclic and random variation within a year is approximately 3 order of magnitude larger, time trends of natural origin was not likely to be detected experimentally.

At present the situation is quite different. From the data of the atmospheric-chemical network (cf. Figure 1) we have now time series since 1954 or earlier of 10 elements. Some of these elements show very marked and consistent changes with time. The chemical climate is apparently rapidly changing at present. This will effect the environment in many respects, positively or negatively, depending on the kind of substance and which part of the environment that is affected. An increase of ammonia, for example, is beneficial to plant life but is technically detrimental due to increased stress corrosion.

Figure 1. The dots on the map denote the sampling stations of the European atmospheric chemical network. All the stations are not administratively coordinated. In some local areas the network density is much larger. Sampling time is one month for both air and precipitation.

NITROGEN (NO_3 AND NH_3)

An element of great biological interest is nitrogen. The addition of nitrogen (NO_3 and NH_3) from the atmosphere to soils, lakes and rivers determines to some extent the produdtivity of these systems. By increasing fallout the systems will be more eutrofic. As can be seen from Figure 2 the fallout of NO_3-N (as Kg per hectare and year) is steadily increasing during the measuring period. The variation between successive years is more or less synchronous, which illustrates the effect of the physical climate. The natural background value for the non polluted situation seems to be around 0.5 Kg NO_3-N per hectare and year. The present day value at the South-westerly part of Scandinavia (Pl, As) is around 3 Kg, an increase by a factor of 6. In northern Sweden (Fo, Rö), being more remote from the emission sources, the corresponding factor is around 4.

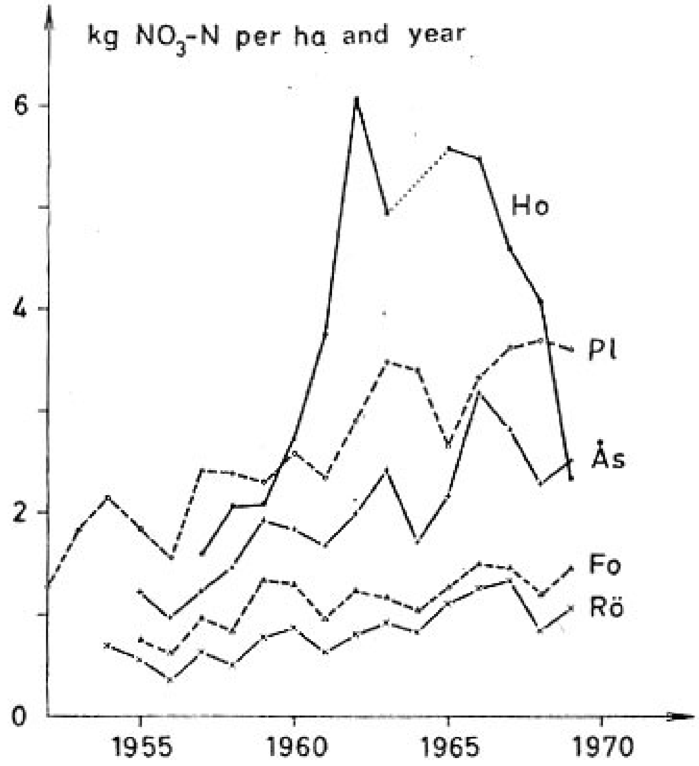


Figure 2. The curves show the yearly increase of nitrate-N in the yearly precipitation. The increase is largest in the South of Scandinavia (Pl, As). The peculiar behaviour of the German station Ho has not yet been explained.

The observed effect is most likely due to three man-made sources: the increased burning of fossile fuels, the convertion of N_2 to NO_x by high temperature engines and thirdly the large increase in the use of nitrogen fertilizers. About 8 million tons of nitrogen fertilizers is consumed annually in Europe and this figure increases approximately by 7% per year. An almost equally large increase in the fallout data has been observed at a part of the stations of the atmospheric chemical network.

The relationship between the use of fertilizer-N and the fallout of fixed nitrogen is visualized in Figure 3. The map of the annual use of fertilizer-N per unit area of each country is fairly congruent with that of the fallout. The centre of the emission coincides with that of the deposition. If fertilizer-N should be the only source to the fallout-N one can compute, that approximately 30% of the fertilizer-N is added annually to the atmosphere in one form or another.

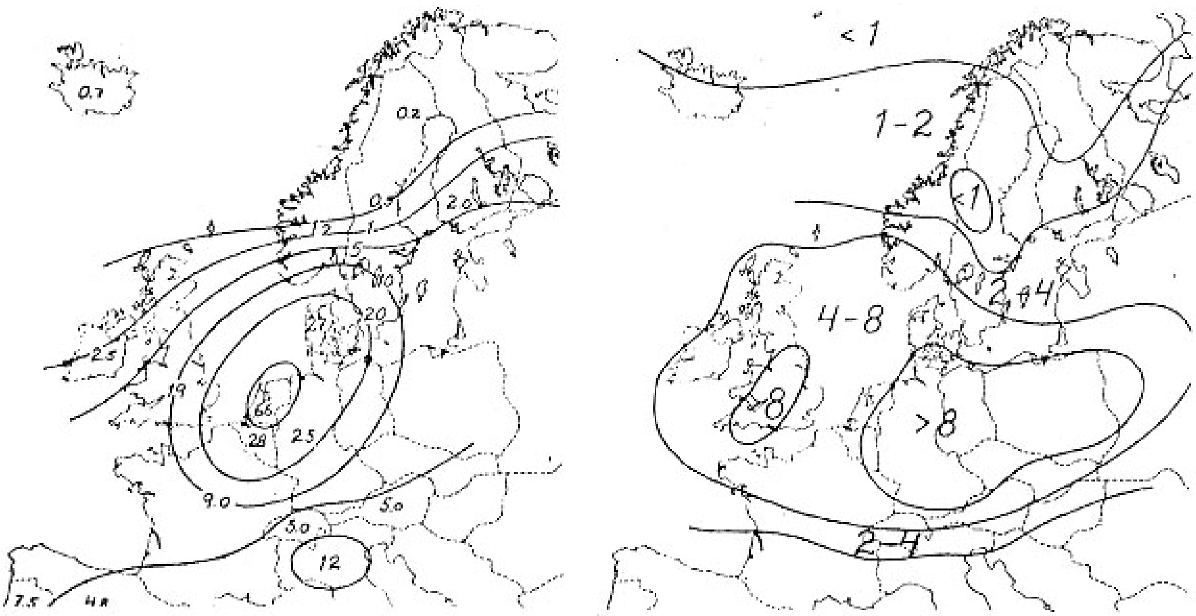


Figure 3. The left map shows the distribution of the use of fertilizer-N in Europe. Figures are given in Kg per year and hectare for each country. The right map shows the distribution pattern of the fallout of nitrogen (NO_3 and NH_3). Figures in the same unit. Note the similarity in the pattern of the isolines.[3]

In many lakes and natural soils, the amount and availability of fixed nitrogen is a limiting factor in the production of organic matter. Therefore growth conditions ought to be improved on forest soils due to the increased fallout of fixed nitrogen. However, this is not known for the present and other factors of the chemical climate such as the increasing acidity of air and precipitation may be counteracting the expected increase of growth rate. The reported increase of the eutrophic state of lakes and rivers in Sweden and Norway may, on the other hand, be an effect of the increased fallout of N. However, specific studies in these respects have not been made yet.

SULPHUR

The emission of sulphur into the atmosphere both in connection with various industrial processes, the production of energy and for heating purposes has proved to be a major environmental problem in Europe, part of US and other highly industrialized areas. In Europe, the sulphur emitted into the air by human activities makes up approximately 80% of what totally exists over that area.

Sulphur occurs in the atmosphere mainly as SO_2, H_2SO_4 and H_2S and the average life time for these compounds in the atmosphere varies from 2 to 4 days. The corresponding transport distance is more than 1000 km. The many sulphur sources in Europe will thus "cooperate" in forming a chemical climate where sulphur plays a dominant role.

The acidic character of most sulphurous compounds gives rise to a variety of damages. Concentration effects show up on human health, deterioration of metals and building materials and on vegetation. Acute damages on plants are well known in many industrial areas. At high concentrations the cells are plasmolyzed; at lower concentrations a destruction of the chlorophyll occurs. Direct chlorophyll damage through the effect of sulphur dioxide exists even outside areas of acute damages. Plants and deciduous trees with a rapid annual circulation of the chlorophyll substances should therefore not be affected in the same way as coniferous trees. For these trees the cumulative effect of sulphur dioxide leads to a destruction of the chlorophyll since the life time of the neddles is up to 7 years.

Lichens have also proved to be a sensitive indicator of sulphur dioxide in the air. At increased content, the lichens die (chlorophyll death of the green algae of the lichens). Such studies can therefore be made to evaluate the distribution of air pollution. The susceptibility of lichens has also a practical side. Large parts of the mountains at higher latitudes are covered by lichens. In recent years the growth of the reindeer lichen has been reduced. If this is related to a general acidification of air and precipitation the reindeer husbandry will be at danger in these areas.

The accumulated effect of the fallout of especially H_2SO_4 will affect arable land, forest soils, lakes and rivers. On the other hand sulphur is an essential element in plant life and one could believe, that an increase of the fallout of sulphur should be beneficial to plant life. In Sweden, however, the addition of sulphur has had no positive effect in this respect. The increased fallout of sulphur has, on the whole, consequently a negative effect on the environment.

Figure 4 illustrates the fallout picture of sulphur over Europe in 1957 and 1963. There is a general increase in the sulphur concentration in the yearly precipitation between these two years. For Scandinavia the figures were almost doubled. The general distribution pattern, however, is fairly similar between the two years and reflects to some extent the position of the different emission areas. The long-range transport to the outer areas of Europe is well recognized for the year 1963.

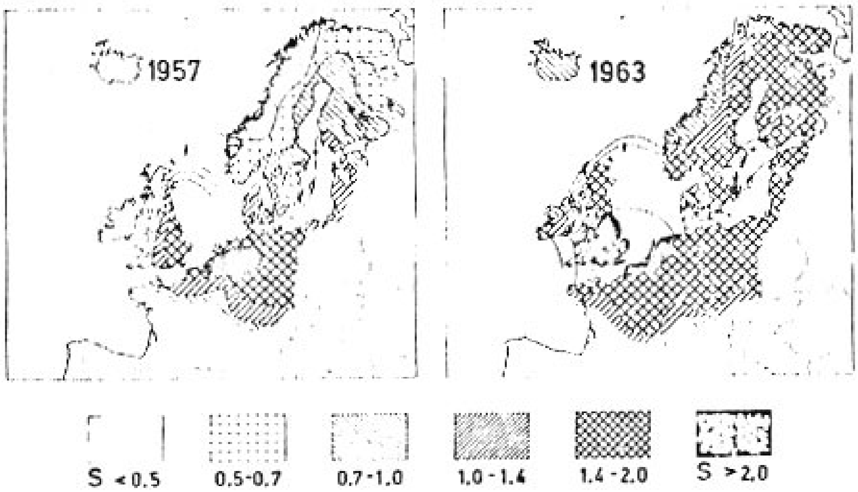


Figure 4. The maps show the distributional pattern in Europe of the yearly concentration of sulphur in precipitation. S denotes only man-made sulphur. Figures are given in mg per litre.

Changes in the fallout of sulphur by precipitation due to increased emission into the atmosphere (3% per year) does not proceed smoothly. Actually the fallout varies considerably from year to year, which indicates that sulphur is effectively coupled with some other source-sink reservoir for sulphur. Both soils and waters contain large amount of sulphur per unit area and exchange reactions will take place between these reservoirs and the atmosphere. During wet conditions H_2S will be formed in the soil and emitted to the atmosphere. After oxidation it will be brought back to the soil and will be measured as an apparent increase of the fallout. Sulphur is thus more or less continuously looping between the atmosphere and the soil and the yearly fallout is to some extent a function of the number of loops. Examples of the yearly concentration of sulphur in precipitation are given in Figure 5.

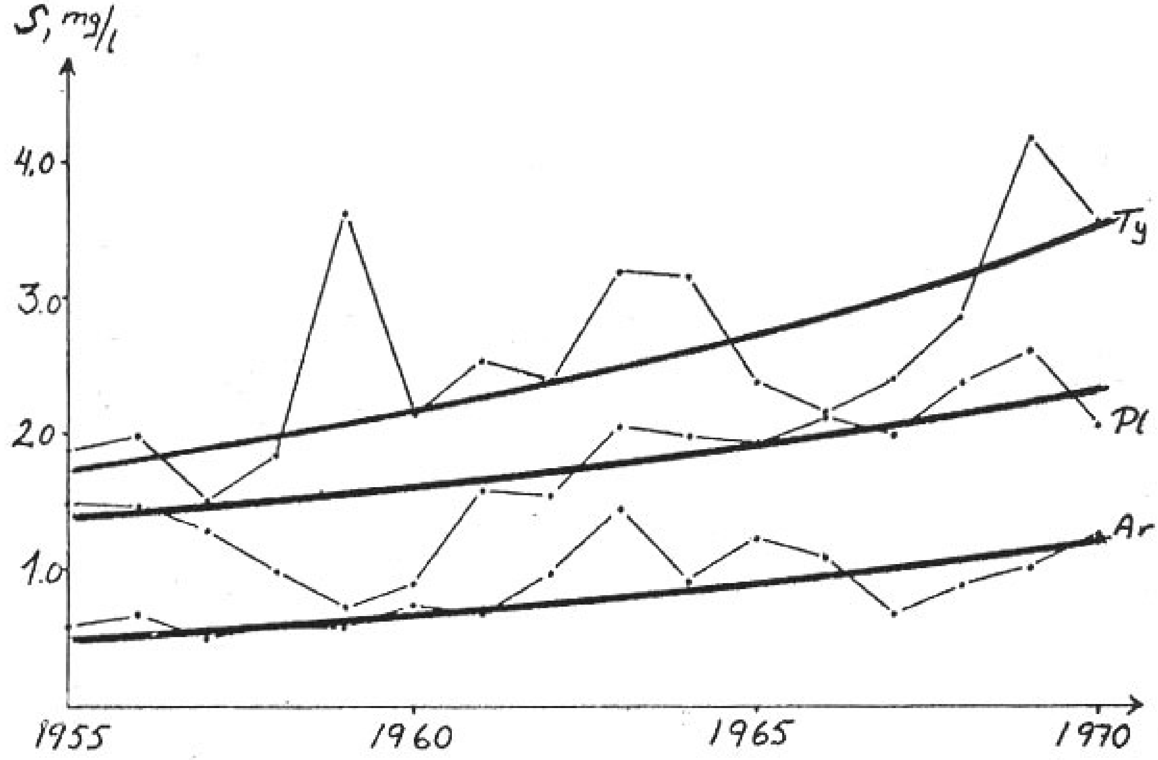


Figure 5. The curves show the increase of the sulphur content of the yearly precipitation at Ty in Denmark and Pl and Ar in Sweden. The thick lines give the approximate trends for the period 1955 to 1970.

Though variable in time the fallout of sulphur does actually increase with time. This is well recognized from changes of the sulphur content in the Swedish river systems, which have been intermittently investigated since 1909. A threefold increase has occurred since that year and in South Sweden the discharges by the rivers have increased from 7 to 22 kg S per hectre and year. Since the man-made sulphur mainly is brought to the soil as SO_2 or H_2SO_4 but leaves the soil as a salt, considerable amounts of cations must be extracted from the soil. Data in this respect are also obtained from the Swedish water chemical network. A consequence of this is that the soil will be less fertile.

THE ACIDITY OF AIR AND PRECIPITATION

Excess acids in precipitation such as H_2SO_4, HCl and HNO_3 leads to its acidification - the pH-value decreases. Figure 6 shows the distribution of the acidity of the annual precipitation in Europe for 1956, the first year in which a regional mapping was possible. Although the network of stations was not completely developed at that time, it can be seen that an acidification centre with a pH-value less than 5.0 occurs over eastern England, Holland and Belgium. Large parts of Scandinavia had almost neutral precipitation.

In 1959, the situation had markedly changed. The "less than pH 5.0 area" had extended greatly, particularly in a north-easterly direction. A new acid class, less than pH 4.5, had now occurred over northern Germany, Holland and Belgium. The availability of Russian data for the years 1958-1961 has made it possible to establish the position of the "epicentre" of the acidification (Holland, Belgium and W. Germany).

As can be seen on the maps from 1961 and 1966, this epicentre did not change in place, but the acidification was constantly increasing outwards. From 1961 the annual precipitation within the centre had an acidity of less than pH 4.0. This is such a high acidity that corrosion will be highly improved. Direct vegetation damages can also be expected, particularly since occasional periods of precipitation have an acidity around pH 3. In one case pH 2.8 was actually measured in Sweden.

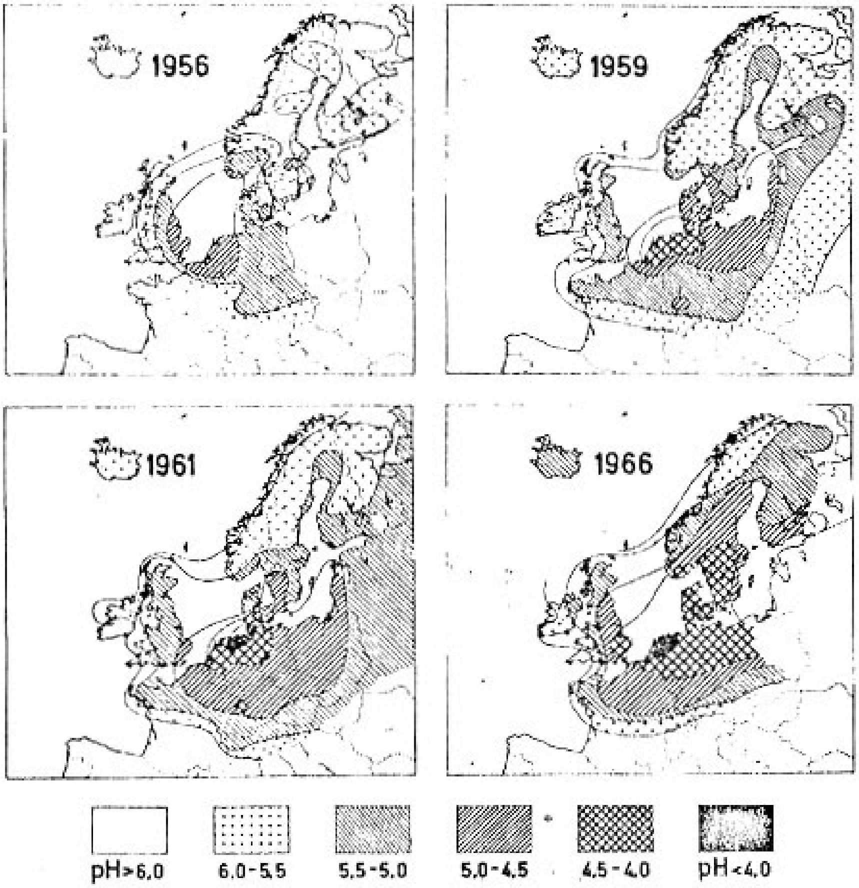


Figure 6. The maps show the distributional pattern of the yearly average pH-value in the precipitation. Note the increased acidity in Central Europe and over most part of Scandinavia. The situation is somewhat more acid in 1970 in comparison with 1966.

On the map from 1966, it can be seen how the acidity had extended across Scandinavia. South-western and central Sweden and southern Norway in particular were exposed to highly increased acidification. If we disregard this effect as being due to climatic fluctuations, this trend has not changed up to 1970. In similarity with sulphur the annual mean pH-value of the precipitation varies from year to year. The negative trend is nevertheless very clear. This is illustrated in Figure 7. The Norwegian stations at Kise and As show a more negative pH-trend than the Swedish stations. This may be due to local emissions from Oslo and to the topography of the surrounding mountains. Most network stations in Europe have a negative pH-trend. Stations far away from the industrialized heart of Europe are almost unaffected as far as we know at present.

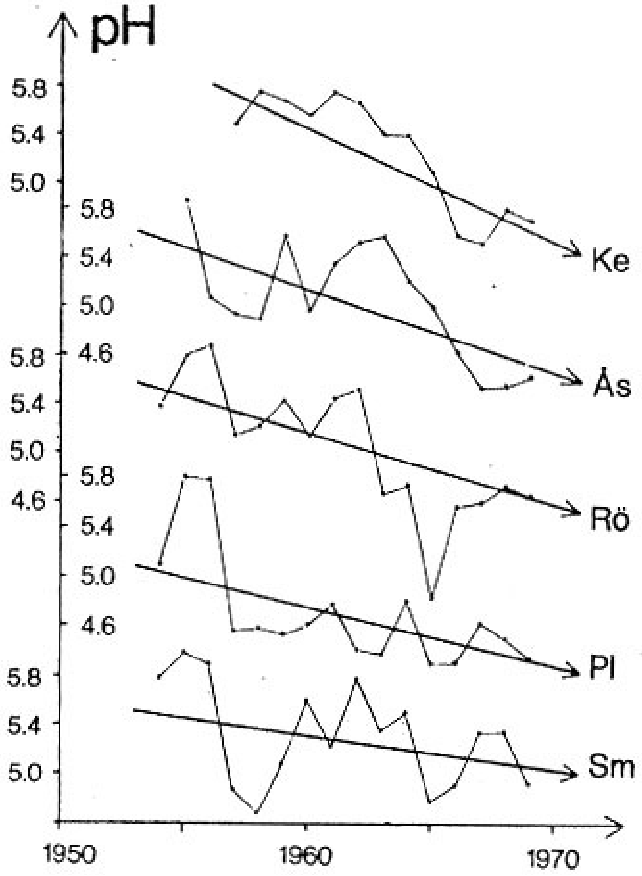


Figure 7. pH-measurements at the stations of the atmospheric chemical network show decreasing values for the most of Europe. The points on the curves are annual mean values. The stations Ke and As are situated in Norway, the rest in Sweden.

Emissions into the atmosphere of acidifying substances such as sulphur dioxide, sulphuric acid, hydrochloric acid and nitric acid give also the air an acidic character. In many cases, the air is more "aggressive" than the precipitation. It has been found, for example, in studies of the rust formation on iron plates, that the downward side of the plates in certain places corrodes more than the upward surface. Relatively, precipitation can have a cleansing effect! This applies also to buildings. The greatest damages are often found in precipitation-protected positions such as under gutters, balconies, window-sills etc.

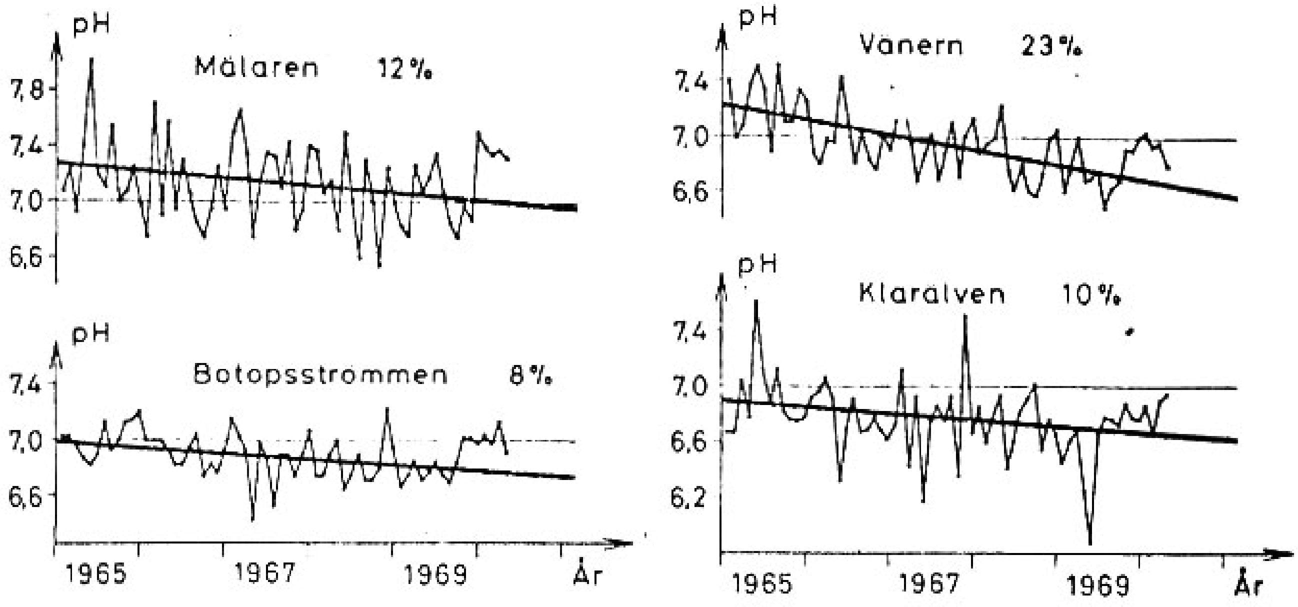


Figure 8. The diagrams give examples of pH-changes (trend and amplitude) over the last 5 years for four lake-river systems in Sweden. The negative pH-trend occurs also at all the other river systems being examined.

The acidity of air and precipitation has widespread effects. Buildings, bridges and other technical constructions are subject to corrosion and other material deterioration; the health of Man and animals is impaired within the most affected areas; direct damages occur on micro-organisms and higher plants; indirectly, the supply of nutrients to the plants will be depleted by acid leaching of the soil; and finally lakes and rivers become acidified, which affects growth and reproduction of fish.

Measurements in a large number of Swedish lakes and rivers show that the pH-value has dropped during the years 1965-1970. Changes have been greatest on southern and central Sweden - that is to say, within the area where the precipitation is most acid. There is consequently a clear connection both in time and in space between the pH of the precipitation and the pH of river waters. Figure 8 gives examples of the variations month by month of the pH-value of some of the examined rivers. The negative trend for these water systems is very clear. Existing fluctuations are partly due to variation in biological activity during the year, and partly to the variation between surface water drainage and ground water drainage, the reservoir characteristics of the water system, industrial discharges etc.

In the case of lake Vänern, the water is acidified at a rate of 23 per cent per year, and in the river Klarälven at 10 per cent. These water courses have become two to four times more acid within a period of only five years. It is of interest to note that a water system as lake Mälaren is acidified at such a high rate as 12 per cent a year. The drainage area of lake Mälaren is in fact calcareous which should neutralize the acid precipitation. The large water surface of lake Mälaren (11 percent) and also that of Botorpsströmmen (about 8 per cent) may have the effect that a considerable amount of acids falls directly on the lake surface. The effect of acid water can be so strong that fish will flee from these water systems or that spawn will not hatch out. Lakes and rivers more permanently acidified are usually empty of fish.

Acid precipitation falling on soils leads on one hand to a depletion of the nutrient supply in the soil, on the other to reduced pH-values. This in turn will influence the solubility of different nutrient elements and also the microbiological life in the soil. In the long run, the pH-value of the soil will be adapted to that of the precipitation, around pH 4.2. The time scale for this process of adaptation cannot be given at present, since it depends on many soil factors which have not yet been investigated. Since the hydrogen ion has a very high adsorption energy on the soil colloids, other cations such as sodium, potassium, calcium and magnesium will be adsorbed by ion exchange and washed out by the precipitation. The content of adsorbed cations in podsolized forest soils is rather small and amounts to only 1,200 to 2,000 kg/ha. The turn over time for these cations due to the fall-out of acids can be calculated to be around 150 years. This means that the base content falls to 50 per cent after about 100 years, to 25 per cent after 200 years and so on. The process will not follow this mathematical relationship exactly, since weathering of the soil minerals will release a certain amount of bases, which compensates the losses. An investigation of Scandinavian forest soils was made in 1970. Some of the results are given in Figure 9.

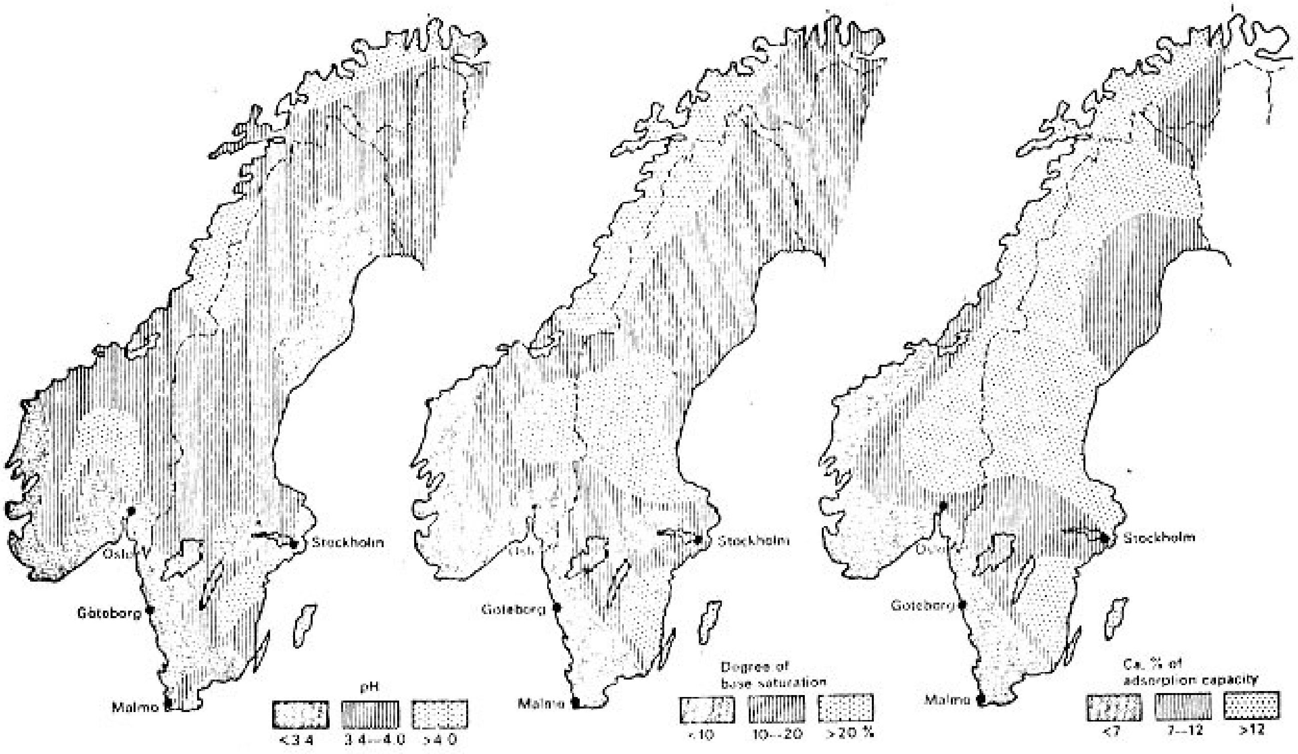


Figure 9 a
Distribution pattern for pH of forest soils in Sweden and Norway. Note the continuous zone of very acid soils along the Scandinavian border facing Central Europe.

Figure 9 b
Distribution pattern for the degree of base saturation (the amount of cations adsorbed to soil particles as percentage of the total amount that can be adsorbed) in forest soils in Sweden and Norway.

Figure 9 c
Distribution pattern for the degree of calcium saturation in forest soils in Sweden and Norway. Low Ca-content, less than 7% occurs within the same coastal area specifically denoted on the previous maps.

The impoverishment of forest soils must be considered a long term reality and is of course related to the rotation period of forest trees, in Scandinavia from 75 to 120 years. The present forest generation will thus be subject to a reduced supply of calcium, magnesium and potassium, which will cause poorer tree growth. Particularly those parts of Sweden and Norway with large amounts of acid precipitation will be most susceptible. Special attention should also be given to the fact that quite large forest areas in Scandinavia already have a very low content of bases (cf. Fig. 9b & c). The base saturation figure is actually less than 10%; that is to say that more than 90 percent of the base cations already consist of hydrogen ions. The margins are consequently very small.

2. THE ACCUMULATION OF CHLORINATED HYDROCARBONS IN SOILS

It is now a well-known fact that many organochlorines are found almost in every part of the world. This must be due to a large-scale atmospheric transport and redistribution of these pesticides since they are used more commonly only in the tropical and the temperate zones of the world. The fallout on soils may eventually lead to a continuous accumulation.

Some years back the annual use of DDT in the world was approximately 200 000 tons and totally about 2 million tons have been emitted into nature. Due to the long residence time of DDT in soils (5 to 15 years) a considerable part of the total output is still undercomposed, and, due to its volatility, DDT will start a global cycling.

In 1966 we started an investigation on the chlorinated hydro-carbons in natural systems, such as soils, sediments and river waters and some results will be presented at this conference. So far only soils have been studied in detail. Soils from about 400 localities have been sampled and analysed. They represent most types of Swedish soils with regard to origin, environmental factors, and the use of the soils such as, cultivated soils, pasture and forest soils. Samples have also been taken at different depths in order to study the vertical distribution pattern. The following organochlorines were investigated: Lindane, Aldrine, Dieldrine, DDT, DDD and DDE. After the discovery of the polychlorinated biphenyls (PCB) by Dr. Jensen, these compounds were also included in the determinations.

The frequency distributions of all data of the top soil are given in Figure 10. The concentration levels are logarithmically spaced. The cultivated soils (upper diagram) seem to consist of two different distribution functions. One is centered around 6 ng/g soil, and the other around 125 ng/g soil where the first relates to untreated and the other to DDT-treated soils. The low level distribution function will then represent soils that have not been treated with DDT, and the occurrence of chlorinated hydro-carbons in these soils must be a result of an atmospheric transport from either adjacent fields or remote sources.

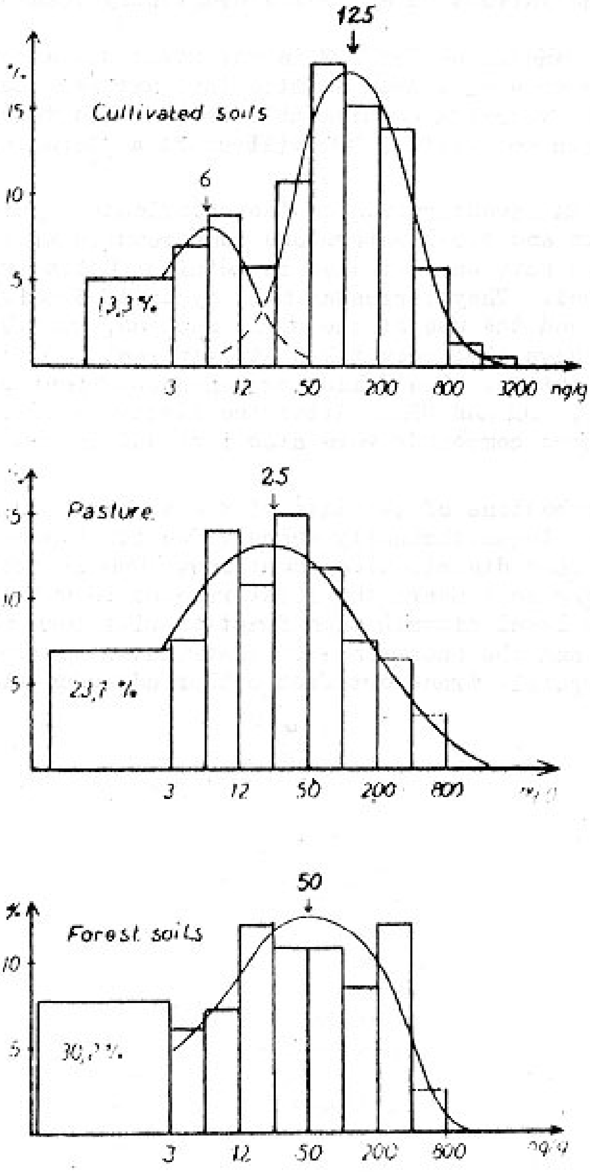


Figure 10. The diagrams show the frequency distribution of Σ DDT for three different soil types. Pasture and forest soils, not being treated with DDT, show increasing values in relation to untreated cultivated soils.

The frequency distribution from pasture soils is unimodal (middle diagram). The highest figures amount to almost 800 ng/g soil. The most probable value is around 25 ng/g soil. This figure is higher than the corresponding figure for untreated, cultivated soils (6 ng/g soil). This indicates that pasture soils provide more favourable conditions for accumulation than cultivated soils, or that the rate of removal of the organochlorines from the soil by decomposition or evaporation is reduced.

Among untreated soils, those which are least exposed to sunshine and high temperature, have the highest figures. This is shown by the frequency distribution for forest soils (lower curve). The most frequent values appear around 50 ng/g soil. Only a few values exceed 400 ng/g soil. However, it is rather surprising to find that, on the average, the highest figures are for forest soils. They have not been treated with organochlorines, and the sampling were mostly far away from farming areas. Consequently, the occurrence of Lindane and DDT in forest soils must be due to both a large scale atmospheric transport and a low decomposition rate owing to low exposure.

To summarize: Untreated Swedish soils contain different kinds of organochlorines, whose concentrations increase with decreasing exposure. The situation for DDT and Lindane is tabled below.

Soil Type	Most frequent concentration, ng/g	
	≤DDT	Lindane
Cultivated soils	6	8
Pasture soils	25	20
Forest soils	50	40

The persistence of the organochlorines in soils varies with both type of compound and soil conditions. We assume a figure of 5 years to be reasonable for Swedish conditions. By means of this figure and assuming an annual Swedish consumption of 50 tons of DDT (before the ban of DDT, 1 January 1970) we may estimate the expected amount in Swedish soils under steadystate conditions. We then obtain a figure of approximately 250 tons. On the assumption that there is no "sink" whatsoever, the total amount of DDT used in Sweden since its introduction here, can be estimated to about 600 tons. Consequently the expected amount may vary between 250 and 600 tons.

On the other hand, the actual amount of chlorinated hydrocarbons in Swedish soils can be fairly well determined from our present data. The figures listed below refer to a soil depth of 15 cm.

Soil type	≤ DDT, tons	Lindane, tons
Cultivated soils	1,000	130
Pasture soils	50	30
Forest soils	1,300	700
Total for all soils	2,350	860

In addition to the above figures, certain deposits of DDT and Lindane occur in sediments and in deeper soil layers. Especially the B-horizon in podsolic soils show accumulation, probably due to the high adsorption on iron oxides. From our present data we can only estimate the deposits in the subsoil (below 15 cm). They amount to roughly 550 tons of ≤ DDT and 250 tons of Lindane.

There is a very great difference between the amount of ≤DDT actually found in Swedish soils, around 2,900 tons, and the amount that could be expected, around 250 tons. Consequently, there must be some source of the organochlorines other than dissemination within the country

The only explanation is, that considerable atmospheric fallout occurs both as direct adsorption from the air and as washout by precipitation. We have actually found DDT and its metabolities in snow during a period of the year when DDT has definitely not been used outdoors in Sweden.

In order to account for an excess of Σ DDT, in Swedish soils, amounting to 2,650 tons (2,900 minus 250) the annual atmospheric inflow can be estimated to be about 600 tons. This is of course a rather rough figure, since, on the one hand, the estimates are based on the assumption that the present concentrations in Swedish soils are at a steady state, and on the other, on an average figure for the decomposition rate in soils. As yet we do not know to which extent these assumptions are correct. A network of stations has now been organized in order to study both the atmospheric fallout of the organochlorines and the subsequent accumulation in Swedish soils. This network will be in operation for many years.

From the above it is clear that Sweden is a sink area, and southern countries are source areas for the organochlorines. We may look upon the situation as if a global destillation occurred along a temperature gradient. If this is correct, then a concentration gradient must appear within Sweden, since the country extends from 55 to 69 degrees North. This can be checked by plotting the data for untreated soils (pasture and forest soils) against latitude. The results are given in Figure 11. Each dot represents the average for 10 to 20 soil samples within the same latitude.

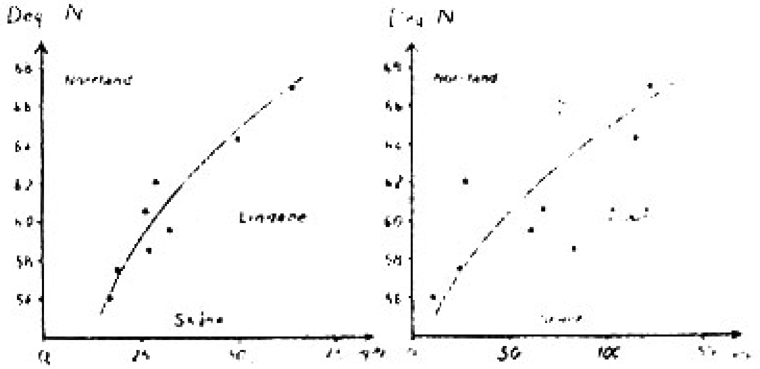


Figure 11. The curves illustrate the effect of increasing accumulation of Lindane and Σ DDT respectively at northern latitudes. The use of these substances in Norrland is almost negligible.

There is some scatter in the data, especially for DDT, which may arise from inhomogeneities in the sampling density. Undoubtedly, however, the organochlorines are enriched to the North. Further sampling is now in progress to verify these results on an extended latitudinal scale. The curves in Figure 11 do not necessarily indicate an increasing fallout northwards. Only on such an unrealistic assumption as that DDT is injected into the stratosphere, this would be true. Most probably the curves reflect the effect of falling temperature and increasing duration of the snow and frost periods towards the North. Since the organochlorines are volatile and fairly resistant to microbiological decomposition under aerobic conditions, the climatic conditions noted above will give rise to the observed effect.

The enrichment of organochlorines at northern latitudes can not be unique for Scandinavia. The same procedure must take place also in other parts of the world, e.g. North America and the USSR. With an annual consumption of approximately 200,000 tons of DDT in the tropical and temperate zones of the world, this global transport and redistribution should be both very extensive and continuous. The accumulation in the North will steadily increase, and biological effects may become apparent in the future. The process can only be stopped by a global ban on DDT.

APPENDIX

NO$_3$-N IN DIFFERENT FOOD-STUFFS

A survey of the content of nitrate in different kinds of Swedish food-stuffs has been undertaken during December 1971. Only vegetative food-stuffs were investigated. The material consisted of fresh, frozen and canned vegetables. The data are given in the table below.

Kind of material etc.	No of samples		NO$_3$-N, ppm of fresh weight
Cereals	3		0
Maize frozen	1		13
Tomato	2		13
Cauliflower	2		14
Potato	1		15
Sweet pepper	5		16
Borecole (not fertilized)	2		17
Cabbage	3		17
Mushroom (not fertilized)	3		17
Green pea frozen	4		19
Cucumber	2		24
Red Cabbage	3		24
Brussels sprouts frozen	4		27
Applepurée (baby food)	3		28
Mixed vegetables "	4		35
Carrot purée "	3		37
French bean frozen	3		59
Carrotdrink (baby-food)	5		60
Broccoli frozen	3	(55–100)	78
Borecole	2		103
Isberg lettuce	7	(78–115)	104
Spinach with ham (baby-food)	4		107
Spinach frozen	16	(146–541)	313
Dill frozen	2		490
Lettuce	16	(109–1222)	554

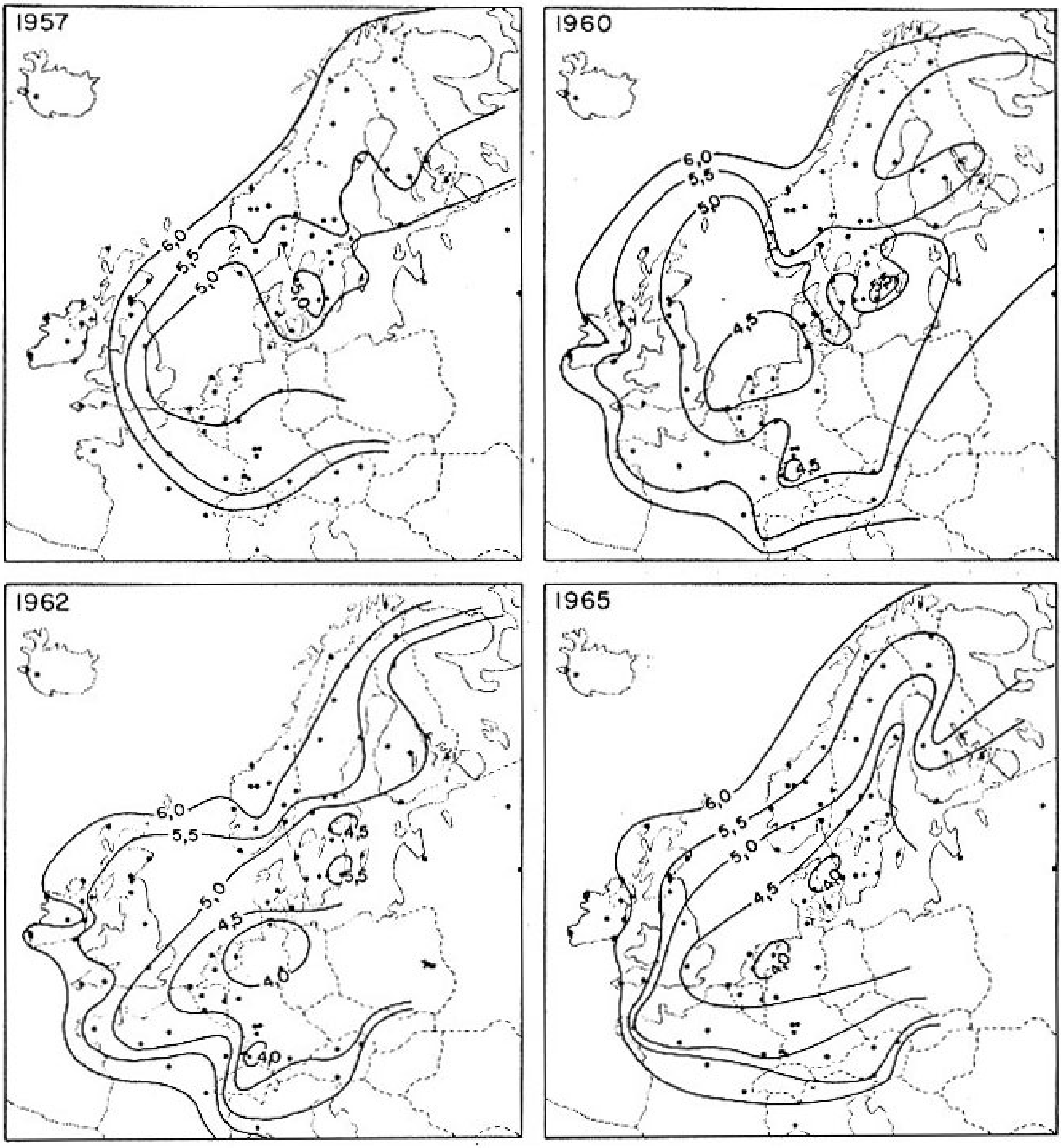
Most of the listed vegetables are grown in Sweden except the Isberg-lettuce, which is imported from Italy, Spain or USA, and ordinary lettuce which is imported from Holland.

The big variation of the NO$_3$-N content in spinach is clearly related to different canning factories.

Factory A	7 samples	181 ppm mean (146–228)
Factory B	6 samples	469 ppm mean (364–541)
Factory C	3 samples	310 ppm mean (295–324)

The content of NO$_3$-N may vary considerably for different parts of a plant. The following example can be given.

Lettuce, innermost	leaves	190 ppm
Lettuce, intermediate	"	350 ppm
Lettuce, outer	"	1050 ppm



Changes in Acidity of the Precipitation, Period 1957-1965 (by Prof. Svante Oden,

The maps show the yearly averages based on monthly measurements at the stations marked by black dots. The pollutants are spread by wind from the various emission sources such as those in the Ruhr area of Germany or in south-eastern England.

The sulphur-dioxide (SO_2) emitted with industrial smoke is converted in the atmosphere to sulphuric acid, and as such represents an acute danger for the entire biologic environment. A research team is at present investigating this problem and the findings will be part of the Swedish contribution to the UN Conference on the Human Environment in Stockholm, June 1972.

SOME FAO ACTIVITIES AND ATTITUDES CONCERNING PESTICIDES

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Introduction

Some explanation is needed for the inclusion of a talk on this subject in a Symposium primarily concerned with fertilizers. I understand that it was felt that future activities and studies relating to fertilizers and the environment might benefit from a knowledge of experience in the pesticides field.

At the outset we can accept that there are a number of similarities. Some of these can be listed as follows:-

Both fertilizers and pesticides are agrochemicals being used in increasing amounts and which are essential to increasing agricultural productivity throughout the world.

Both are responsible for environmental changes of some kind.

Both are subjected to public discussion and criticism on the latter grounds.

In both cases much of the criticism is not based on objective study of the available facts.

However, there are important differences. The most striking is that pesticides by their very nature are toxic whereas fertilizers generally are not. Some pesticides are toxic to only a very narrow range of species; but most of them are more or less toxic to a wide range, which often includes man and other non-pest species. As a result, over the years, there have been numerous poisonings and fatalities from pesticides. The fact that these incidents have often followed failures to take simple precautions - amongst packers, distributors and users, has led to stricter supervision and control by authorities in many countries. Similarly, the occurrence of residues in foods has raised doubts, stimulated much research and led to the introduction of tolerance levels and other restrictions. In short, it has long been accepted that new pesticides should only be introduced after critical assessment of the possible risks and that subsequently they are only used under adequate technical supervision.

This leads to a description of the FAO Pesticides Programme since it is designed essentially to ensure safety in the introduction and use of pesticides.

FAO Pesticides Programme

This does not refer to a programme designed to increase the use of pesticides: there is no such programme! FAO's activities in the plant protection field only lead to any increases in use of pesticides insofar as studies and advisory activities of the respective biologists, at headquarters or in the field, lead to recommendations that pesticides rather than other control methods are appropriate for the particular conditions. The FAO Pesticides Programme commenced in 1959 and followed a period during which a number of fatalities had occurred amongst field applications. The accidents were largely due to unsatisfactory practices in the use of some recently introduced pesticides of relatively high acute toxicity, and it was felt that governments needed guidance. In 1962 an intergovernmental conference on the use of pesticides in agriculture was held in Rome and FAO subsequently established a programme aimed to raise standards in supervision and use of pesticides. Groups of experts were formed to advise on specific aspects of the subject.

One group of experts dealing with the official control of pesticides has drawn up advisory papers and prepared a list of standard specifications to help governments in the inauguration and administration of schemes for supervising the introduction and use of pesticides. Such schemes are normally based on the principle that pesticides should not be used unless they are first registered with the authorities. Advice has been provided from Headquarters and consultants have made visits to various countries requiring assistance on this subject. Furthermore, the advice has always been that Departments of Health and of Agriculture should both be involved.

Another group of experts which meets jointly with a WHO group of experts on an interdisciplinary basis, has been concerned with residues of pesticides in foods. Each year it considers the available data on the occurrence of residues of particular pesticides in foodstuffs. Its task is to assess the data critically and, when the data are adequate, to make recommendations for tolerances, or acceptable residue limits, which are considered suitable for general adoption for commodities moving from one country to another.

When the group finds that the data are inadequate, attention is drawn to the deficiencies and to the kind of research that needs to be done in order to remedy them. Some recommendations are made on a temporary or conditional basis pending the conduct of further research to clear up doubts about specific points which are listed. The reports of this group summarise the data considered. Subsequently, the recommendations for maximum acceptable levels or tolerances form the basis of inter-governmental discussions which are organized under the joint FAO/WHO Codex Alimentarius Commission with a view to building up a series of internationally agreed tolerance levels. These particular activities are concerned with residues in food. Nevertheless, in 1969 the group expressed some uneasiness regarding the distribution of DDT in the environment with consequential occurrences in food; and it recommended that "its use should be restricted to circumstances in which there are no satisfactory alternatives".

The third group of experts set up for the 1962 Conference has been concerned with the increasing occurrence of strains of pests that are resistant to the pesticides formerly used. This latter problem needs to be tackled not only to ensure a continuous basis for controlling pest species but also to overcome the tendency of farmers to apply more pesticides to overcome resistance when it occurs.

Another expert group has been concerned with promoting research programmes for the control of major pests by the integration of all methods of pest control, including biological and chemical methods, based on ecological considerations. Particular attention has been paid to the development of integrated procedures for the control of pests of cotton because this is a crop on which excessive amounts of pesticides have often been applied, sometimes only to provide assurance against possible attack by pests. The general conception of this part of the programme, therefore, is to make sure that pesticides are only used where they are really needed.

Aid to Developing Countries

FAO is responsible for projects designed to improve competence in the control of pests in many countries. These projects normally are broad in conception, containing major inputs in entomology, plant pathology and similar biological subjects. Some include assistance in setting up procedures for regulating the introduction of new products. Others are substantially concerned with the ability to measure pesticide residues. These are mainly concerned with residues in foods but the facilities developed are being employed for making measurements in various other environmental materials such as soil and water. But resources for this work are limited at present and it is hoped to increase this activity, since data on the actual occurrence of residues are essential to any rational consideration of their importance in any particular situation. The need for measurements is by no means confined to foods and materials of terrestrial origins. The Fisheries Department of FAO is very interested in measuring the occurrence of residues in fish and water and the FAO Technical Conference on Marine Pollution here in Rome (December 1970) paid much attention to monitoring of the occurrence of residues in the marine environment.

Attitudes on Some Important Points

We recognize that pesticides have sometimes been applied without sufficient study of needs or of alternatives; also that some organo-chlorine pesticides are more persistent than is needed to control some of the pests against which they are used and that their residues have become distributed widely in the environment. Nevertheless, many widely reported statements on this subject cannot be sustantiated when examined objectively and in the light of the facts. For this reason, it is essential to assess such information objectively and critically on an inter-disciplinary basis before deciding on any necessary action.

In deciding on action such as the withdrawal of a cheap and widely used product furthermore, it is necessary to take into account the various likely consequences, such as any new hazards or any economic or – on the DDT question – any social effects which might follow. FAO is following such a policy, whilst encouraging research and other activities leading to the adoption of satisfactory alternatives. With its multiple responsibility for the promotion of productivity in agriculture, for technical assistance in developing countries and for the maintenance of standards of quality in food and with its background of experience in assembling experts on a multi-disciplinary basis, in my view FAO is well suited to provide objective information and advice of this kind.

In summary, the activities of FAO in the pesticide field have been largely directed to the encouragement of higher standards of scientific and technical supervision of introduction and use. Alternative methods of pest control are encouraged and any excessive uses discouraged wherever possible. By increasing the technical and scientific input, we are confident that it will continue to be possible to continue to make full use of pesticides in agricultural production throughout the developing world.

EFFECTS OF THE APPLICATION OF INORGANIC AND ORGANIC MANURES ON THE MARKET QUALITY AND ON THE BIOLOGICAL VALUE OF AGRICULTURAL PRODUCTS

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This meeting is consecrated to a subject "Effects of Intensive Fertilizer Use on the Human Environment". Part of it will be my special theme.

The term "human environment" affords - at least for my paper - an introductory definition. It may be given first:

In our opinion this conception comprehenses not only the "surroundings" of men in its narrow ecological sense (climate, microclimate, soil, subsoil, groundwater, topography) but also human food in terms of food-plants grown under certain ecological conditions, and - in our special case - treated with high amounts of fertilizers. The physiological or in exception even potential toxic consequence for men via the so treated food-plants are also subject to this concept.

This statement we have to bear in mind for the following arguments and experimental results.

Agricultural and horticultural production of plants used as human food can be regarded from at least two principal view points. The first,

"Economics"

- base of every productivity - is one of it. It is somewhat confronted with the second view point,

"Human Nutrition and Health"

scarcely considered and mostly negated by many representatives of Agriculture and Horticulture (1).

On the first look this confrontation seems rather strange but it is not in the view of learned experts in nutritional science or from the well known consumer's standpoint. The "nutritional" group of experts has fought the other group, agriculturists, in refusing their antiquated opinion, maximum yield ought to be the real, the only aim of modern plant production.

Food-plants or their products - fruit, vegetables, potatoes - are eaten preferentially because of their high "biological value" based on dietetic and health keeping properties. This is totally different with food derived from animals.

This food is used chiefly as basic sources of protein and fat offering to the consumer high calories. We know nowadays that plant products serve as a valuable source of health keeping properties (1, 2).

Furthermore, food-plants are regarded as effective dietetic help against the diseases of civilization, esp. those of the heart, blood vessels and circulation with fatal termination (1, 2).

Various research worker have proved that the supply of animal protein raised the level of cholesterol in the serum, whereas the supply of protein derived from plant-food lowered it significantly (1, 2).

According to Holtmeier's experimental results (1) sodium and chlorine in NaCl are jointly responsible for the development of oedema and rise of blood pressure in essential hypertony. In any living organism, plant or animal, potassium is antagonistic to sodium according to physiological function of both cations in the living cell.

Meneely and co-workers (1) found in nine experiments to determine the longevity of 945 rats that with increasing oral applications of NaCl the systolic blood pressure, the serum cholesterol, the total exchangeable body-sodium and electrocardiographic abnormalities increased. If by supplying KCl the ratio of K : Na = 1 : 1 was attained, the consequence was an astonishing prolongation of the average longevity. With higher applications of NaCl the high blood pressure could be normalized again by supply KCl.

From Figures 1 and 2 it will be seen that animal foods, in part, have very high contents of Na and Cl and that these values are not balanced by correspondingly high values of K. This is particularly acute in haddock, in cheese (Emmentaler), in mayonnaise and in butter. Moreover, eggs and milk do not have such a favourable proportion of (Na + Cl) : K as most plant products.

In food-plants or their component organs, ripe peas, lentils and spinach stand out above all other representatives by their high potassium contents and relatively low sodium and chlorine. Also our major food-stuff, the potato, has a favourable proportion, as well as most kinds of fruit.

In this it must be taken into account that - according to our recent experimental results - by attractive methods, cooking with plenty of water, by throwing away the water used in cooking, and by strong seasoning with cooking salt, an unfavourable partial displacement of the minerals mentioned can take place to the detriment of potassium. This emphasizes the great value of pressed vegetable- and fruit-juices for dietetic purposes. Furthermore and that will be proved later on fertilizing has a distinct influence on contents of potassium in food-plants. The same is true to Magnesium. Sufficient amounts of Mg in our food avoid heart troubles and circulation disorders (3).

Therefore, it seems necessary to me that criteria of the "Biological Value" of food-plants comprehensing nutritional and health keeping properties prevail in agricultural production over a "cosmetic like" review of quality as found in "standards" of fruit and vegetables. The same attitude is necessary toward one-sided measures to attain the highest yield ever possible (4).

This is not only a "presumption of fact" but a statement of high evidence. This may be proved not only by experimental results given later on but also by conclusions from analogy toward products of technique.

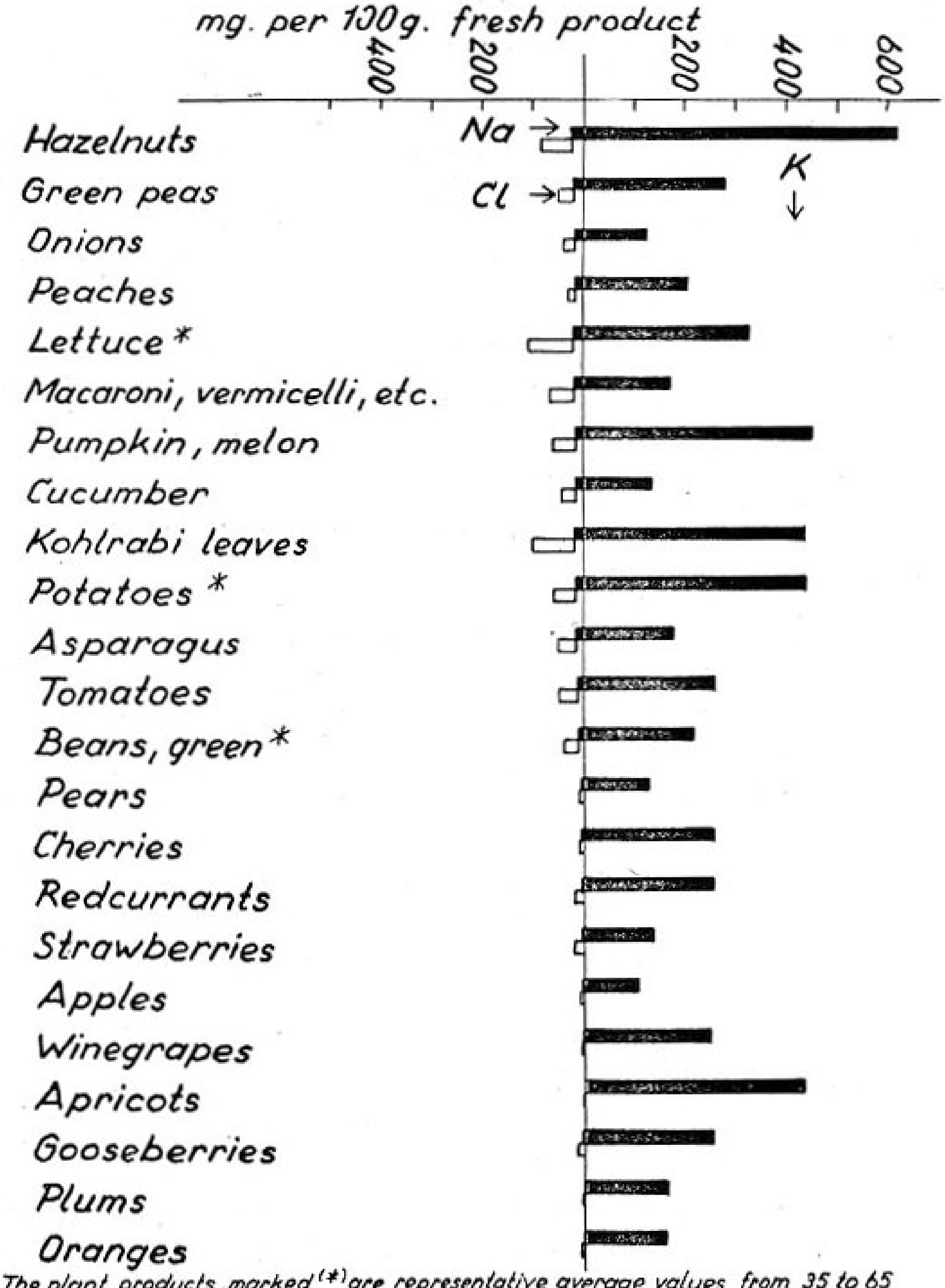
Two questions arise in this respect:

1. Is the attempt to establish an analogy between technical and agricultural products permissible?

2. Can criteria for quality in machines, motive fuels, and lubricating oils, e.g. power, useful life, productivity and capacity for resisting premature wear, logically be applied to food-plants serving men as bearer of energy and health keeping properties?

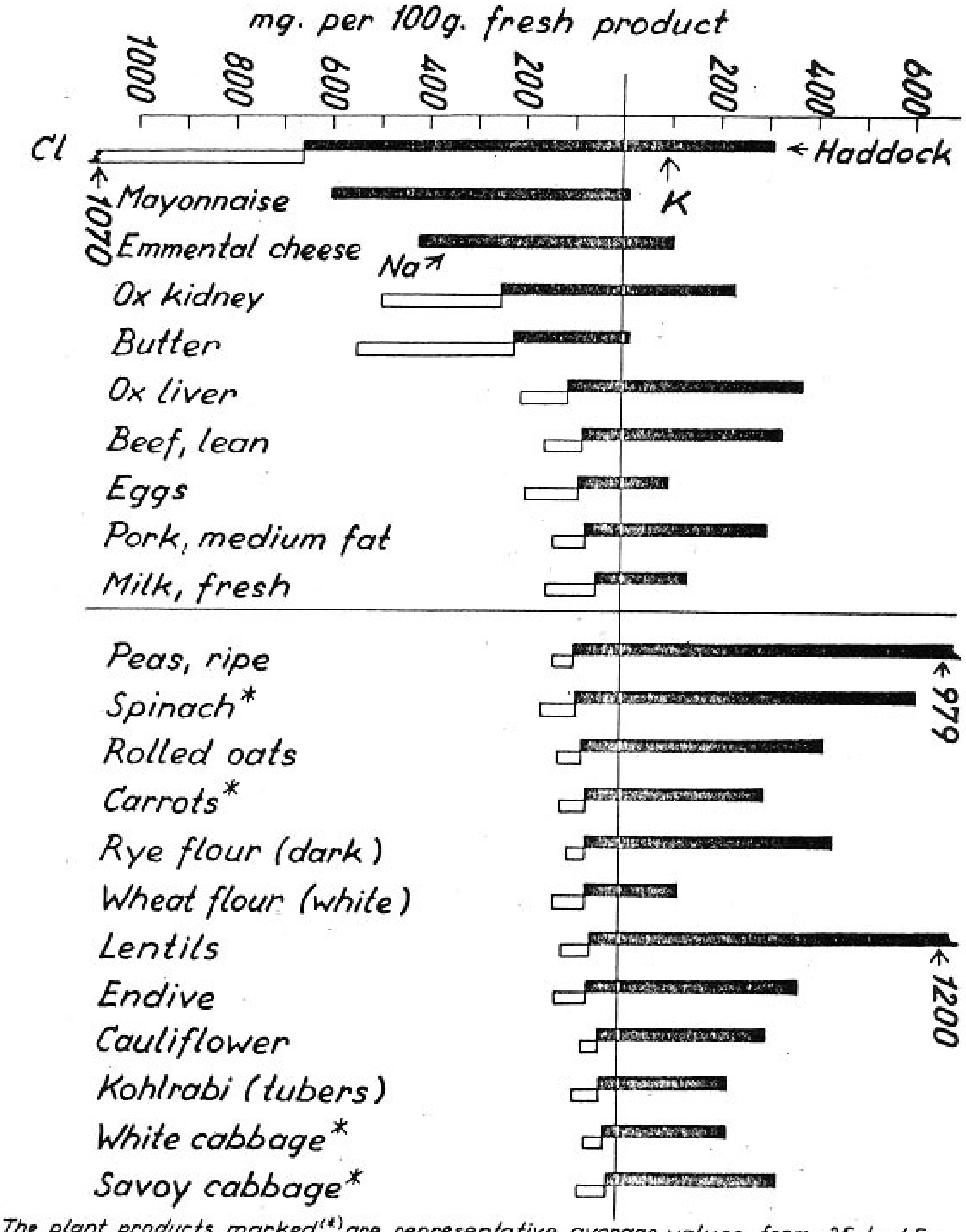
These questions must be answered in the affirmative if one takes as a basis the aforementioned claims of the consumer to nutritious foodstuffs unadulterated by foreign substances and assumes this to be generally applicable. This conclusion is cogent, since food for the human organism should ensure for the body a maximum and as long lasting as possible standard of efficiency without premature "wearing out", serving, in a sense, as preventive therapy.

Fig. 1 Contents of Na, Cl and K in products derived from plants



The plant products marked (*) are representative average values from 35 to 65 analyses (lettuce, green beans) or 129–206 (potatoes). The material was derived from long-term variety, locality and fertilizer experiments. The other analytical values are taken from KNIPPING and LOOSEN (cit. (1))

Fig 2 Contents of Na, Cl and K in products derived from animals



The plant products marked(*) are representative average values from 35 to 65 analyses (white cabbage, carrots) or 129-206 (savoys, spinach). The material was derived from long-term variety, locality and fertilizer experiments. The other analytical values are taken from KNIPPING and LOOSEN (cit. (1))

Therefore, the consumer's claim to "sound food" is the focal point and is fully justified. It is expected of the producer and of the trader that this requirement be satisfied.

It is well known that Maximum Yield has been since about one century utmost the only criterion for estimating fertilizer-trials. No further scope carried any important weight in agricultural chemistry.

Therefore, two questions arise for other scopes:

1. What umpire criteria for estimating Optimum Biological Value do exist?
2. What happens to the Biological Value of food-plants when the yield - forced by exceeding fertilizer supply - reaches its Maximum? Here again what is serving as umpire criteria to judge these results?

The first question can be answered as follows:

The term "Biological Value" embraces the nutritional value of a food-plant, its wholesomeness including flavour and its value for the maintenance of human health. As a complex term it cannot be defined with reference to the presence of a few chemical substances in the plant. It is only by nutritional experiments that it can be characterized sufficiently. To a certain extent it represents the sum of all chemical substances with a positive action which are present in the contents, whereas those with a negative action lower the level of the final quality assessment (1).

The majority of the chemical contents of a food-plant, or those of a plant part used as food, are present quantitatively in different orders of magnitude, represented roughly in the following expanding range: trace elements, essential oils, vitamins, mineral substances, sugar, fatty oils, protein and starch. These substances present in the contents are partly of an inorganic, partly of an organic nature; they exert a positive or negative action on the maintenance of human health and are neutral, synergic or antagonistic to one another.

In spite of this abundance of chemical substances which makes up the Biological Value, we can nevertheless pick out certain substances contained in the plant products which are present in such a high concentration that they decisively determine the Biological Value of their career. This can even be the role of one single substance - and certainly in a positive or negative direction; with other foodstuffs two or several of such determining substances may be present, e.g. in carrots β-carotene and sugar, in apples vitamin C and a favourable relation sugar/acid.

The second question is related to a complex which is rather difficult to disentangle. It can be answered in combination with trials (outdoors and indoors) with rising amounts of fertilizers.

Discussing the problem of manuring in general, F. Scheffer (5) took the following stand in 1960:

"At this point we have established that the best means of improving both yield and quality is a balanced manurial treatment". He added more precisely "a balanced optimum combined manurial treatment - organic and inorganic."

We agree with Scheffer's statement and can confirm it by our experimental experience since 1937.

In 1930 Scheunert and his co-workers (6, 7), in an experiment with six generations of rats lasting for twenty-eight months - there were in all over 1000 rats in each group - established the following:

Rats whose food was derived from plots treated with inorganic fertilizers, were more fertile and lived longer. Likewise they had the advantage over the control group in the number of their offspring, while growth and upbringing remained within the same bounds as were observed for rats whose food had received no inorganic fertilizer.

The solitary case of cancer that occurred during the course of the experiment was in a female rat of the first generation at the "grey old age" of 2 1/2 years and this can correspond to a human age of about 70 years (7). A genuine malignant tumour (sarcoma) was found on the kidney of this little female who belonged to the group "without inorganic fertilizer". According to the reports of the research worker the survivors of this group were not so healthy in other respects as the surviving animals of the group"with inorganic fertilizers", who showed a greater resistance to infectious diseases.

From the point of view of experimental technique some fundamental objection must be raised to this experiment. The products used for food in the control series came partly from unmanured, partly from biologically dynamic manured experiments "or were derived from experimental plots which likewise had not received fertilizers" (7). The quantities of cereals fed in both of the series to be compared did not show a locality in common with those from different fertilizer treatments. Cereals of the series "with fertilizers" came from a locality which differed from that of the cereals of the series "without fertilizers". Since information about the varieties as well as the statistical significance of the experiment are lacking, these experiments are of little scientific value.

Long-term fertilizer experiments with different kinds of vegetables which were carried out during the years 1936-44 at Grossbeeren near Berlin (Fig.3) and at Weihenstephan near Munich under exactly defined conditions (8, 9, 10) for the most part showed that with the combined treatment farmyard manure + NPK were obtained the highest yields, the best marketable crops, and in the biochemical evaluation, most higher protein, carotene, vitamin C and contents of minerals, but lower sugar contents, than with farmyard manure alone. In dietary studies carried out in connection with these experiments differences in the fertilizer treatments had no effect on the nutritional status and on the health of adults. In an experiment in infant nutrition the series "Farmyard manure + NPK, however, in three different experiments proved superior in comparison with farmyard manure alone, obviously as a result of the higher contents of vitamins and minerals of the products. This superiority refers to the average daily gain in weight, the contents of vitamin C and of carotene in the blood, to the teething, to the red blood picture and to the serum iron.

However, even these experiments, which were analysed statistically and were carried out under exactly defined conditions for several years, suffer from defects which can be seen in the brevity of the duration of the individual experiment.

These, as well as experiments with nitrogen and potassium described later, at present permit the following conclusion to be drawn:

1. The Biological Value of our fodder and food-plants is not impaired when the dressings of organic and inorganic manures are accurately adjusted to the physiological requirement of the plant, so that there is neither a deficiency of a nutrient nor overmanuring (e.g. with liquid manure or with nitrogenous manure).

2. With vegetables a combined treatment (organic basal + additional inorganic fertilizers) gives the best results. The yield, external appearance and Biological Value are then at an optimum.

3. In the field of plant nutrition the cry of "only natural" has no justification on a scientific basis.

These long-term fertilizer experiments in Germany during the years 1936-1944 were carried out in a balanced optimum combined manurial treatment - organic and inorganic. <u>F. Scheffer</u> (5) signified 1960 such a fertilizing experiment as ideal.

Fig. 3. Experiments with Vegetables (sixfold replicated), Grossbeeren/Berlin
O – Stable Manure – Stable Manure + NPK – NPK

What happens as far as the Biological Value of food-plants is concerned when experiments other than the aforementioned touch more the actual situation in agriculture: shortage in organic manure, relatively low contents of humus in the soil and high amounts of inorganic fertilizer supply to vegetables (4).

We have done quite a lot of work in this direction (4, p.11-15). Significant results with a great number of vegetables including potatoes will support our following statements given in close connection to the following experiments.

1. Nitrogen

None of the plant's major nutrients equals or even approximately resembles nitrogen in its physiological behaviour. N is necessary in the first place as an integrating constituent of the protein, essential for life, as well as the chlorophyl and the niacine of the Vitamin B-group.

A marked deficiency or an excess of an optimum N-dressing, which is specific for every genus or even for every cultivar of plants, give rise to physiological disturbances which exercise effects on the quality of food-plants, N-fertilizing is necessary for getting yields on a commercial scale, indispensable for sufficient food supply especially on behalf of the population of undeveloped countries, and essential for improving market quality and Biological Value.

This refers only to a normal supply of nitrogen. An excess of N given by the cultivator will increase yield to a maximum, but may induce simultaneously a lack in Market Quality and a loss of nutritional value.

According to a special investigation of mine in 1971 (4) a catalogue of detractions in MARKET QUALITY of food-plants may be set up. Shortage of time does not allow to go in any details:

EXCESS OF NITROGEN causes first of all quite a number of non-parasitic "diseases" as lessening the resistance against mechanical damage at harvest and during transport in potatoes, a reduction in favourable proportions of graded fruit and vegetables, losses of flavour and above all a decline in keeping during winter storage. Furthermore, too much nitrogen stimulates particularly certain diseases of plants as rust, downy mildew, septoria, and botrytis and insects as lice and mites (4).

This affords more application of pesticides. In consequence we may get more pesticide residues in and on food- and fodder-crops leading - besides the physiological decrease of important nutrients by the excess of nitrogen - to a further lowering of the Nutritional Value, due to toxic residues and their metabolites (4). The principal pathway as mentioned may be demonstrated by Fig. 4.

Nitrogen is consequently in the same way a promoter or detractor of quality! Excessive nitrogen supply also results in a decline of chemical constituents important to nutrition and health and on the other hand in an augmentation in biogenic toxicants to undesirable levels, as Nitrate/Nitrite in plants. Furthermore, too much nitrogen in manuring leads to a decrease in contents of methionine, the important, essential amino acid, and consequently of the Biological Value of protein (EAA-Index) as shown in Table 1. Undesired increases in contents of Free Amino Acids and of enzyme activity are also noteworthy.

Beyond that contents of dry matter, total sugar, Vitamin C, essential oils and - amongst the minerals - potassium, magnesium, and phosphoric acid are decreased by an excess of nitrogen supply.

In barley destined for brewing and in sugar beet high amounts of nitrogen are detrimental as regards technology. High amounts of nitrate in spinach may be potential health hazards to infants causing methemoglobinemia when nitrate is reduced to toxic nitrite.

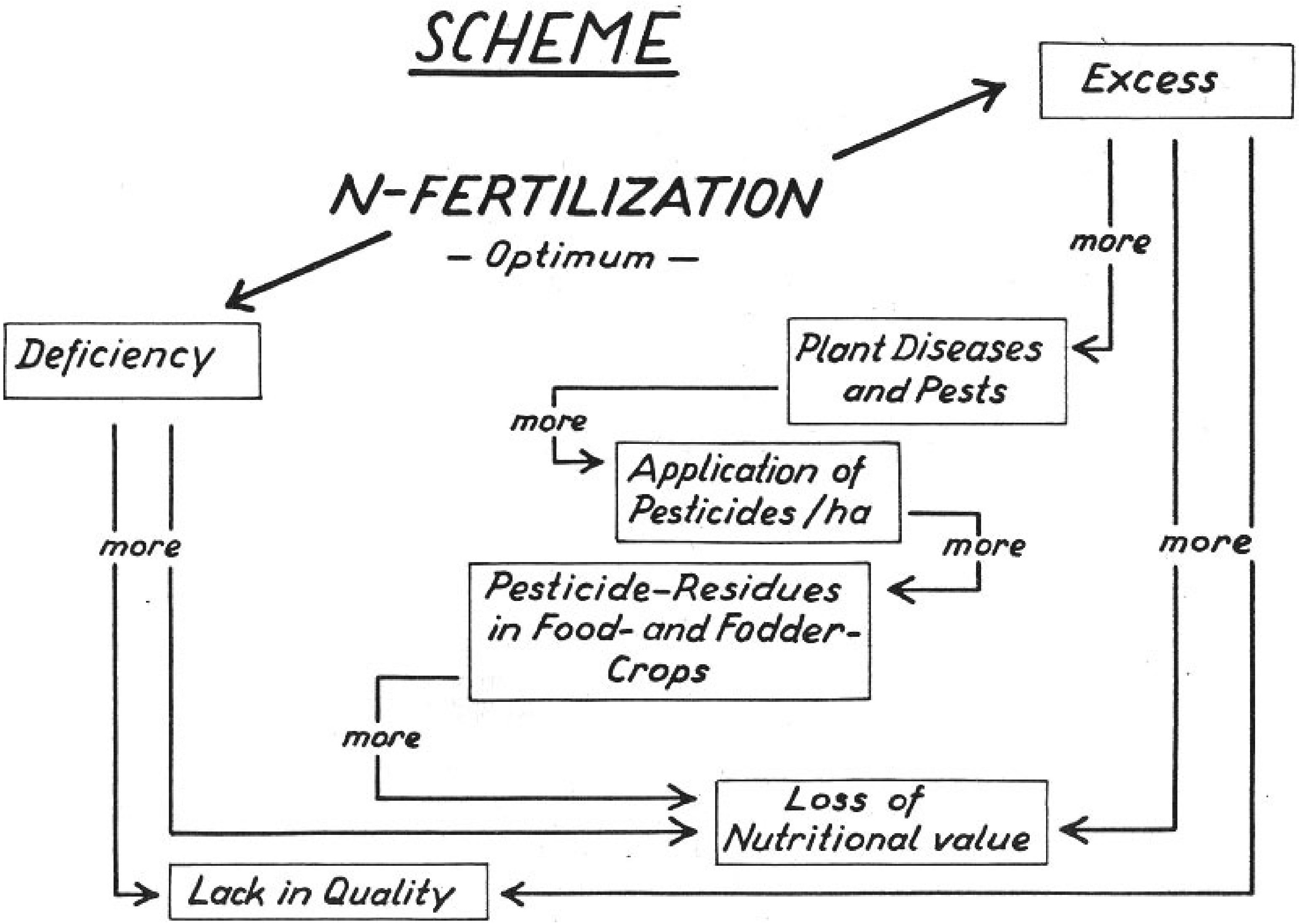


Figure 4

According to W. SCHUPHAN

N–Trial with SPINACH (Cultivar: „Matador")

(Plots 10 m², concrete frames, GEISENHEIM. Yield: 16.5.1960)

N-Supply	Methionine %		Significance		EAA–Index	
	Fr.(x)	Dr.(xx)	t	p	8 EAA	7 EAA (Methionin = 0)
N_0	0,017	0,24			72	47
			3,83	< 0,05		
N_1	0,019	0,30			71	47
			2,26	> 0,05		
N_2	0,018	0,33			71	47
			27,08	< 0,001		
N_3	0,007	0,13			60	45
			9,44	< 0,001		
N_4	0,003	0,06			54	44

(x) Basis: Fresh matter

(xx) " : Dry matter

Table 1

Now, let us see some results of experiments in order to elucidate the potential danger of an excess of nitrogen in fertilization. The results are mostly attained in long-term trials. Therefore they have a high significance.

In such experiments with potatoes (12, 16) we were able to show that excessively heavy applications of N up to 200 kg N/ha cause in fact high gains in yield and in crude protein but only a retarding gain in pure protein. In consequence - and that is by no means surprising - the culminating point of the curve showing the optimum of the Biological Value of protein equals only a N-supply as low as 50 kg N/ha. (See Fig. 4a)

Hunnius and co-workers (17) found in trials in Bavaria with different potato-cultivars during the years 1964-1969 that a N-supply of 120-130 kg N/ha attained an optimum result in yield on most of the sites. A decrease of the "intrinsic" quality could not be observed within this range.

On the other hand Norwegian potato trials with 3 cultivars carried out in 1963-1968 by R. Enge and R. Baerug (18) on 4 levels of nitrogen 50, 100, 150 and 200 kg/ha gave the following results:

1. Nitrogen fertilizer increased the enzymatic greying of pre-peeled potatoes and the discolouration after cooking.

2. The flavour (taste) of the cooked potatoes was affected by nitrogen fertilizer: The higher the amount of fertilizer the lower the flavour (taste) score.

3. The influence of nitrogen on the texture of cooked potatoes was negative except for sloughing where the effect was positive.

4. The protein content was strongly affected by nitrogen fertilizer. The increase in crude protein was substantial (about 40 percent in series C) when the nitrogen application was increased from 50 to 200 kg of N per ha.

Pastures normally receive heavy dressings with N-fertilizer. C. Lee and co-workers (19) recently found that grass which was grown in N-fertilizer experiments caused goiter in rats when amounts of 450 kg N/ha had been applied to the grassland plots. "It was suggested that nitrate is partly, but not entirely responsible for the changes associated with intensive nitrogen fertilization."

Interdependence between the herbicide 2,4-D and N-fertilizers in crops has been also observed. Presence of 2,4-D caused - equal to high N-fertilization - significantly higher contents of nitrate in plants compared with the control. (20).

Fig. 5 elucidates the results of an experiment in pots with increasing amounts of nitrogen. This experiment with corn-salad (Valerianella olitoria L.) was carried out in a phytotrone. It shows in its analytical findings correlations between yield, dry matter, crude protein, free amino acids, and the Biological Value of protein calculated as EAA-Index according to B.L. Oser (12). It can be taken from the graph that yield, contents of crude protein and free amino acids (not very useful from a nutritional point of view) are simultaneously rising with mounting supply of nitrogen in fertilization. But protein quality (EAA-Index) already reached its optimum with only 0.2 g N/pot. It is also well known that N-fertilizing gives rise to a decrease in dry matter. This is true in a range between 0.1 and 0.4 g N/pot.

In German viniculture as well as in European growing centers of outdoor and indoor crops of vegetables the application of nitrogen has been considerably increased since about 20 years (Fig. 6). This gave rise to a more or less severe pollution of groundwater with nitrates, to high contents of nitrate in food- and fodder-plants and to hazards in human health unknown before as it may be shown in a scheme (Fig. 7). Some years ago up to 150 mg of nitrate/l and even more was found in the groundwater of the slopes and plains surrounding the two

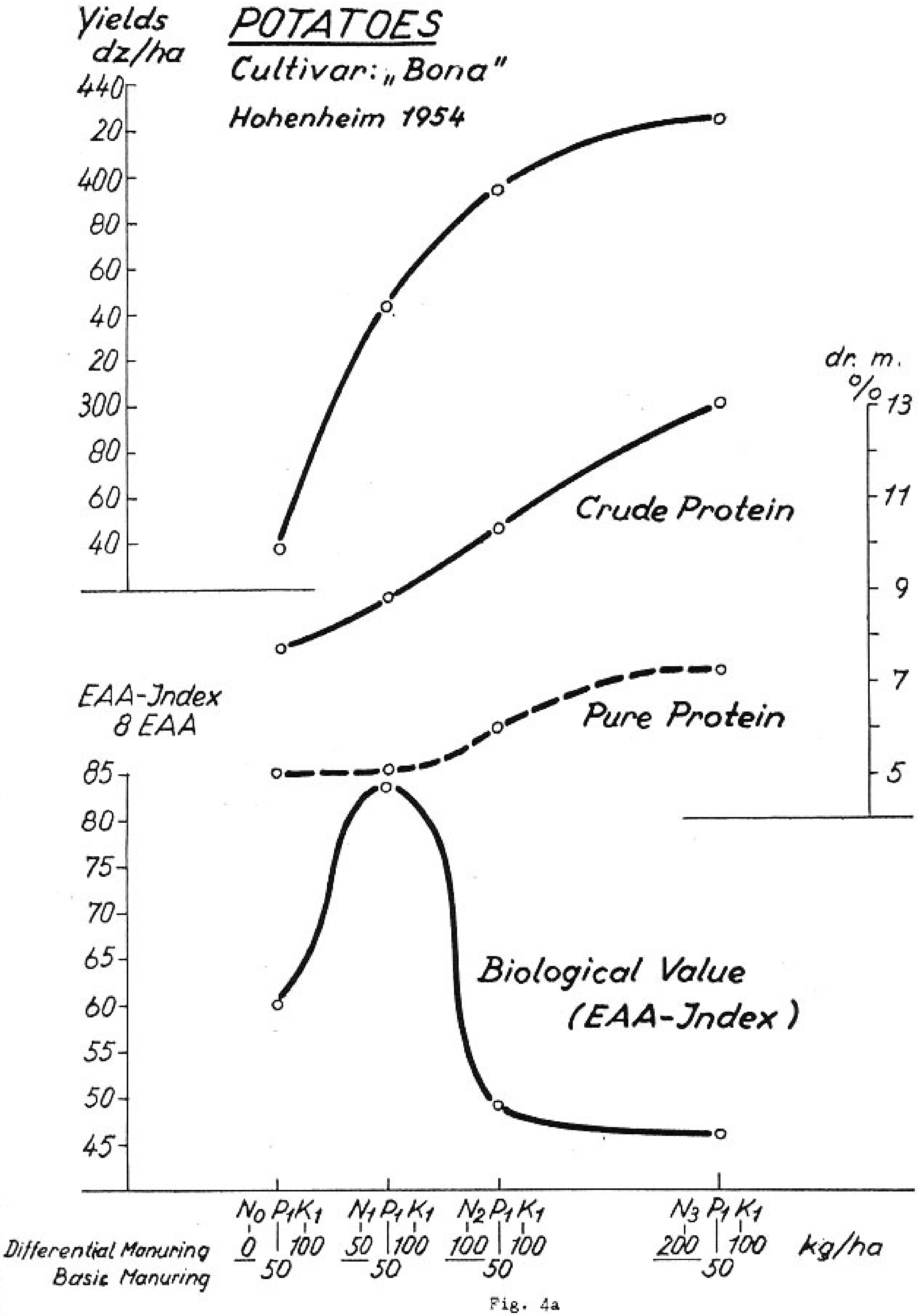
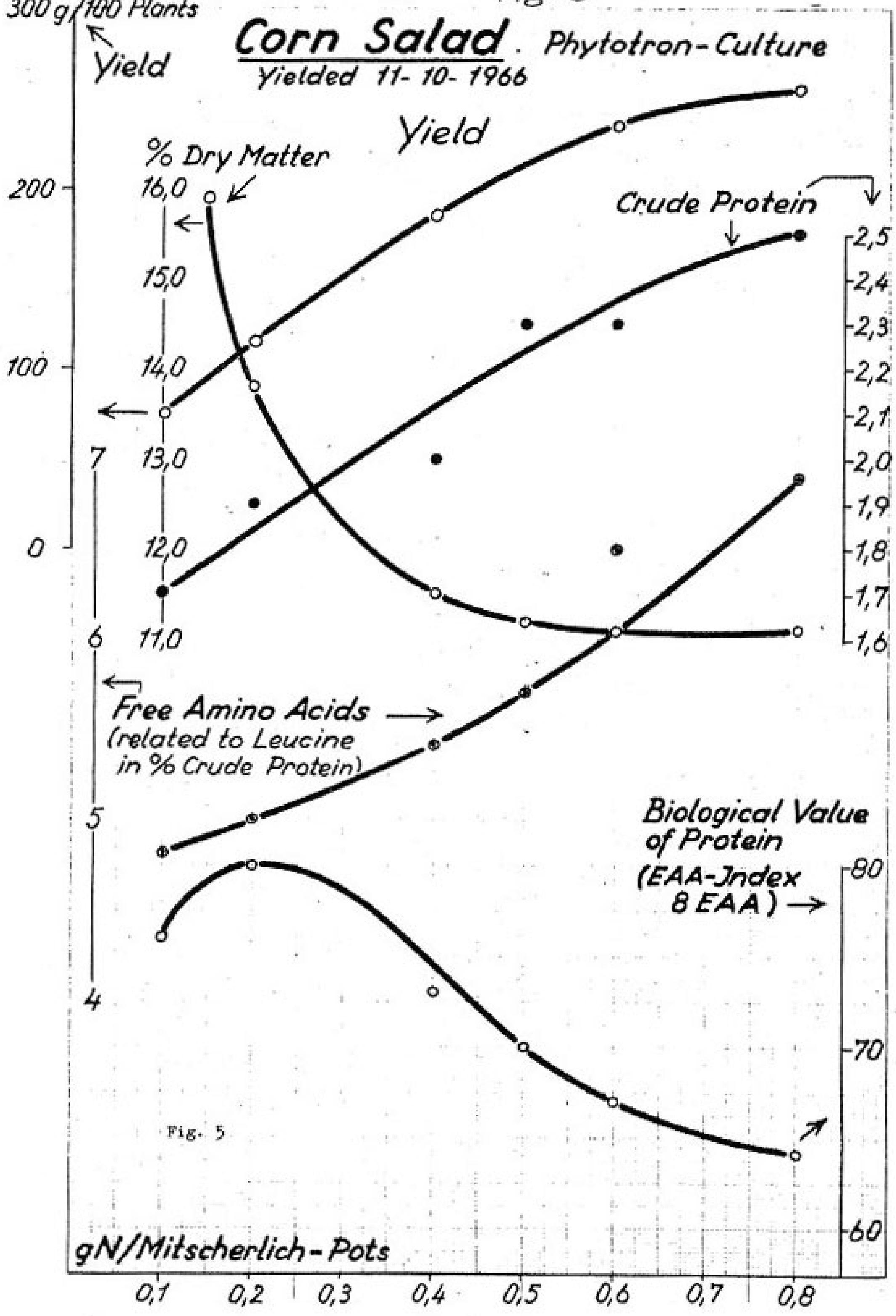

POTATOES
Cultivar: „Bona"
Hohenheim 1954
Yields dz/ha
440
20
400
80
60
40
20
300
80
60
40
dr. m. %
13
11
9
7
5
Crude Protein
Pure Protein
EAA-Index 8 EAA
85
80
75
70
65
60
55
50
45
Biological Value (EAA-Index)
N0 P1 K1
N1 P1 K1
N2 P1 K1
N3 P1 K1
Differential Manuring
Basic Manuring
0 100 50
50 100 50
100 100 50
200 100 50
kg/ha

Fig. 4a

Fig. 5


Corn Salad. Phytotron-Culture
Yielded 11-10-1966
300 g/100 Plants
Yield
200
100
0
Yield
% Dry Matter
16,0
15,0
14,0
13,0
12,0
11,0
Crude Protein
2,5
2,4
2,3
2,2
2,1
2,0
1,9
1,8
1,7
1,6
7
6
5
4
Free Amino Acids
(related to Leucine
in % Crude Protein)
Biological Value
of Protein
(EAA-Jndex
8 EAA)
80
70
60
Fig. 5
gN/Mitscherlich-Pots
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8

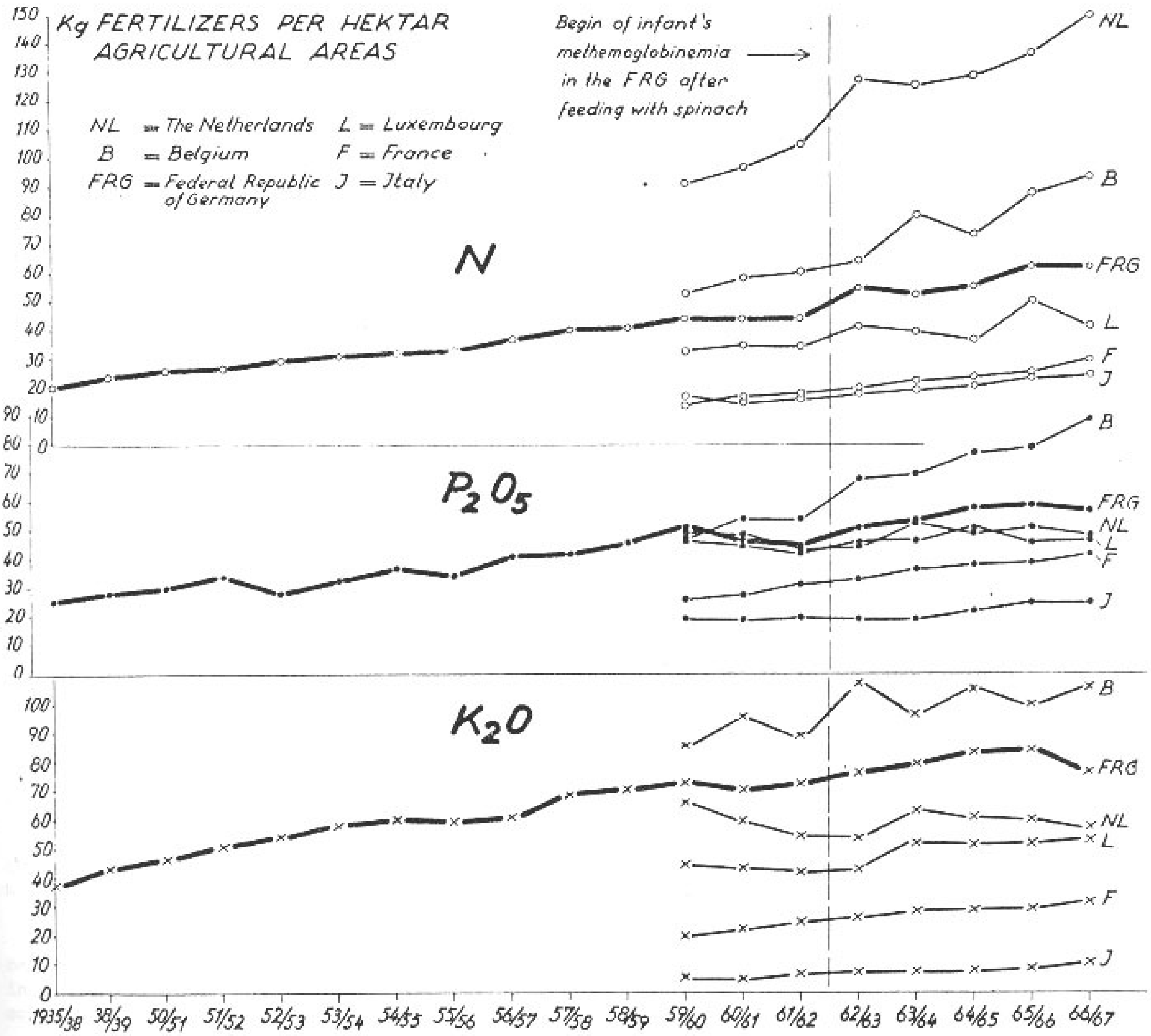

Kg FERTILIZERS PER HEKTAR AGRICULTURAL AREAS
NL = The Netherlands
B = Belgium
FRG = Federal Republic of Germany
L = Luxembourg
F = France
J = Jtaly
Begin of infant's methemoglobinemia in the FRG after feeding with spinach
N
P_2O_5
K_2O
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
90
80
70
60
50
40
30
20
10
0
100
90
80
70
60
50
40
30
20
10
0
NL
B
FRG
L
F
J
B
FRG
NL
L
F
J
B
FRG
NL
L
F
J
1935/38
38/39
50/51
51/52
52/53
53/54
54/55
55/56
56/57
57/58
58/59
59/60
60/61
61/62
62/63
63/64
64/65
65/66
66/67

Fig. 6

Circulation of Nitrogen in Nature and Potential Hazards occuring with a non-qualified N-Fertilization.

(According to W.SCHUPHAN)

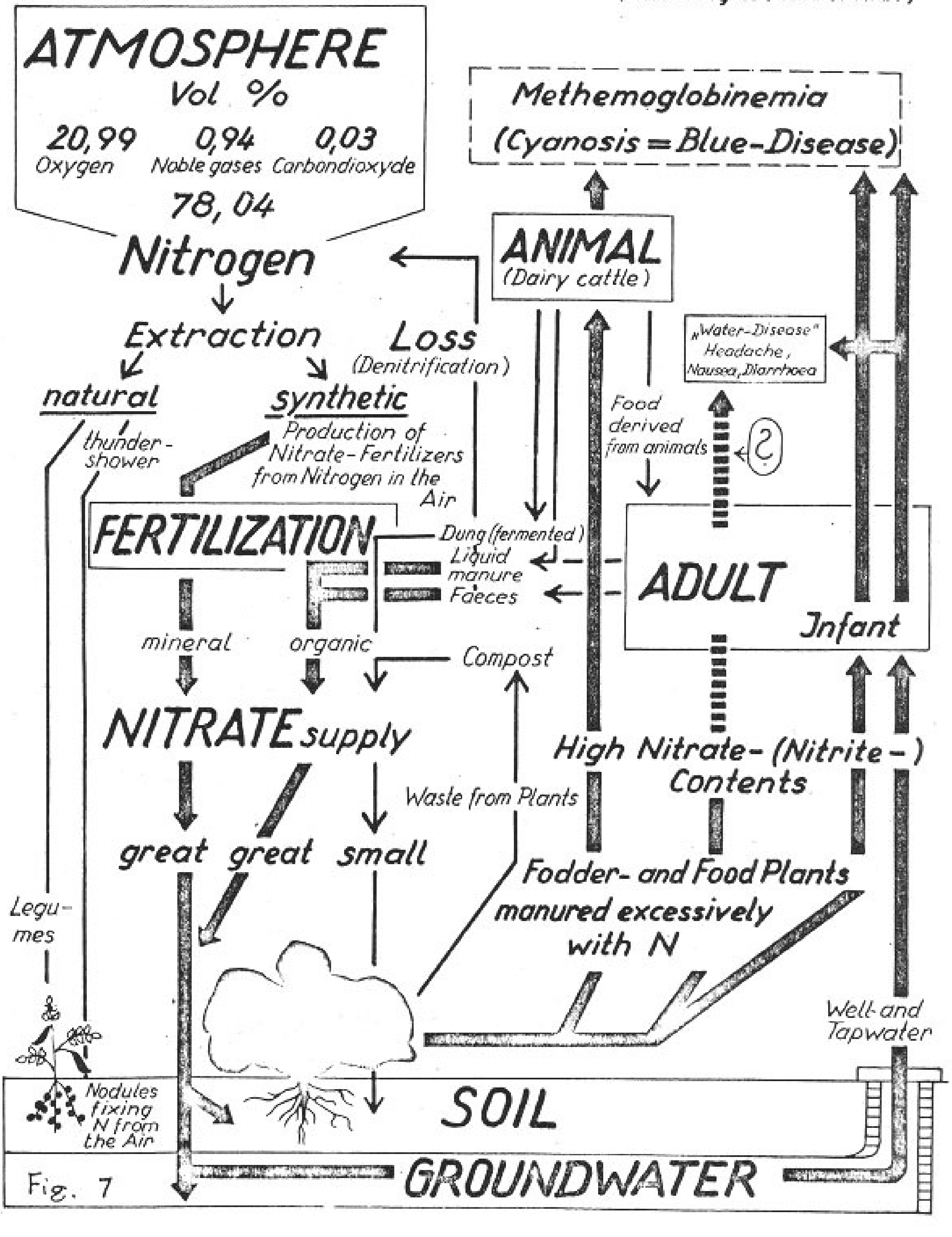


Fig. 7

German streams "Rhein" and "Mosel". This water, polluted by nitrates derived from N-fertilization of crops, must be used as drinking water, mixed with somewhat less or not contaminated groundwater of other sites.

Presence of high contents of nitrates in plants as a result of excessive amounts of N-fertilizers may be dangerous to human health. Plants such as spinach preferentially used in Germany for feeding infants, caused severe hazards to children's health in 1959, 1961, 1963 and 1964. A number of infants in Hamburg, Kiel and Berlin suffered from circulation troubles and methemoglobinemia after being fed with spinach containing high amounts of nitrate. Nitrate can be converted to highly toxic nitrite by the aid of bacteria or by enzymatic conversions during long transports. The same conversion can eventually take place in storage of spinach before cooking or processing respectively, as a result of keeping cooked spinach under room temperature.

As demonstrated in Fig. 8 we found in seven years' trials with increasing amounts of nitrogen to spinach correspondingly high yields simultaneously accompanied by rising contents of nitrate. In German textbooks of vegetables (21, 22) it is pointed out that an amount of 80-100 kg N/ha will be a normal supply to the spinach plant. In this range the contents of nitrate are found still tolerable. Some years ago, much higher contents were found in spinach production of a German deep-freezing industry using very high amounts of N. This industry grew a new high yielding spinach cultivar of a steep growth-type suitable for mechanical harvesting. The N-supply exceeded in this case even 300 kg N/ha. It may be taken from the graph (Fig. 8) that this procedure will consequently lead to very high contents of nitrate in spinach detrimental to infants.

It has been recommended (23) to treat such a spinach, which had been given very high amounts of Nitrogen, in a special way. Water-soluble nitrate should be removed from spinach by exceeded blanching. Losses of water-soluble compounds of nutritive value including vitamins and minerals, e.g. potassium and magnesium would be undesired consequences as seen in Fig. 9.

It could be taken from Fig. 8 that each of our experiments with spinach received from 1960 to 1963 each year one of the following amounts of nitrogen: 0, 60, 120, 180 and 240 kg/ha. In 1964 the experiments were changed to the following levels of N: 0, 80 kg/ha (normal nitrogen level recommended for spinach in vegetable textbooks), 160, 240 and 320 kg/ha. These comparable findings on the same site were obtained over a period of seven years, producing significant results.

According to Fig. 10, increased amounts of N-fertilizers had a negative influence on the sugar and ascorbic acid contents of spinach in both test groups. On the other hand the mean measure of the carotene contents hardly changed.

It may be taken from Fig. 11 that minerals react in a peculiar manner in spinach. The cation potassium occurring in spinach in relatively large amounts decreases strongly when influenced by higher amounts of supplied nitrogen. This is in contrast to Na, which increases considerably with increased nitrogen fertilization.

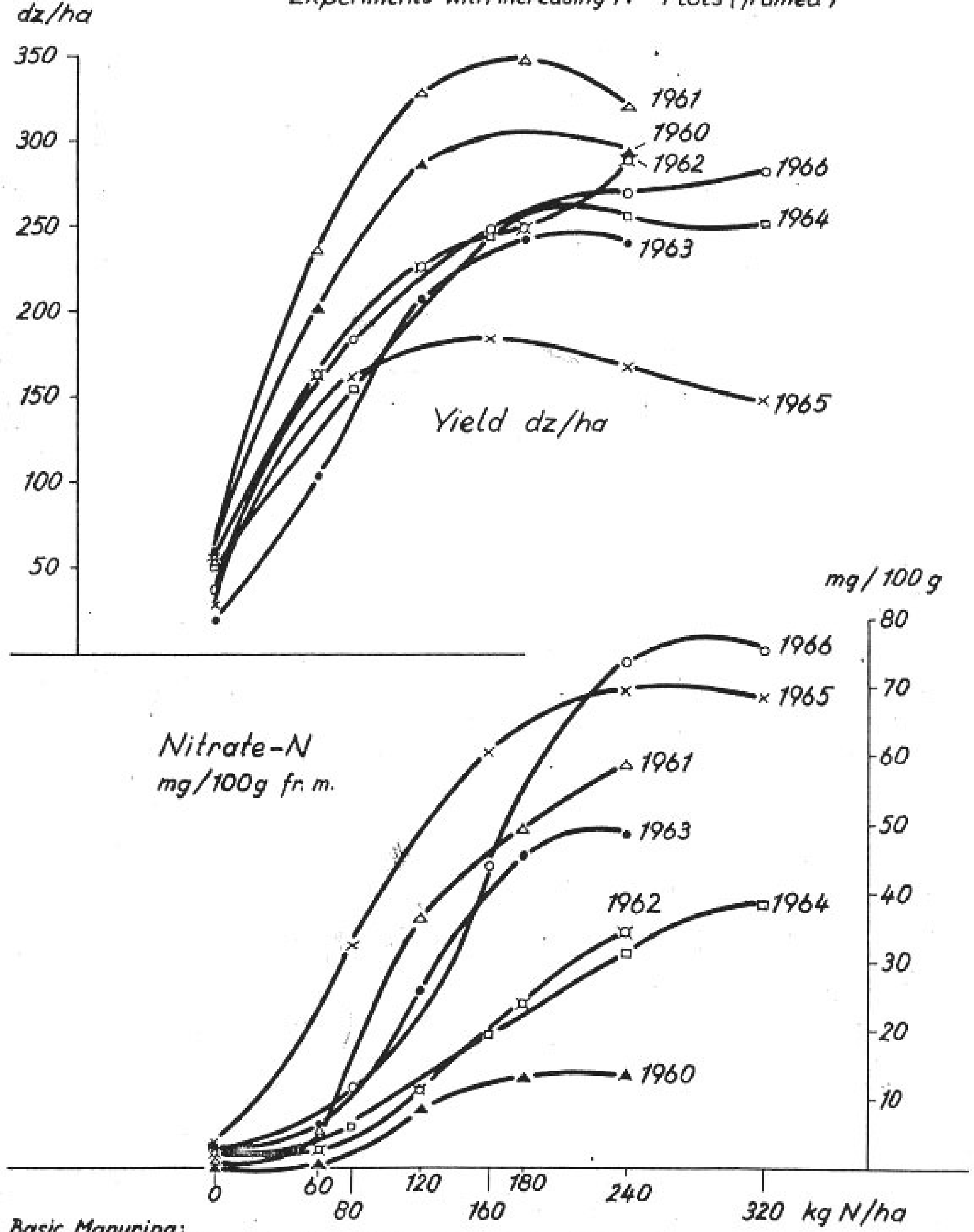
Experiments with spinach in 1966 on the same plots, now in partial shade, led to the following results (Fig. 12): Shading was remarkably associated with a loss in yield and a decline in content of total sugar but with a steep rise of nitrate. It has not been taken into the graph that ascorbic acid and all minerals were diminished by partial shading, too.

2. Potassium

In further experiments with increasing amounts of K-fertilizers to spinach on both muck- and sandy soils we found rather a peculiar result: although we gave in our 8 trials potash-magnesia sulphate as K-source, contents of magnesium decreased considerably as seen in Fig. 13. The depletion of Mg towards the control (K_o) was K_1 -20%, in K_2 -29% and in K_3 even -35%. As expected contents of potassium rise with increased K-supply (Fig. 14).

SPINACH (Early)

Experiments with increasing N – Plots (framed)



Basic Manuring:
P_2O_5: 1960, 1961, 1964–66 = 120 kg/ha K_2O = 200 kg/ha
1962, 1963 = 60 kg/ha

Fig. 8

SPINACH (Cultivar „Früremona"). LOSSES of valuable constituents in BLANCHING in reference to intensity of N-SUPPLY.

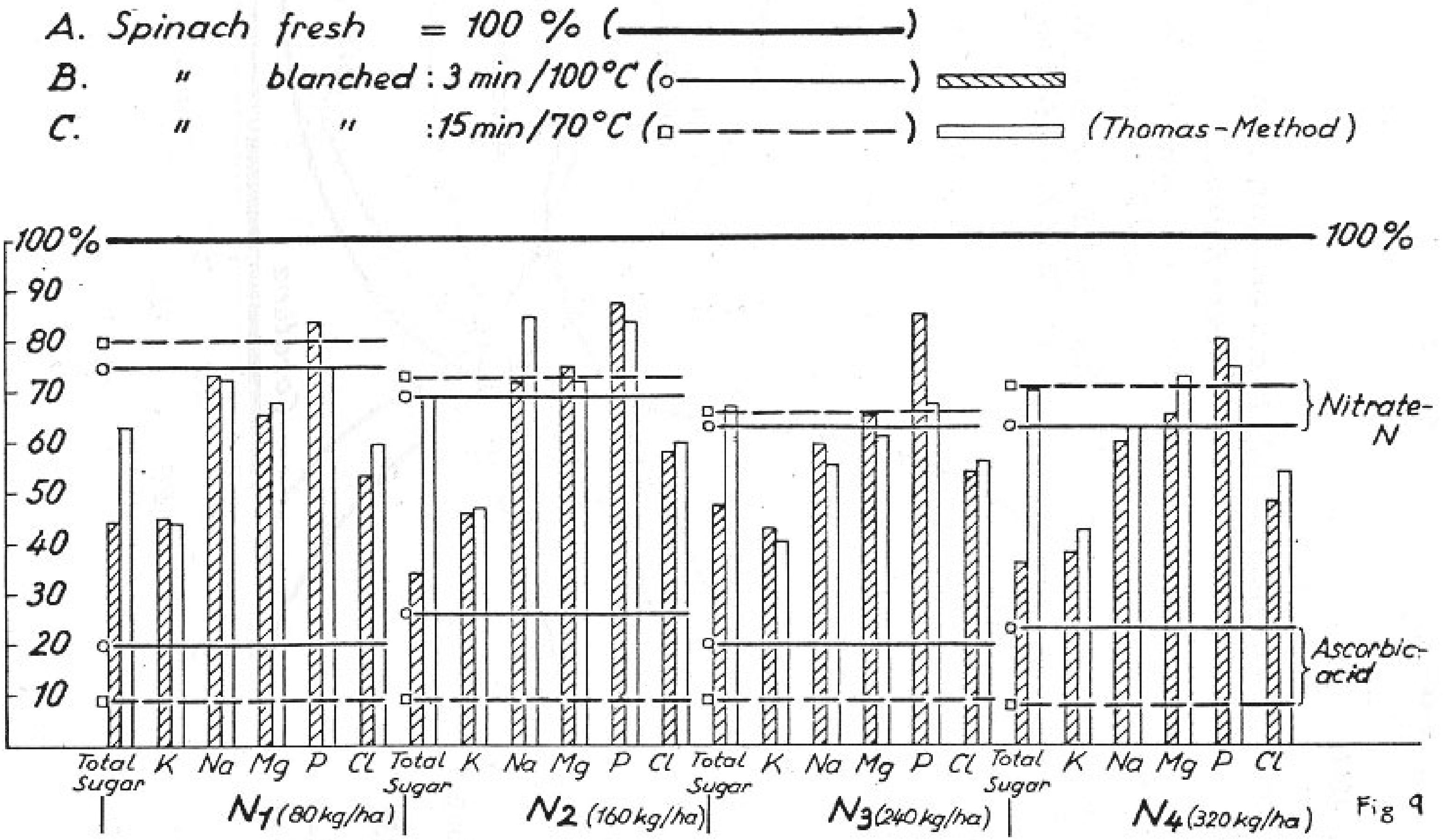


Fig 9

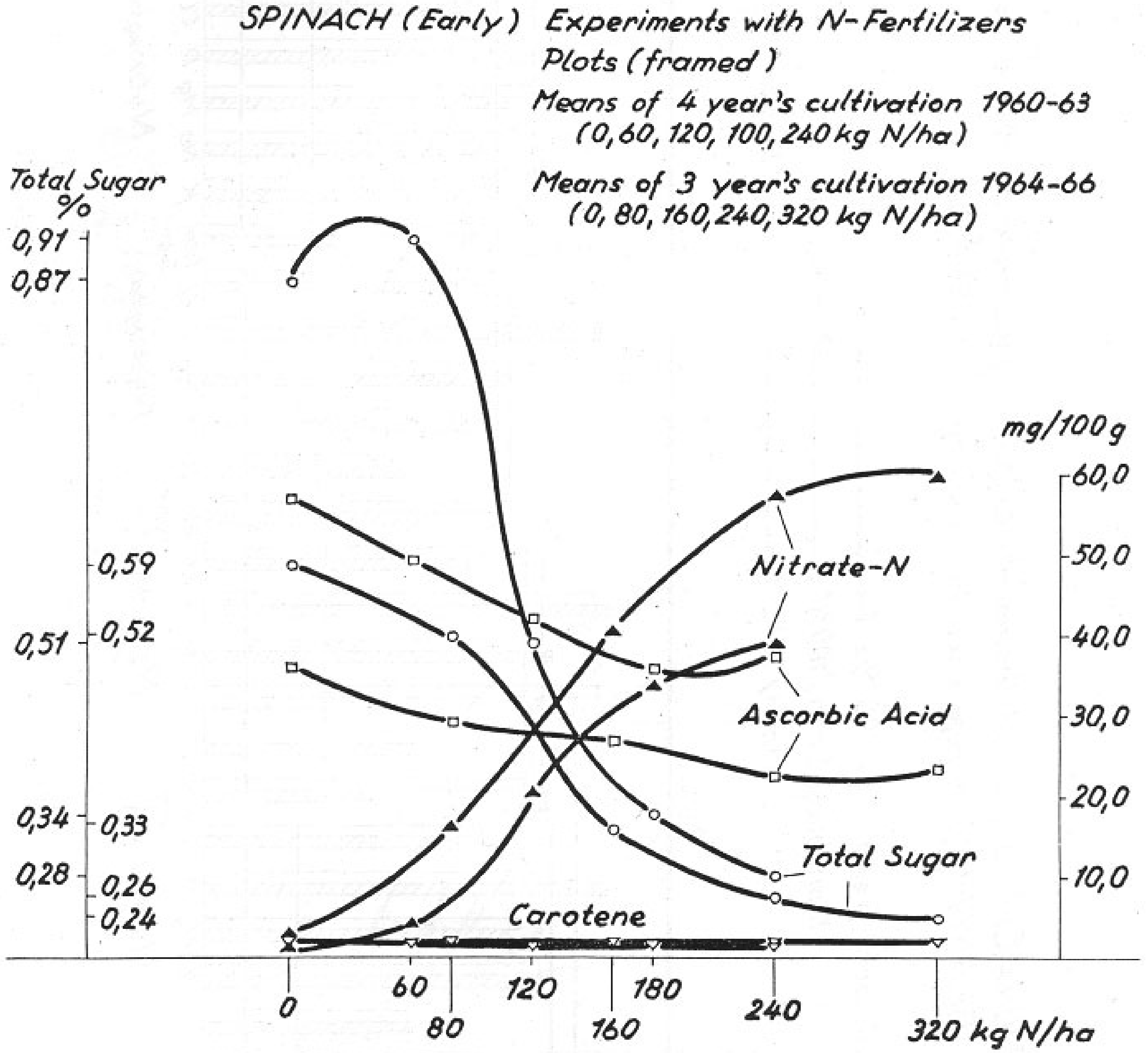
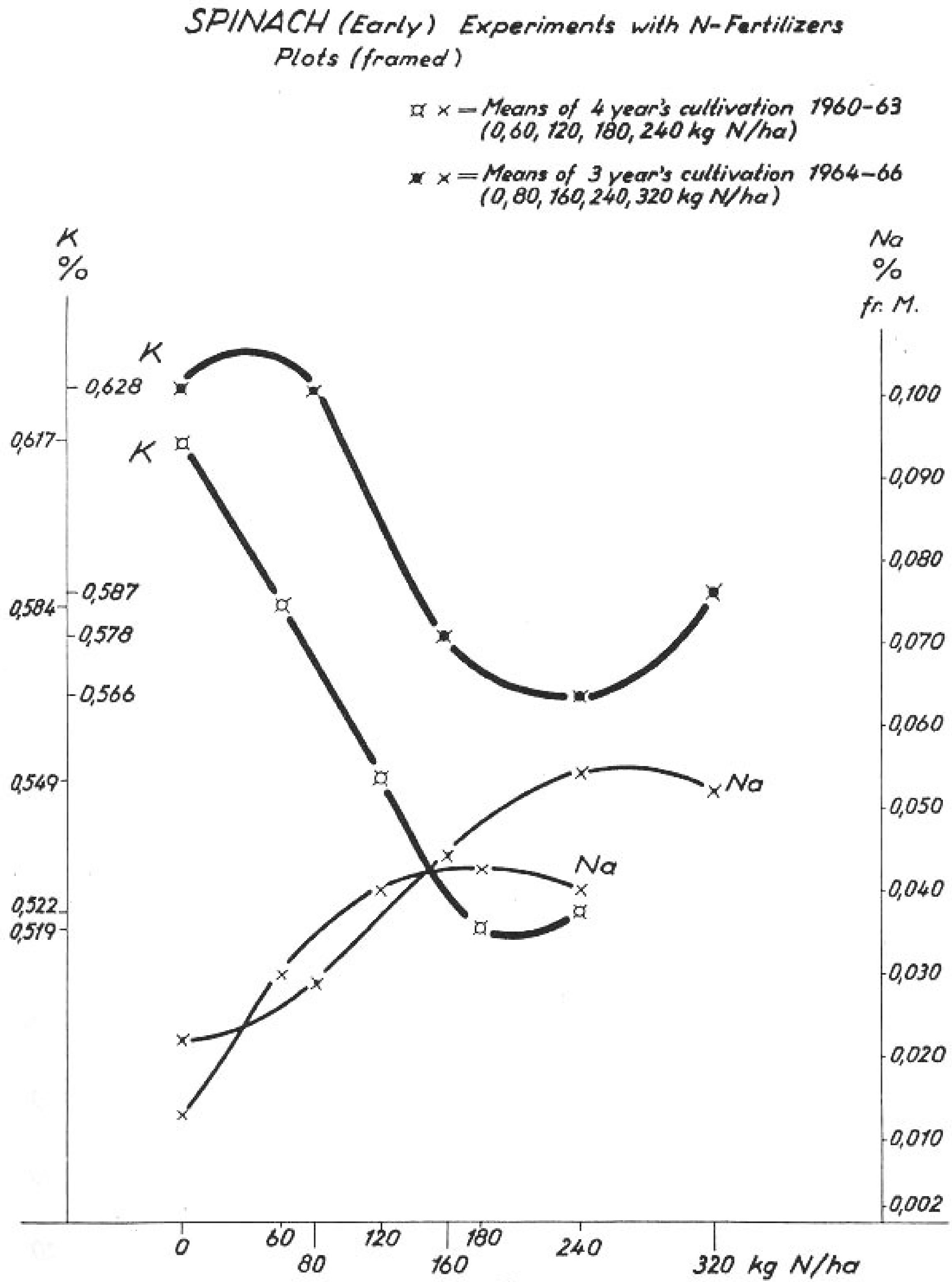

SPINACH (Early) Experiments with N-Fertilizers
Plots (framed)
Means of 4 year's cultivation 1960-63
(0, 60, 120, 100, 240 kg N/ha)
Means of 3 year's cultivation 1964-66
(0, 80, 160, 240, 320 kg N/ha)
Total Sugar %
0,91
0,87
0,59
0,51
0,52
0,34
0,33
0,28
0,26
0,24
mg/100 g
60,0
50,0
40,0
30,0
20,0
10,0
Nitrate-N
Ascorbic Acid
Total Sugar
Carotene
0
60
80
120
160
180
240
320 kg N/ha

Fig. 10



SPINACH (Early) Experiments with N-Fertilizers
Plots (framed)

Fig 11

Fig. 12

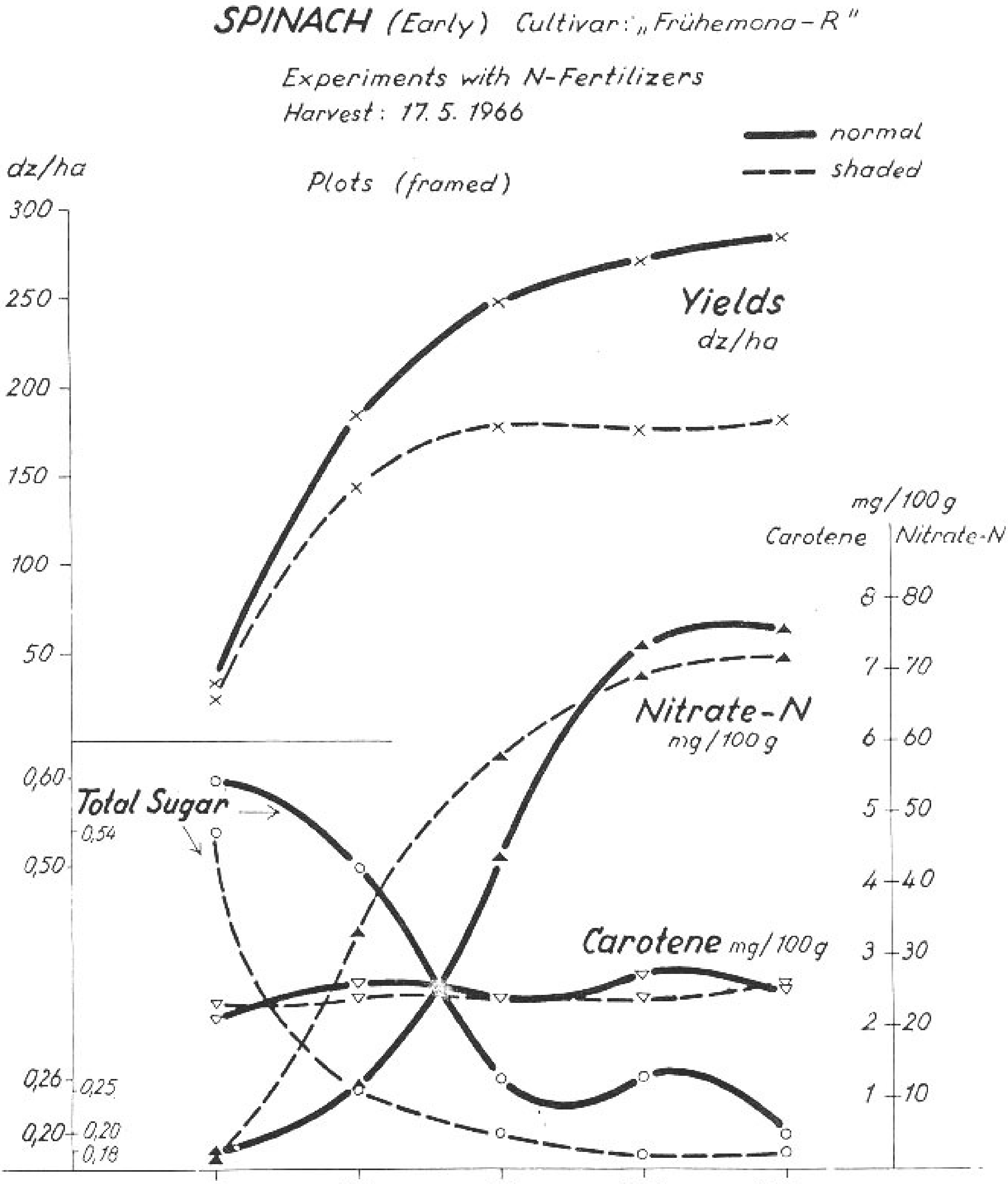

SPINACH (Early) Cultivar: „Frühemona – R"
Experiments with N-Fertilizers
Harvest: 17. 5. 1966
normal
shaded
dz/ha
Plots (framed)
300
250
200
150
100
50
Yields
dz/ha
mg/100 g
Carotene
Nitrate-N
8 80
7 70
6 60
5 50
4 40
3 30
2 20
1 10
Nitrate-N
mg/100 g
0,60
0,50
0,26
0,20
0,54
0,25
0,20
0,18
Total Sugar
Carotene mg/100g
0
80
160
240
320
Fertilization
kg N/ha

Fig. 13

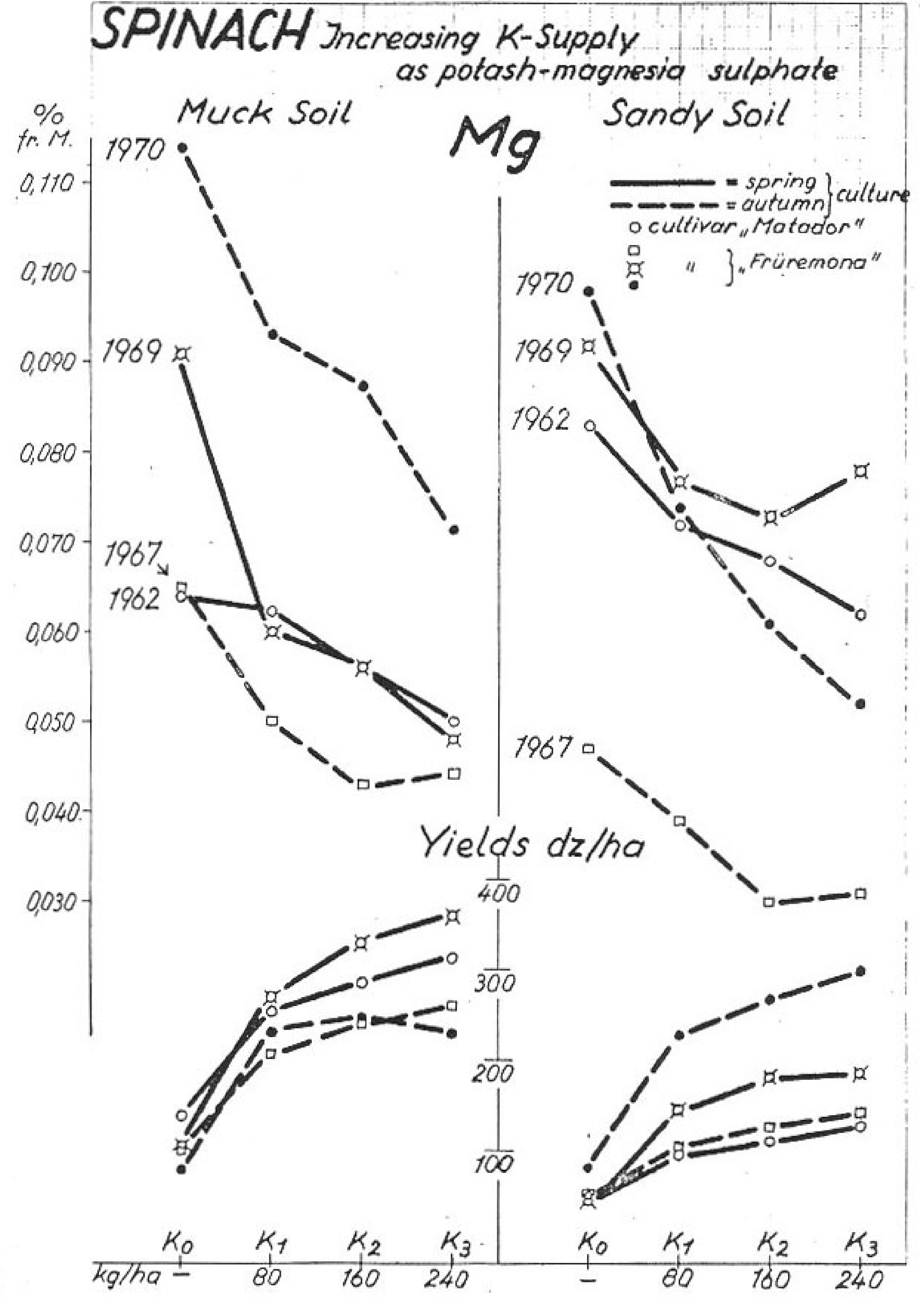
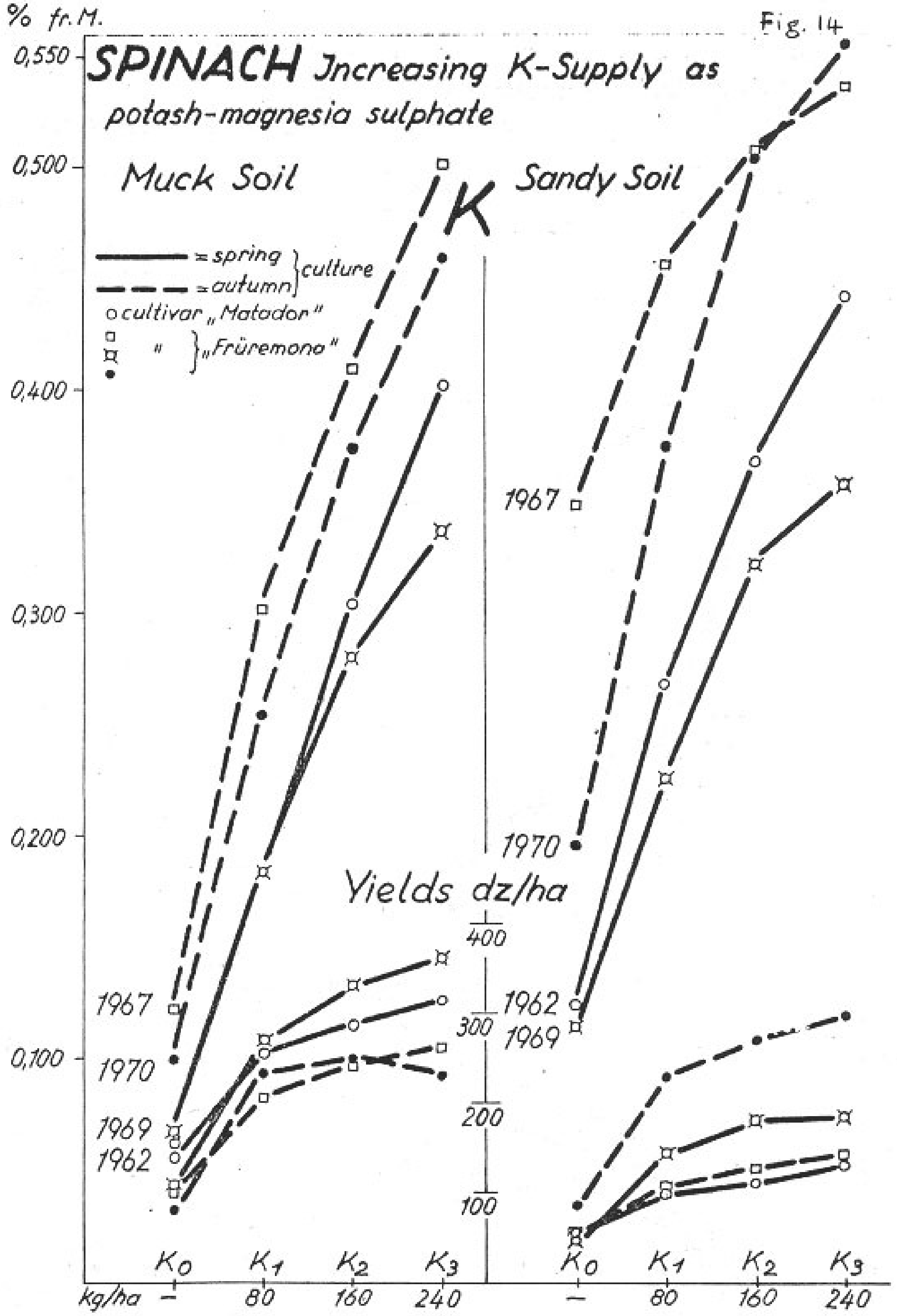

SPINACH Increasing K-Supply as potash-magnesia sulphate
Muck Soil
Sandy Soil
Mg
% fr. M.
0,110
0,100
0,090
0,080
0,070
0,060
0,050
0,040
0,030
1970
1969
1967
1962
1970
1969
1962
1967
= spring
= autumn
culture
o cultivar „Matador"
□ ¤ ● " „Früremona"
Yields dz/ha
400
300
200
100
K0 K1 K2 K3
K0 K1 K2 K3
kg/ha — 80 160 240
— 80 160 240

Fig. 14


% fr.M.
SPINACH Jncreasing K-Supply as
potash-magnesia sulphate
Muck Soil
Sandy Soil
K
= spring
= autumn
culture
○ cultivar „Matador"
□
¤ " „Früremona"
●
0,550
0,500
0,400
0,300
0,200
0,100
1967
1970
1969
1962
1967
1970
1962
1969
Yields dz/ha
400
300
200
100
K0
K1
K2
K3
kg/ha
–
80
160
240
K0
K1
K2
K3
–
80
160
240

Discussion

These results of a detrimental influence of high fertilizer dressing to important nutrients of food-plants have to be seen in connection with corresponding increases of biogenic toxicants as well as with losses of valuable minerals as K and Mg in modern methods of processing of vegetables as demonstrated in Fig. 9.

It has also to bear in mind the dangerous two-edged role of nitrogen given in excess upon production of maximum yield simultaneously promoting pests and diseases and in consequence toxic pesticide residues from increased plant treatment with pesticides.

The question arises if losses of important nutrients, chiefly of minerals in food-plants may already influence men's health whose living conditions, whose customs of eating have considerably been changed with growing prosperity since about 20 years. Should that be partly the origin of a growing increase of "diseases of civilization" as circulation and heart troubles? Nowadays we know that a sufficient oral supply of minerals such as K and Mg play an outstanding role in the physiology and pathology of the so-called "diseases of civilization" (3).

Are we able to decide those questions by our experiments on food-plants. Certainly not. In order to prove this long-term trials on men would be necessary. But we can answer these questions to a certain extent in the affirmative. Meneely's experiments (1) with 945 rats gave already a convincing evidence of how sufficient supply of K is able to balance the relation of K to Ma, onesidedly influenced by NaCl in all our meals, will save health and longevity - at least of rats.

Another aspect, important to production of food in general, seems to me noteworthy. As a high fertilizer supply of N and K to food-plants in order to gain maximum yield is somewhat suspect as regards Market Quality and Biological Value of products we may call for an adequate reduction in yield at least in all our vegetables including potatoes. Certainly this claim would enrage the agricultural economists. But on the other hand an entirely senseless overproduction in the Common Market, sanctioned by economists, would enrage another group. Experts of nutrition and men with common sense as tax-payers cannot understand that over-produced commodities are destroyed to their expense.

I believe that my slogan created in 1961 when the German edition of my book "Zur Qualität der Nahrungspflanzen" was published is actually more justified than ever:

> "Acceptable appearance is demanded today,
> High nutritive value tomorrow."

NO_3-N IN DIFFERENT FOOD-STUFFS *

A survey of the content of nitrate in different kinds of Swedish food-stuffs has been undertaken during December 1971. Only vegetative food-stuffs were investigated. The material consisted of fresh, frozen and canned vegetables. The data are given in the table below.

Kind of material etc	No of samples	NO_3-N, ppm of fresh weight
Cereals	3	0
Maize frozen	1	13
Tomato	2	13
Cauliflower	2	14
Potato	1	15
Sweet pepper	5	16
Borecole (not fertilized)	2	17
Cabbage	3	17
Mushroom (not fertilized)	3	17
Green pea frozen	4	19
Cucumber	2	24
Red Cabbage	3	24
Brussels sprouts frozen	4	27
Applepurée (baby food)	3	28
Mixed vegetables -"-	4	35
Carrotpureé -"-	3	37
French bean frozen	3	59
Carrotdrink (baby-food)	5	60
Broccoli frozen	3	(55-100) 78
Borecole	2	103
Isberg lettuce	7	(78-115) 104
Spinach with ham (baby-food)	4	107
Spinach frozen	16	(146-541) 313
Dill frozen	2	490
Lettuce	16	(109-1222) 554

Most of the listed vegetables are grown in Sweden except the Isberg-lettuce, which is imported from Italy, Spain or USA, and ordinary lettuce which is imported from Holland.

The big variation of the NO_3-N content in spinach is clearly related to different canning factories.

Factory A	7 samples	181 ppm mean	(146-228)
-"- B	6 -"-	469 -"-	(364-541)
-"- C	3 -"-	310 -"-	(295-324)

The content of NO_3-N may vary considerably for different parts of a plant. The following example can be given.

Lettuce, innermost	leaves	190 ppm
-"- , intermediate	-"-	350 -"-
-"- , outer	-"-	1050 -"-

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* Compiled by Johan Bergholm, Agricultural College of Sweden, Uppsala.

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RESEARCH ON THE EFFECT OF INTENSIVE FERTILIZER USE ON HUMAN ENVIRONMENT IN BULGARIA

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N. Poushkarov Institute of Soil Science, SOFIA

In the course of the last 10 years, agriculture in Bulgaria has made a marked progress as regards intensification of production. Fertilizer use proved to be one of the most important factors of intensification of production. The average amount of NPK active substances is at present 180-200kg per ha, i.e. 150-180 kg per ha for cereals and 250-350kg per ha for cash crops, fruit-trees and vegetables. In accordance with the plans for further development of intensive farming (1975) the above quoted average amount for the country will increase to 250kg per ha.

It is well known that Bulgaria is one of the greatest producers of vegetables, fruit and grapes for fresh consumption. This has made our Government and the research organizations take measures to find a solution to the problem of any possible pollution of human environment as a result of intensive fertilizer use.

Two research institutes are involved at present in the work carried out on that problem: the Institute of Hygiene at the Ministry of Health and the N. Poushkarov Institute of Soil Science at the Ministry of Agriculture and Food Industry. The research work carried out so far concerns mainly the effect of nitrogen fertilizers. There are two reasons for this:1. the nitrogen compounds are mobile; they are applied in large amounts and penetrate easily to ground waters used for drinking and irrigation; 2. the nitrates introduced into the human body with food and water cause a disease called metahemoglobinemia in babies 3. and ruminants 4.; according to some medical research they are also the reason for endemic goiter (6).

Lyochev (1), from the Institute of Hygiene, has studied the effect of N fertilizers on the content of nitrates in drinking water. The results obtained are given in Fig. 1. It is obvious that there exists a correlation between the amount of fertilizers applied during the 1953-1966 period and the percentage of water containing nitrates in the districts of Sofia, Pleven, Vidin and Plovdiv (the correlation coefficient is equal to 0.85). But the correlation coefficient of the non-standard amounts (30mg per 1) is 0,54, which shows that the amount of nitrates in the water is still low.

Irrespective of all that, the positive correlation existing between the amount of fertilizers introduced and the content of nitrates in drinking water is a very serious warning.

Vegetables and fodder crops grown in different regions of the country have been the object of another study related to the same problem. So far, it has been established that under the climatic conditions of the country, a low humidity and a high solar radiation, a comparatively small possibility existed for accumulation of toxic amounts of nitrates in the plants. The results obtained from the studies carried out by scientific workers in Plovdiv are given in Table 1. It is obvious that the amount of nitrates is within the range of the admissible content of nitrates. Similar studies have been carried out at the Institute of Hygiene on spinach samples taken from the market in Sofia; The average amount established is 12 mg per 100 g of fresh product (2), i.e. below the admissible rate (50 mg per 100 g of fresh product) (8).

It is well known that the toxic amounts of nitrates are chiefly accumulated in the presence of a high humidity and a low temperature, which occur during the autumn vegetation period (9). According to the data obtained at the Institute of Hygiene from investigations with spinach grown during late autumn at the rate of 120 kg of nitrogen per ha, the amount of nitrate was 113 mg per 100 g of fresh weight. Other samples from glasshouses gave a content of 382 mg per 100 g of fresh weight.

The special experiments carried out at the N. Poushkarov Institute of Soil Science with lettuce show that fertilizers applied late in autumn have provoked a marked increase in nitrate content (Fig. 2). The data obtained from analyses of vegetable samples taken from the market in Sofia in December showed an increased amount of nitrates (Table 2).

The purpose of our experiments was to find ways to overcome the nitrate accumulation in vegetables and fodder crops. One of the ways is to decrease nitrogen fertilizer rates but this is a contradiction to the main task of increasing production. The other trend is to improve the synthetic and metabolic processes in the plants. It is well known, that besides the effect of solar radiation and humidity, the catalytic effect of some chemical elements is also of some importance.

To this end pot experiments with maize and lettuce were set up with cinnamonic forest soil. The following rates of nitrogen fertilizers as ammonium nitrate were studied: 0, 250, 375, 500, 1000, 2000 and 4000 mg per kg of soil. The latter were combined with three levels of other elements as a blanket treatment, noted down as B_1 and B_2 and B_3 Combinations of two more levels of trace elements have also been used with lettuce and one with maize, noted down as T_1 and T_2 (Table 3). The elements were introduced into the soil as pure chemicals. Gramoxone was tested as a growth regulator in another experiment at the rate of 0.0015 ml per kg of soil. The content of nitrates was determined at the stage of the 7th-9th leaf in air-dry material (7).

Results

The data obtained showed that the content of nitrates increased with the increase of the nitrogen fertilizer rates. As regards maize the limit of the toxic amount of nitrates, i.e. 0.77 per cent of NO_3 after Harker and Kamey (5) was reached at the rate of 500 mg of N per kg of soil. In lettuce, the rate of 250-500 mg of N per kg of soil increased the content of nitrates twice or even thrice as compared to that in maize (in this case the difference in season could have been the reason for such an increase). At the rate of 4000mg of N per kg of soil the percentage of nitrate in maize was 1.65 per cent and in lettuce, 1.88 per cent of dry matter, or in other words, very close to the lethal limit for ruminants according to the above quoted authors.

The data obtained showed that when major and trace elements were combined the content of nitrates decreased (Table 4) . If the average amount of nitrates in the lettuce at B_1 and T_0 was taken as 100 it was considerably lower at B_2 and B_3. Thus, if no trace elements were introduced (T_0) and the blanket treatment was B_3 the content of nitrates decreased by 7 per cent as compared to the case of B_1; When trace elements were introduced with T_1 a decrease of 36 per cent was present and with T_2, 48 per cent.

The data given in Table 5 show that when high rates of major and trace elements were combined, the largest decrease in nitrate content at 2000 mg treatment was observed. The effect of trace elements proved to be higher with maize than with lettuce.

The content of nitrates in maize decreased in the presence of a combination of B_3 and gramoxone for all the rates of nitrogen fertilizers (average of 34 per cent) (Fig. 4). No such stable effect was observed with lettuce (Fig. 5). Further experiments are needed in this respect.

The experiments carried out also showed that the decrease of nitrates, as a result of treatments with major and trace elements, did not affect the decrease of total nitrogen (Fig. 6a, b).

Conclusions

The results obtained from these first experiments on the problem make us think that the decrease of nitrates is due to the intensification of the metabolic processes in the plants; the interaction of major and trace elements provokes a higher decrease of nitrates.

Therefore, the main conclusion that could be drawn is that nutrition should be well balanced in order to prevent nitrate accumulation in the plants.

Furthermore, with the increase in the amount of nitrogen fertilizers actually used a certain increase can be observed in the danger of accumulation of nitrates in some crops, such as vegetables and fodder.

The third conclusion concerns drainage waters and it indicates the necessity for complete erosion control to prevent both solid and liquid run-off of the soil.

OUTLOOK ON FUTURE RESEARCH WORK ON THE EFFECT OF FERTILIZER USE ON HUMAN ENVIRONMENT IN BULGARIA

A number of state agencies have been set up recently in Bulgaria to control both the practical measures required and scientific research work on human environment.

The Institute of Soil Science is in charge of research on soil conservation and plant protection from harmful substances that could be taken up from the soil. This work is coordinated with the investigations carried out by the institutes under the Ministry of Health, the Ministry of Heavy Industry and the Ministry of Forests and Control of Human Environment.

According to plans, research work on soil conservation and plant protection should proceed along two main lines:

1. Study of environment in glasshouses and in the fields as regards accumulation of harmful substances in vegetables and fodder crops and especially as regards nitrates under the effect of fertilizer application.

In this connection there should be established methods of intensification of metabolism and photosynthesis with a view to achieving a maximum use of nitrogen for synthesizing of useful organic matter. That aspect is in fact a continuation and extension of the already initiated work, some results of which have been reported at this session.

2. The other aspect of the work concerns complete erosion control on different watersheds and the introduction of a modern system of land use in different regions of the country with respect to the maximum use of fertilizers and minimum amounts of solid and liquid run-off permitted, the latter being the reason for filling rivers and dams with ooze and polluting them with soil material and water containing a high content of residual amounts of nitrogen, phosphorus, potassium, herbicides and pesticides.

According to the project, it is envisaged that research will be included on prevention of pollution resulting from the slurry emitted by large animal-breeding farms (in the near future hundreds of large farms, will be constructed in Bulgaria each one for several million broilers, 15-20 thousand livestock, about 1000-1500 cows and 50-80 thousand pigs for fattening).

The study will include investigations on erosion control, the washing away of soil and chemical substances by the gravity of water, the penetration of different polluting substances in drainage water into the ground waters which are used either for drinking and irrigation or for water supply to rivers and dams. The combined management, biological and engineering practices of erosion control and pollution of the environment should be studied. Four watersheds have already been selected covering 10-40 thousand ha; they are under the supervision of the research organisation, as well as the Ministry of Agriculture and Food Industry and the Ministry of Forests and Control of Human Environment.

The N. Poushkarov Institute of Soil Science plays an important role in planning and studying the effect of the application of different erosion control practices and control of pollution. This project is included in one of the programmes of the UNDP/FAO project 472 - BUL 6: Strengthening of the Nikola Poushkarov Institute of Soil Science in Sofia.

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Table 1

NITRATES IN SOME CROPS

Crops	NO_3 content in per cent of dry matter
1. Alfalfa, II out (stage of blossoming)	0.22
2. Cook's foot (stage of tasseling)	0.39
3. Mangelwurzel (leaves)	0.65
4. Maize (stage of 12th leaf)	0.37
5. Maize (after vegetables)	0.45

Table 2

CONTENT OF NITRATES IN SOME VEGETABLES

Crops	NO_3 content in mg per 100 g of fresh weight
1. Cabbage I	17
2. Cabbage II	44
3. Leeks	18
4. Spinach I	71
5. Spinach II	57
6. Spinach III	23

Table 3

BLANKET TREATMENT

	Nutrients and other elements in g per kg of soil						
	P	K	Ca	Mg	S	Na	Cl
B_1	2	2	1.28	0.25	1.0	0.06	0.05
B_2	4	4	2.56	0.5	1.5	0.12	0.10
B_3	8	8	5.12	1.0	2.0	0.24	0.20

	Trace elements in mg per kg of soil						
	Bo	Mo	Mn	Zn	I	Fe	Cu
T_1	1.5	0.1	2.5	6	0.1	30	1
T_2	4.5	1.0	7.0	12	0.3	60	2

Table 4

DECREASE OF NITRATES AS A RESULT OF INTERACTION BETWEEN MAJOR AND TRACE ELEMENTS

Level of trace elements	Salad			Maize		
	Level of major elements					
(T)	B_1	B_2	B_3	B_1	B_2	B_3
T_o	100	93	78	100	96	81
T_1	102	85	66	57	60	61
T_2	91	82	52	–	–	–

Table 5

INTERACTION AT 2000 MG OF NH_4NO_3

Level of trace elements	Salad - NO_3%			Level of trace elements	Maize - NO_3 %		
	B_1	B_2	B_3		B_1	B_2	B_3
T_C	1.39	1.30	1.08	T_0	1.14	1.10	0.93
T_1	1.42	1.18	0.92	T_1	0.65	0.68	0.70
T_2	1.27	1.14	0.73				

EFFECT OF FERTILIZERS ON CONTENT OF NITRATES IN DRINKING WATER

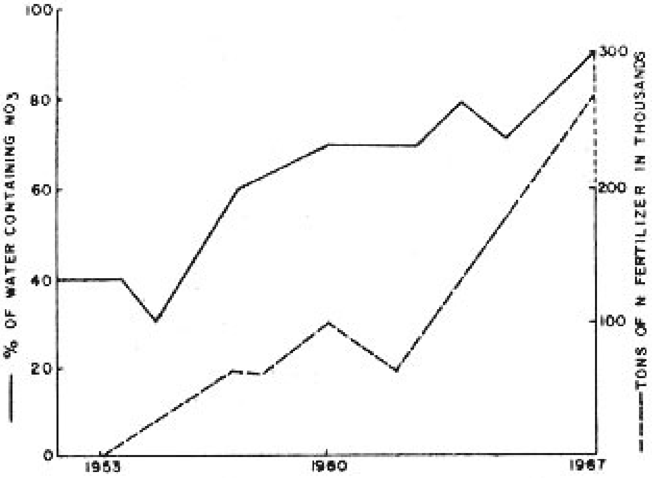

FIG. 1

EFFECT OF NITROGEN FERTILIZER ON CONTENT OF NITRATES IN SALAD CROP

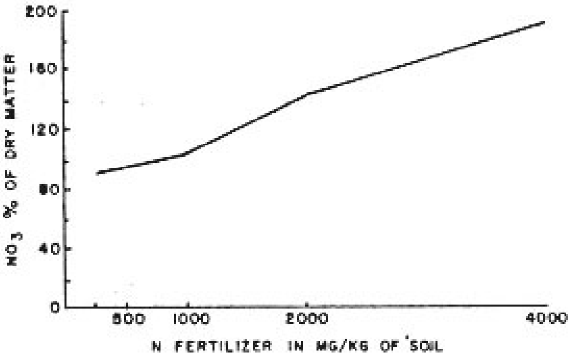

FIG. 2

EFFECT OF MAJOR AND TRACE ELEMENTS ON CONTENT OF NITRATES IN SALAD CROP

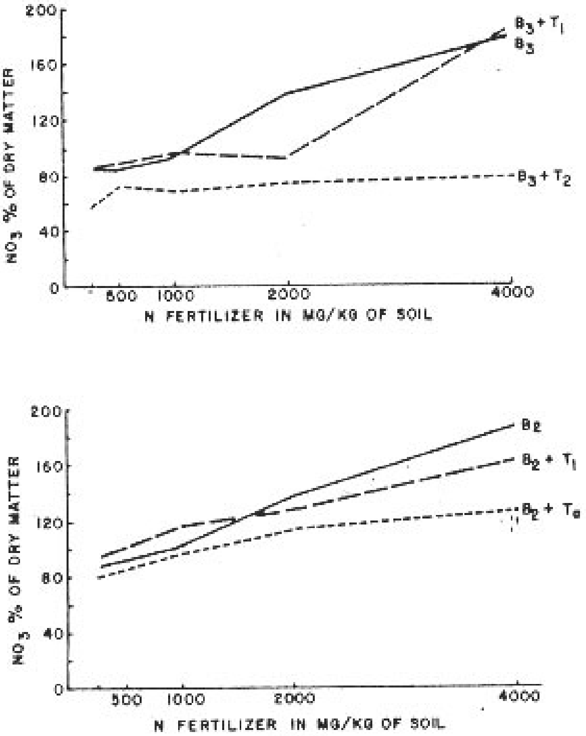

FIG. 3

EFFECT OF GRAMOXONE ON CONTENT OF NITRATES IN MAIZE CROP

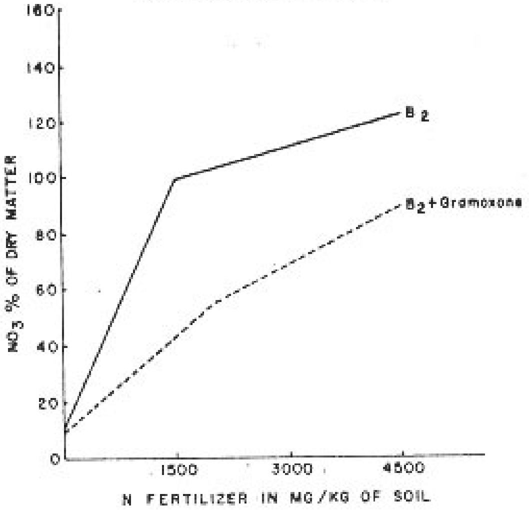

FIG. 4

EFFECT OF GRAMOXONE ON CONTENT OF NITRATES IN SALAD CROP

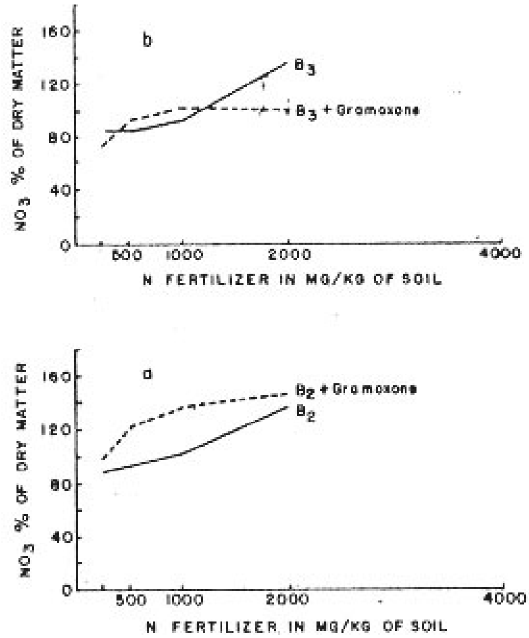

FIG. 5

RELATIVE AMOUNT OF NITRATES IN TOTAL NITROGEN IN MAIZE CROP

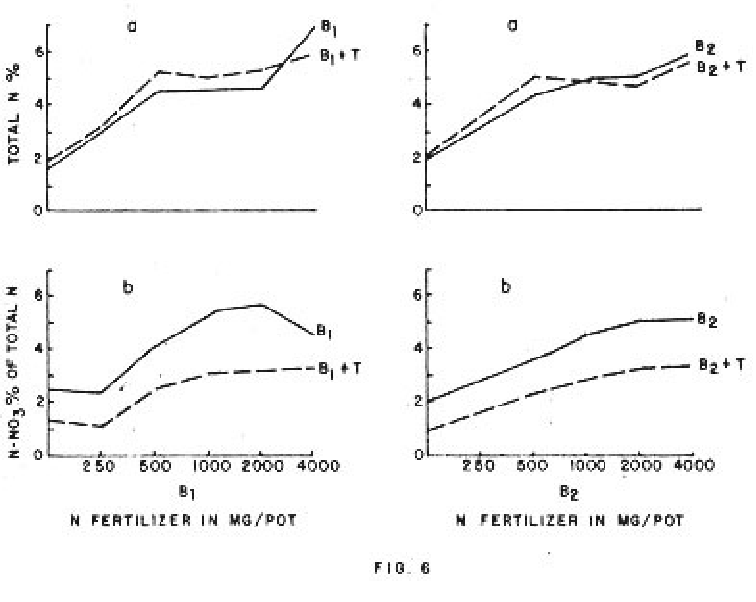

FIG. 6

THE MAIN SOURCES OF EUTROPHICATION OF INLAND WATERS WITH SPECIAL REFERENCE TO THE COMPARATIVE MAGNITUDE OF POLLUTION SOURCES

O. Jaag

CONTENTS

A. The progressive deterioration of Swiss lakes and rivers and our struggle to keep waters clean

- 1. Phosphorus and nitrogen
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B. The ABCs of wastewater purification

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Cont'd

C. The contribution of agriculture toward eutrophication in Switzerland

3. Relative share of the agricultural contribution in the total nutrient load imposed on some Swiss lakes, and the consequences that result therefrom
4. Consumption and application of fertilizers
5. Possible agricultural measures to reduce the supply of nutrients into water bodies
6. Final considerations about phosphorus and other plant nutrients economy.

Acknowledgment

Having worked at one hand with limnological problems on a considerable number of Swiss rivers and lakes for many years and on the other hand dealt with problems and modern aspects and techniques of solid wastes treatment, reutilization and disposal in Switzerland and abroad, it was a honour and a pleasure for me to accept your invitation to prepare reports on both these topics as my contribution to your panel meeting to be held from January 25 to 30, 1972, in Rome.

Therefore, I collected the results summarized in quite a lot of reports and lectures I had worked out in the course of the last decades.

Then, during the fall of 1971 I became aware that two comprehensive reports were being drafted in our Institute, the one worked out by the directors of the WHO International Reference Center, Mr. D. Stickelberger and Mr. H.R. Wasmer entitled "Survey of Solid Wastes Management Practices", the other prepared for OECD by Dr. R. Gächter, EAWAG, and Dr. O.J. Furrer, Swiss Federal Research Institute for Agricultural Chemistry at Liebefeld-Berne entitled "Der Beitrag der Landwirtschaft zur Eutrophierung der Gewässer in der Schweiz".

Since we all felt that double work on the same subject should be avoided, these authors allowed me to adapt their reports in a manner to be useful for the present panel meeting. Therefore, many elements of my report have been taken from the mentioned papers which represent an analysis as well as a synthesis of the total of the appropriate experience available today.

I would like to express my best thanks to D. Stickelberger, H.R. Wasmer, R. Gächter and O.J. Furrer for having allowed me to use their excellent studies.

8600 Dübendorf, 20.1.1972

Prof. Dr. O. Jaag

A. THE PROGRESSIVE DETERIORATION OF SWISS LAKES AND RIVERS AND OUR STRUGGLE TO KEEP WATERS CLEAN.

When some 15 000 years ago the Alpine glaciers receded, the waters of the lakes that formed were so clear that every pebble could be seen at the bottom. Self-purification, a faculty inherent in every body of water, easily eliminated all organic matter that developed naturally or which was discharged from the shores; thanks to this continuous process of mineralization our lakes and rivers were kept clean.

It was only when the proliferation of pollutants reached disconcerting proportions owing to spreading civilization and industrialization that the detrimental effects on our waters became apparent. This led to a catastrophic deterioration in the chemical and biological equilibrium of our lakes and rivers, a development which made it more and more difficult to supply industry as well as residential areas with drinking and service water; fish populations were decimated, and bathing and swimming became dangerous as a result of bacterial contamination.

All European countries were beset by this blight, and Switzerland looked on with apprehension as it spread to the waters of the USA, Latin America, Japan and practically all areas of the civilized world. Water pollution soon became a world-wide problem of paramount importance.

Switzerland began the struggle to preserve its waters as early as the 1920s; experts resorted to all the ways and means available to warn the nation of the imminent danger; national and cantonal legislation was set up to enable us to do battle on the broadest front possible.

Private associations for the conservation of our waters formed in numerous European countries. Finally these national associations merged to constitute the European Federation for the Protection of Waters. In 1965, after the international congresses in London and Tokyo and later in Munich and Prague, the International Association on Water Pollution Research, which held its 5th congress in San Francisco and Hawaii in 1970, was set up.

Water consumption in all European countries, like in the USA, is constantly on the rise and is now increasing at the same rate as that of population and industrial expansion. Our most pressing task is therefore to preserve our natural water supply, our lakes, rivers and groundwater.

The first mechano-biological water purification plant in Switzerland became operative in the year 1916. However, it was only after the 1930s and particularly after the implementation of the Federal Act for the Protection of Waters against Pollution in 1955 that the construction of sewage and industrial wastewater purification plants followed in rapid succession. Today there are - I am pleased to say - some 400 central mechano-biological purification plants in operation, 100 under construction, and construction credit has already been approved for an additional 100 wastewater purification and wastes disposal plants, all for Switzerland's small area of 16 000 square miles. At present approximately 50 % of the Swiss population as well as its industry are connected to modern purification plants. Up until now more than 3 billion Swiss francs or roughly 1 billion US dollars have already been spent on these plants and the necessary sewerage systems. By the time the first round in our fight to preserve our waters will be won, close to 10 billion Swiss francs or about 2 1/2 billion US dollars will have been disbursed for sewerage systems and purification programmes for domestic and industrial wastewater. This is a very high sum for a country with not very much more than six million inhabitants.

At present wastewater purification includes primary treatment (sedimentation) and biological treatment either with trickling filters or according to the activated sludge system.

The deterioration in our natural waters described above is due to what we call eutrophication.

The phenomenon of eutrophication in our waters as I mentioned before shows itself in the silting of rivers and lakes as well as in their overproduction of algae and weeds. Even though much of the process remains unclear, we can better understand these effects by considering the physiological laws of plant life. Our knowledge is still especially fragmentary with respect to the role of trace elements, which influence the production cycle of a body of water. Uncertainty begins where it can be established that lakes have "turned", despite the absence of an obvious cause for the disturbance in their chemical and biological balance. For example, what were the causes for the sudden appearance in 1825 of the Burgunderblut algae in the Lake of Morat (Murtensee) - imbalance triggered by wastewater from a numerically small population without industry worthy of mention?

But the massive development of other species of algae, previously unknown locally, confronts us with the same riddle. At present, Liebig and Mitscherlich's laws on plant nutrition offer the only explanation, ascribing eutrophication to substances which cause explosive vegetal growth as soon as the nutrients have reached a minimal concentration, either through gradual or sudden enrichment. From previously conducted investigations it can be seen that it is usually the content of phosphorus salts which is at the source of the eutrophication of our waters. As a rule, nitrogen compounds are present in such large quantities that a further increase of their concentration could hardly have the effect of additionally favoring production.

Among the main eutrophic materials, that is, the various oxidized elements in nitrogen and phosphorus, the following mean values are found in Swiss waters:

	Normally present in mg/liter			
	in lakes	rivers	streams	pure groundwater
Ammonia NH_4^+	0-0.1 (to 1)	0.01-1	0.01-1	0-0.05
Nitrate NO_2^-	0.0 - 0.05	0-0.05	0-0.1	0 - traces
Nitrate NO_3^-	0-1	up to 2	up to 10	up to 10
Phosphate PO_4^{---}	0-0.5	0-1	0-1	up to 0.05

These are insignificant concentrations; yet they suffice to trigger the proliferation of the flora that serves the animal plankton and, in turn, the higher fauna, as food.

Nitrogen compounds already get into our waters through rain, for although nitrogen, which comprises 80 % of the atmosphere is chemically very inactive, electric discharges in the air from oxygen and nitrogen compounds that accumulate in small quantities in the water and soil. Far greater amounts of nitrogen are discharged into our lakes and rivers from domestic and industrial wastewaters and especially from the effluents of purification plants.

In addition, thanks to the oxygen present in soil and water, nitrogen is absorbed by bacteria of various kinds and by the ubiquitous blue-green algae.

Our campaign against eutrophication must therefore be aimed at restricting the addition of phosphorus compounds as much as possible. But how do the basic nutrients used by the farmer to fertilize his crops get into our waters? It is not difficult to establish which eutrophying materials come from sewage treatment plants and to determine their exact amounts and content. It is much less simple - if not impossible - however, to judge the afflux of phosphorus and nitrogen compounds resulting from agricultural fertilization or even from the breakdown and dissolution of mountain rock, both sources which contribute to the eutrophication of water in a drainage area. As they are difficult to quantify, the accretion of these nutrients can only be estimated; nevertheless we know that, as a whole, the amount they represent is as great as or greater than the measurable nutrients from sewage plants.

Despite this uncertainty, many Swiss municipalities - especially the Cantons of Zurich and Berne - decided to demand as complete a removal of phosphorus compounds as possible from the wastewater of sewage plants, at least in the catchment area of lakes (tertiary treatment). At present, the eutrophication of rivers is causing us almost no concern because the equilibrium of their waters is not being disturbed. Indeed, a great organic load is necessary to produce a sharp reduction in the oxygen content of a body of running water.

Let us first consider the most important nutrient elements for plants.

A. 1 Phosphorus and nitrogen

Phosphorus is present in soil in the form of phosphates, various forms of apatites as well as tri-, di-, and monocalcium phosphate. Organic phosphoric compounds such as phytin and nuclear acids, absorbable by plants, have also been found in the soil. Phosphoric compounds in different soils reach concentrations of 0 to 0.3 %.

Nitrogen compounds are practically non-existent in the original rock. They get into the soil with precipitation from the atmosphere on the one hand and as products of the decomposition of organic substances on the other hand. In our soil nitrogen compounds show values of 0.15 to 1.5 %. Nitrogen is mainly present in an organic form, in organisms living in the soil. Their biomass can be calculated by multiplying the quantity of nitrogen by 20. In its inorganic form, nitrogen is present as ammonia or nitrate, which are adsorbed at soil colloids or which circulate with soil-water. Washout is considerable in bare soil, but can be reduced to 1/10 by growing plants. This fact is of rather great importance in respect to the eutrophication of natural waters.

Potassium must also be mentioned among the eutrophying elements; it is easily washed out and shows values of 0.2 to 4 %.

In addition, the micro-elements, the mechanism about which only very little is known, certainly play an important role.

Soil fertilization consists of farmyard-manure on the one hand and artificial fertilizers on the other hand.

Farmyard manure: 3 parts of liquid manure and 1 part of faeces, varying in quantity and composition from one species of cattle to the other. The dry weight is rather uniform from 3.8 to 4.1 tons/year and/ton of live weight.

Compared with normal artificial fertilizer, farmyard manure is relatively poor, especially with regard to phosphorus. Plants treated with farmyard manure therefore need additional phosphoric fertilizer.

Human faeces per capita and year make up 4 400 g N and 540 g P. The human faeces of the Swiss population (6.3 millions) make up 28 300 tons N and 3 400 tons P/year. Cattle faeces make up 7 to 8 times the quantity of N and P of human excreta per year. These values are not much different from those of the rest of Europe and the United States.

Inorganic fertilizers were first manufactured in the middle of the last century when salpeter was imported from Chile to England in 1842; superphosphate was produced, Guano came from South America and potassium chloride was discovered in the Rhine valley in 1860.

In 1900 the world production was 300 000 tons N, 900 000 tons P_2O_5 and 250 000 tons K_2O. In 1965 the world demand was estimated at 16 million tons N, 10 million tons K and 12 million tons P. Since 1950 the yearly nitrogen production has increased by 11 % and that of both P_2O_5 and K_2O by 3 to 4 %. Similar figures are predicted for the next years. The need for N in 1970 is valued at 20 million tons, that for P_2O_5 and K_2O at 13-15 million tons.

Recent investigations have shown that considerable quantities of such fertilizers are washed out by rain.

Important leaching and the discharge of liquid manure into fishing waters can have catastrophic effects. It is not surprising that in Switzerland, for instance, a fish kill occurs every one to two days owing to liquid manure, whose ammonia content is lethal to the aquatic fauna.

In connection with cattle-breeding, there are also the effluents from grass silos, which present an acute danger to surface-waters, not only because of their high BOD value (50'000 to 100'000 ppm), but also for their high content in total nitrogen, i.e. more than 3'000 ppm, of which 1/3 is present as ammonia-nitrogen.

Another source of P and N is the air. Indeed, atmospheric precipitation contains solid, liquid and gaseous impurities and shows values ranging from less than 1 mg/l to up to 7 mg/l. Although these quantities are very small, when introduced into surface water, they stimulate plankton growth.

A.2. The struggle against eutrophication

The human excreta per capita and per day have been calculated to be 13 g N and 1.4 g P, of which 88 % N and 58 % P are soluble. In synthetic detergents different polyphosphates are used. As an average we can value the content of synthetic detergents at 7-12 % P. In the German Federal Republic the production of detergents containing phosphates has doubled between 1959 and 1966, and the increase has not slowed down in recent years.

The discharge of P from detergents is quantitatively sufficient to explain the extraordinary increase in the plankton development in the Lakes of Constance and Geneva in recent years.

Food processing industries also discharge phosphoric and nitrogenous materials.

Further sources of nitrogen and phosphorus are street cleansing and run-off from streets, squares and highways. According to figures from the United States, street run-off contains approximately 4 times more nitrogen and 2 times more phosphorus than the water from rivers. In forest regions an average of 0.88 g/m^2 of nitrogen and 0.1 g/m^2 of phosphorus accumulate; these indications correspond to 7 and 3 % respectively of the amounts found in domestic wastewater in the same regions.

B. THE ABCs OF WASTEWATER PURIFICATION

It is in keeping with his innate need for order and cleanliness that man removes all the wastes he produces in the course of his daily activities; his main concern is to avoid nuisances and detriment to his surroundings as far as possible.

Very early in the history of mankind it was recognized that the solid and liquid wastes produced by man and animals contained chemical elements that had natural fertilizing value and could enhance the yield of all types of crops. In rural regions, human and animal wastes were therefore carefully collected in cesspools and manure ditches. In this way human and animal excrements can supply the plant nutrients that must be returned to the soil after harvesting.

Not so very long ago the fecal matter generated in the cities was collected in containers and spread on arable land; in Zurich, in fact, this type of disposal was continued until the beginning of this century. In the meantime, however, the flush toilet was invented, whereby the excrements are diluted, loosing their value as a fertilizer. Nevertheless it proved to be easier to remove waste material from houses and communities on a continual basis through a sewerage system. But where was it to be discharged? The easiest way was to discharge it directly into the nearest receiving body, river or lake. Thus the household and community were kept clean and orderly, but man had reckoned without his host. The pollutants in the wastewater contaminated the receiving body to such an extent that increasingly intolerable conditions developed.

Water pollution involves hygienic dangers as a result of the bacteria in the wastewater, which can cause infections in man and animals such as typhus, paratypoid, diarrhea, cholera and other diseases, possibly even polio. Other consequences of water pollution are: oxygen depletion especially in the deep layers of our lakes; fungi formation in river beds through unsightly, slimy strands that cover plants and rocks; odor nuisance and toxic gases such as sulfur dioxide, ammonium and methane.

In lakes which had formerly had a healthy biochemical balance the pollutional load caused a disruption which had catastrophic consequences for fisheries, water sports and the esthetics of the landscape in general. Mountains of detergent foam formed, ugly streaks of dirt and oil floated downstream, the waters became turbid and discolored; chocked by algae and ooze, water became difficult and expensive to purify. These were the consequences of a continuous strain on the self-purification capacity which is inherent to every water body but which also has its limits. It is for this reason that this development must be nipped in the bud. Domestic and industrial wastewaters must, before being discharged into a natural receiving body, be treated so that the water can purify itself, through the natural processes of decomposition and mineralization.

B.1. Collecting and conducting wastewater through a sewerage system

All the water and wastewater that accumulates in a community from houses and streets is conducted, through pipes of constantly increasing diameter, to the main canal of the sewarage system and finally to a wastewater treatment plant. Sometimes domestic wastewater and run-off from roof-tops, streets and public squares are collected in separate ducts; then again both rainwater and domestic and industrial wastewater can be conducted in a single sewerage system, called a mixed system.

In some cases it may even be worthwhile for large industrial complexes to collect their wastewater in several separate ducts. In older municipalities and private companies, however, a separate collection system is unfeasible because of the complications and high costs involved. Yet in new agglomerations such as satellite cities or in rapidly developing neighbourhoods, the separate collection system offers very definite advantages.

B.2. Wastewater treatment

Before reaching the actual treatment installations in a purification plant, the wastewater collected flows through a number of preliminary treatment installations. The rainwater discharge channel regulates the amount of water that enters the plant, preventing the plant from being overloaded during heavy rainfalls. The excess water is usually discharged through a threshold built into the inlet canal and lead to a storm-water tank or directly to the receiving body. Storm-water tanks for overflow have been proved necessary.

They remove the pollutants, which are particularly concentrated in water at the beginning of a heavy rainfall. If the excess wastewater that spills over the threshold is discharged directly into the receiving water, this body of water would be subject to an additional pollutional load. Wastewater treatment plants will therefore have to be designed in such a way that rainwater discharge would be necessary only very occasionally. The sludge retained in the storm-water tank is removed from time to time along with the sedimented pollutants from other sections of the plant.

The main inlet channel of a wastewater treatment plant has a built-in coarse bar screen that removes large objects such as wood, paper, and pieces of cloth and plastic from the wastewater. The debris that accumulates in this way is collected either manually in the case of small plants or by means of mechanical cleansing machines in larger plants. It is then buried, composted or pulverized in a comminutor built into the inlet channel and subsequently dumped back into the wastewater duct for further processing in another part of the plant.

To keep track of the amount of wastewater entering the plant, the water is channeled through a Venturi canal, a bottle-neck in the inlet duct, where it is measured and continuously registered with a water gauge.

Since sand is carried along in the wastewater channel, presenting a danger for pumps and other machinery and for digestion in the digestion chamber, it must be removed in a sand trap. Fats and oil, which also impede the purification process, must be removed as far as possible in an oil separator. This consists of deep channels from which air is pressed. The air bubbles carry the oil and fatty material to the surface of the water where it is skimmed off.

B.3. Sedimentation or primary settling tank

Next the wastewater is channeled to a round or rectangular primary settling tank where the heavier solid wastes can settle. The sludges that accumulate, called primary sludges, are removed from this tank and pumped to the digestor chamber before anaerobic decomposition starts.

It is important to try to retain as much solid waste material in the settling tank as possible in order to eliminate as much fecal matter as possible; yet, on the other hand, this installation must not take up more space than absolutely necessary.

The effects of sedimentation in the primary settling tank are all the greater, the longer the wastewater is kept there. A longer retention time, however, presupposes larger installations, which, in turn, entail greater financial outlay. Thus the design of the plant must be calculated so that optimum utility can be obtained with the least possible construction layout. Optimum conditions, however, differ from country to country and even from municipality to municipality. The mean time of passage of the wastewater in a settling tank, for instance, varies from less than one hour to two or even more hours.

The amount of space available and a number of other criteria will determine the design of the primary treatment installations, that is, whether the tank is to be round or rectangular, shallow or deep.

B.4. Sludge digestion

In the digestor the sludge goes through a process of anaerobic fermentation, under the exclusion of air, during which digestor gas (2/3 methane 1/3 CO_2) is produced. The calorific value of this gas, which is collected in a gasometer, is 6 000 kcal/m^3, that of the gas supplied by the utility services is only 3 500 kcal/m^3.

Sludge retention time in the digestor differs. Formerly, three to four months had been considered necessary to kill off pathogens and intestinal worm eggs. Recently, however, digestion time has become shorter and shorter so that sludges today are kept in the digestion chamber for only a few weeks. Of course, sludges are still more hygienic, the longer the digestion period, because the intestinal worm eggs, due to their hard outer shell, are extremely resistant to external influences.

The digested sludge is practically odorless and cannot decompose any further. Since the organically-bound elements found in urine and excrements are present in a mineral form in the sludge, it is valuable as a fertilizer and soil improver. Because of the high phosphorus content in digested sludge, farmers have added it to liquid manure, which contains mostly nitrogen and potassium.

Despite the advantages of sludge, resistance has of late been building up against its application. The veterinary and milk hygienists, for example, called undigested sludge unhygienic and traced damage observed in cheese production as well as worm diseases among great parts of the population back to sewage sludge. As a result, the Swiss regulations for the delivery of dairy products of 1954 forbade the use of sewage sludge in agriculture during the vegetation period, that is, from March to October.

Despite these obstacles, ways and means had to be found to make sewage sludge, of which more and more was being generated each year, popular. The Federal Institute for Water Supply, Water Purification and Water Pollution Control (EAWAG) of the Swiss Federal Institute of Technology was instrumental in this undertaking. In close collaboration with agricultural research institutes, it carried out experiments and projects to find new markets for sludge, on the one hand, and on the other hand, to find acceptable ways for hygienizing sludge through pasteurization, as this is done abroad. In this way, the sludges can be used in agriculture without detriment to man or animals.

A further possibility for using sewage sludges is composting in admixture with household refuse. During fermentation, temperatures rise to 70° C and more so that all undesirable microbes, worm eggs as well as weed seeds which had resisted wastewater treatment are killed off. The final compost is completely hygienic.

Important uses for sewage sludge and refuse compost are in vegetable gardens and vineyards, where the compost acts as a soil improver. Soil erosion after heavy rainfalls and, as a result, the depletion of plant nutrients can thus be prevented. Then, too, the soil is easier to till after heavy rain because it dries more quickly.

As has been determined in tests carried out in conjunction with the Forestry Research Institute of the Swiss Federal Institute of Technology, excellent results can be achieved with refuse-sludge compost in tree nurseries. This is a great improvement over the former method of producing compost from woodcutting wastes. Refuse-sludge compost is also in demand in orchards and the florist business, which facilitates the disposal of domestic and industrial refuse to a considerable extent.

It is a matter of course that the compost should be of an indisputable quality. The first prerequisite is that it be free from shards and cullet. Compost destined for agricultural use must also have reached a certain degree of maturity. A research project is now under way to determine which types of plants compost is most suited for and which quantity is most advantageous.

Despite the more widespread use of compost, agriculture in Switzerland has not been able to absorb completely the sewage sludge generated in urban areas. Thus, an alternative to reutilization has to be found. An effective solution lies in incinerating the digested sludge with subsequent heat recovery as this is done in Geneva, Zurich and Lausanne. Each municipality must find the most appropriate way to solve its specific sewage sludge problem with the least possible outlay.

B.5. Secondary wastewater treatment

Despite mechanical treatment, the water that leaves the primary settling tank still contains a very high percentage of pollutants since not more than 30 percent of the waste material, in relation to the crude wastewater, can be removed at this stage. The remaining 70 % is still found in solid or suspended form. Thus if treatment is limited to the primary stage, putrefaction and odor nuisance result. One of the dangers of polluted rivers, especially when they are dammed up, is that there can also be contamination of the groundwater. Examples of this are supplied by events in Augst on the Rhine, Wettingen on the Limmat, Klingnau, Wohlensee on the Aare and finally Verbois below Geneva. The lesson to be drawn from this sad sequel is that polluted rivers, if dammed, can badly contaminate the groundwater. In fact, the self-purification process of the leachates continues in the groundwater, which leads to oxygen depletion and the dissolution of the iron and manganese salts in the soil. This makes the groundwater useless for drinking or service purposes.

As a result of these technological mistakes in water management, the necessity of both mechanical and biological treatment was realized.

But what, in fact, does biological wastewater treatment mean? The object is to remove the pollutants that are not eliminated in the primary settling tank through biological treatment in such a way that the self-purifying capacity of the water can cope with the water discharged from the plant without difficulty.

The organic and inorganic waste materials in the raw wastewater that flows from the primary settling tank to the secondary treatment tank must be mineralized so that only a very small amount of pollutants remains in the wastewater treatment plant's effluent.

A number of processes are possible for the biological treatment of wastewater:

a) agricultural utilization and irrigation or spray irrigation;

b) field irrigation method;

c) soil filtration;

d) trickling filter method;

e) submerged trickling filter-method;

f) the classical activated sludge process; total oxidation, installations and plants with relatively long reaction periods for which several systems have been evolved;

g) oxidation ponds.

The first and second processes have been used abroad, especially in Germany, since the middle of the last century. Soil filtration has been practised mainly in the United States. All 3 methods have aroused very little interest in Switzerland because of the lack of land available.

B.5.1. The trickling filter

According to folklore, "the process of self-purification is completed after the water has flown over the seventh stone". It was on the basis of this principle that the Englishman, J. Corbett, invented the trickling filter.

The trickling filter field of the city of St. Gall in Switzerland was one of the first biological treatment installations far and wide. A trickling filter consists of layers of fist-sized rocks of various materials (limestone, lava slags, artificial stone and other material). These layers are heaped on top of a grate that is pervious to air and water. Somewhat larger rocks are placed directly over the grate in order to facilitate the passage of air and water. The top layer should also have coarser material to prevent fungi growth and the formation of puddles. The entire installation can be surrounded by a wall to increase the movement of air currents and retain warmth. The trickling filter can be covered to prevent the psychoda, the filter flies, from flying off. In this case, however, the installation must be ventilated artificially.

Wastewater contains bacteria in great quantities. Since they find unlimited quantities of food they develop and multiply very quickly by splitting, decomposing and mineralizing the pollutants' complex molecular structures through the agency of enzymes that are found in specific fermentation systems. From these biochemical processes the bacteria draw the energy they need for life. These bacteria as well as micro-organisms, fungi, macro-organisms and algae settle on the surface of the trickling filter rock, forming what is called biological slime. The wastewater from the primary settling tank is evenly distributed over the surface of the trickling filter by means of a rotating sprinkler. This activates the organisms in the biological slime; they mineralize the organic waste material in the water. The wastewater then percolates through the layers of rock and after approximately 20 minutes (longer for higher filters) flows out through the grate biologically clean. During this period the bacteria and pathogen count will have been reduced at least ten times.

The biological slime on the surface of the rocks breaks off either from time to time or continually, to be floated away, while new slime forms to renew the patches. The sludge that breaks away settles in the secondary sedimentation tank and is then digested.

Trickling filters can remove at least 90 percent of the crude water's pollutional load.

B.5.2. Activated sludge system

The English have made considerable contributions to the development of effective methods of biological wastewater treatment. British experts evolved the trickling filter in its modern form, and they are to be credited with the invention of the activated sludge system. Although it was formerly believed that aeration was sufficient for wastewater purification, research scientists like Ardern and Lockett recognized the role of bacteria in mineralization. The fermentation systems enabled them to mineralize organic waste material, a process in which oxygen plays a key role. The bacteria do not grow on a surface but multiply in the wastewater itself. As in the trickling filter, they use the substrate, that is, the organic waste material, as a source of energy and for metabolism. Contrary to conditions in trickling filter, however, the bacteria multiply only if they are supplied with sufficient oxygen. For artificial aeration to be effective, the wastewater in the entire system must be kept in motion continually. This can be done by means of a rotating brush aerator or pressurized air.

Extensive testing on a semi-technical scale at the Swiss Federal Institute for Water Supply, Sewage Purification and Water Pollution Control has shown that slowly degradable, synthetic detergents hamper or, in some parts of the plant, even impede proper mixing of the wastewater. This has, fortunately enough, been recognized by detergent manufacturers, who have replaced hard detergents with easily degradable products.

After having been treated in the primary settling tank, the wastewater is led to the activated sludge tank. Care must be taken that no toxic substances get into the tank, as great damage can be caused to the activated sludge, that is, the bacteria flakes that thrive on the substrate. The advantage of the activated sludge system over the trickling filter is that the aeration tank can merely be emptied after a poisoning. To make it operational the tank has only to be refilled, while damage to the trickling filter entails more complicated repairs. Sometimes the filter must be completely rebuilt after which a running-in period of weeks is necessary before the installation is completely operational.

A further advantage of the activated sludge process lies in the fact that the plant operator has better over-all control and that he can adjust the amount of air pressed into the system to the wastewater flow to obtain optimum operating conditions.

The same degree of purification is reached with the activated sludge system as with the trickling filter. Construction and operating costs of both systems are practically analogous.

The sludge removed from the activated sludge tank is taken to the secondary settling tank for treatment. Part of the activated sludge that settles here is led back to the aeration tank, while the excess sludge, called secondary sludge, is mixed with the primary sludge in the digestor.

During the mechanical and biological treatment processes the pollutants in the wastewater are mineralized. Thus the main elements of the organic compounds are now found in the form of CO_2, water, mineral nitrogen compounds, sulphates, phosphates etc. These compounds, however, can in turn act as nutrients in lakes and rivers where they stimulate algae growth. The eutrofying minerals from wastewater treatment effluents must be removed if our lakes and rivers are to be saved.

Recent tests have revealed that it is mainly phosphorus that triggers off eutrophication. This recognition allows us to hope that once phosphorus compounds will have been removed from treatment plant effluents as completely as possible, we will have come that much closer to our ultimate goal: water pollution control.

B.6. Tertiary treatment: Removal of main eutrophying substances

Phosphorus compounds can be removed through the addition of ferric chloride, aluminium sulphate or lime to the biological treatment basin of a sewage treatment plant. The same thing can be done in a special installation built behind the final settling basin. Naturally this raises construction costs, but the costs of the precipitating agents used are even higher.

We are not yet certain of the growth-limiting effects of nitrogen compounds, but it is quite possible that the removal of nitrates from our waters will be required sooner or later. For this reason attempts at denitrification are being made in a number of places. Many colleagues even proposed that the phosphorus and nitrogen compounds in sewage treatment plant effluents be eliminated simultaneously.

Denitrification can be accomplished artificially by channeling waste water into an oxygen-free system where the nitrate reduces itself to molecular nitrogen, which escapes as a gas into the atmosphere. However, I know of no treatment plant so far, in which a denitrification process of this sort is being carried out.

What has been said, suggests that nitrogen compounds must be regarded as partially responsible for the eutrophication of our waters - even if this has not been proved - and that the amounts of nitrogen should ideally be kept to a minimum. Thus there develops an inevitable contradiction between demand and measures to step up production on the one hand, and the campaign against eutrophication on the other. There is no doubt that nitrogen fertilizers stimulate the production of food to a very considerable extent. Our task is thus to use all means at our disposal to attain maximum crop yields through nitrogen fertilization, while simultaneously keeping the nitrogen enrichment of our waters to a minimum to avoid the unfavorable effects of eutrophication.

Nitrogen compounds are more easily washed out of fertilized soil than phosphorus compounds. In applying both chemical and farmyard fertilizers care should therefore be taken, if only in the most basic interest of the farmer, to avoid the loss of nitrogen and its being carried directly into the water.

Natural waters, rivers, lakes and indirectly groundwater receive and dissolve eutrophying substances from

a) concentrated effluents from wastewater purification plants
from communities and industries (concentrated discharge)

b) agricultural fertilization
the air
drainage areas of cultivated grounds
runoff from highways, roads, streets, squares and other sources
(diffuse discharge).

Obviously the former sources are relatively easy to gage while the latter ones can only be roughly evaluated in respect to quantity.

B.7. Conclusion

From the sewerage system and agriculture the following amounts accumulate per m^2/year 1.66 g N and 0.17 g P.

Our experience with several lakes, for example the Lago di Tovel (Italy), Zeller See (Austria), Lake Washington (USA) gives us reason to believe that conditions can be more favourable in some cases. The Lake of Zurich has also shown signs of improvement, as was to be expected since all municipalities along the lake will soon have complete biological treatment and some practise phosphate elimination already now.

Indeed, oxygen conditions in the lower layers of the Lake of Zurich have improved in the past few years, and the massive development of algae and weeds has stopped. Let us hope that this impression will be confirmed and prove to be of a permanent nature. In any case, this is no time to despair, it is our duty to do our utmost to support and accelerate the improvement of our waters. We must not be deterred by the high costs energetic action entails.

If the towns of Zurich and Winterthur at first followed the advice of foreign experts and realized only the primary or mechanical stage of wastes purification through sedimentation, these communities nevertheless soon felt compelled to treat the overflow from the primary settling tank biologically.

Whether treated in trickling filters or using the activated sludge system the degree of mineralization is very satisfactory, corresponding to a 90 % reduction in the biochemical oxygen demand and more. However, during this process nitrogen and phosphorus are transformed to an inorganic state and thus provide a source of nourishment to the microscopic and macroscopic plant life as nitrates, phosphates, sulphates and other oxidized compounds. These elements must therefore be eliminated as far as possible in the third stage of purification.

Some suggestions for eliminating nitrogen date back to the end of the 1920s, but it was not until very recently that definite, satisfactory solutions could be found. One of our main problems is precipitating phosphorus compounds from sewage plant effluents by adding a chemical precipitant. Iron salts, especially ferric chloride, aluminium sulphate and lime are mainly used to this end.

Lime has proved to be an excellent flocculant but has an undesirably high pH and forms voluminous sludges that are difficult to dehydrate.

Iron salts and aluminium sulphate have produced better results. With approximately 200 to 250 mg aluminium sulphate/liter 95 % of the total phosphorus or up to 99 % of the phosphate phosphorus can be removed, leaving only 0.06 mg P/liter.

Until now, however, iron precipitation has achieved the best results. Two methods have been proposed:

a) phosphorus compounds can be precipitated by adding $FeCl_3$ to the activated sludge so that the iron phosphate falls into the sewage sludges and is carried to the digestion chamber (there is no danger that they might dissolve in the anaerobic medium) or

b) iron precipitation can be provided for in a basin located behind the secondary settling tank. 10 mg/liter of Fe (in the form of $FeCl_3$) generally suffice to reduce the phosphorus concentration to 0.65 mg. Higher concentrations of iron (up to 30 mg/liter) can increase the rate of elimination to 92 % with a residual iron concentration of 0.5 mg/liter.

Precipitation after the final sedimentation basin is more effective but entails more construction and operating costs since an additional treatment tank and more chemicals are needed.

The canton of Zurich has recommended phosphate precipitation for all communities along the lake. Fortunately other cantons are following this example in the belief that all means should be mobilized to enhance the self-purification capacity of their waters.

Nitrogen compounds are more difficult to eliminate within the framework of conventional purification methods than phosphorus.

It is our great misfortune that the removal of eutrophying elements is not always enough to protect our lakes and rivers against deterioration. Pesticides, fungicides, growth-stimulating substances, hormones and other active elements are finding their way into our waters in ever-increasing quantities. We must fight against the accumulation of these substances present in wastewater or in the run-off from land used for agriculture and forestry.

The fight against water pollution entails a very significant financial layout for Switzerland as well as all industrialized countries. The outcome of this struggle is not at all certain. However, since healthy water is our most fundamental need, we must do all within our power to protect our endangered environment.

A new menace to water is the temperature increase caused by discharges of cooling water after use by the conventional or atomic power plants. This thermal pollution of the receiving waters is still something new, but it will probably grow into one of the major problems of water protection. In any case, extremely sound regulations regarding the thermal load that can be borne by water will have to be set up on the base of wide range and long term thinking.

A recording of the present state of the Swiss lakes and rivers has already started. This "status quo" will, as soon as a number of atomic power plants have been put in service, enable us to define and prevent the detrimental effects of thermal pollution from the points of view of biology, chemistry, fishing, etc.

C. THE CONTRIBUTION OF AGRICULTURE TOWARD EUTROPHICATION IN SWITZERLAND

C.1. Introduction

Scientific phytophysiology has taught us how - by maintaining optimal external conditions and by providing the plants with optimal nutrition - agricultural yields can be increased to a maximum as regards both quantity and quality. This, as well as the experience acquired in the course of years, has gradually brought deep changes in the practice of cultivation. Thanks to the sensational results of research studies effected by the modern phyto-physiologists, among which we find the names of SACHS, PFEFFER, LIEBIG, MITSCHERLICH and, more recently, VOISIN, we now know the chemical elements that are indispensable for the normal development of plants, those that cause plants to develop more fully and also those that are liable to harm or even destroy plants. Proper dosage is of course very important, i.e. the quantitative ratio between the different elements, as well as consideration of synergisms, antagonisms and oligo-dynamical effects.

Basing upon such findings, a new science has developed as regards application of fertilizers; it includes consideration of the regional and local climatic conditions, as well as of the local soil characteristics.

The rapidly spreading eutrophication of a large number of water bodies is doubtless due to the unnaturally increased introduction of nutrients. Among the macro-nutrients found in lakes, phosphorus and sometimes nitrogen too were identified as the minimum factors. Since both these elements, together with potassium, are the principal ingredients of anorganic fertilizers, it may logically be assumed that, in addition to the communal and agricultural waste waters, losses of nutrients from intensively cultivated areas finally reach the water bodies and contribute to their eutrophication.

The supply of nutrients in water bodies may originate

- from the atmosphere
- from soils not influenced by man (natural basic charge)
- from soils utilized by agriculture and forestry
- from waste waters.

Precipitations reach water bodies either directly or indirectly via surface or underground effluents. If they fall on urban areas (roads, squares, roofs) or unproductive land and water surfaces, their contribution toward eutrophication is direct, owing to their content in phosphorus and nitrogen compounds. In Switzerland, such areas take up a surface of approximately 10 000 km^2. The remaining 31 000 km^2 or 76 % of the total surface are productive land. Nutrients diluted in rain water and falling on land utilized by agriculture and forestry fertilize the soil in the same way as does elementary nitrogen fixed by the soil bacteria. Unfortunately, no data is available on the concentration of nitrogen and phosphorus in rain-water in Switzerland. Such data would enable us to evaluate the importance of this source of nutrients in our country. The inevitable negligence of this source of nutrients results in a slight overestimation of the proportion of nutrients brought into water bodies by agriculture, in our evaluation of the relative contributions from agriculture and from waste waters.

The estimation of the contribution from waste waters is based on the following data:

nitrogen	12 g per capita and day
phosphorus	3 g per capita and day.

As regards phosphorus, about half this amount comes from detergents.

The leaching and erosion of nutrients depends on various factors such as topography, type of soil, climate, cultivation methods etc.

C.2. Amounts of nitrogen and phosphorus contained in water and originating from land utilized by agriculture and forestry.

C.2.1. Direct measures effected under natural conditions in the catchment areas of various receiving waters.

This study was based on the following publications:

Prealpine area:

Keller, H.M. (1970) Der Einfluss der Wassermenge auf den Chemismus kleiner Bäche, beobachtet in kleinen Einzugsgebieten im Alptal Sz; Dissertation ETH Zürich Nr. 4562.

Krummenacher, T. Die Nährstoffbilanz des Alpnacher Sees; Dissertation ETH Zürich, in Vorbereitung.

Eawag (1955) Investigation on the Lake Sarnen basin; unpublished.

Eawag (1959) Die Verunreinigung von Linth und Limmat; unveröff.

Central Plateau:

Ambühl, H. (1960) Die Nährstoffzufuhr zum Hallwiler See; Schweiz Z. Hydrol., 22.

Eawag (1960) Der Murtensee; unveröffentlicht.

Pleisch, P. (1970) Die Herkunft eutrophierender Stoffe beim Pfäffiker See und Greifensee; Vierteljahresschr.Natf.Ges., Zürich, 115.

2.1.1. Influence of the water volume on the chemistry of brooks, as observed in small catchment areas in the Alptal (Canton Schwyz).

During a period of two years, Keller took samples - generally every week - from four brooks and simultaneously determined the momentary run-off of each brook at the time of the sampling.

Table 1 Utilization of the catchment areas under observation in the Alptal.

Catchment area	surface km^2	forest %	marshy meadows/ foothill bogs %	pastures %
I	0.72	56.0	37.1	6.9
III	1.55	63.0	25.0	12.0
V	1.08	37.7	20.3	42.0
VII	0.52	92.6	3.8	3.6
VIII	0.93	93.5	6.5	-

In consideration of the frequence of highwater and low water the following annual loads were determined:

Table 2 Annual nitrogen loads in the Alptal (kg N/km^2·a)

	Nitrate-N	Ammonium-N	Total anorganic N
I	112	37	149
III	119	30	149
V	171	22	193
VII	148	15	163
VIII	104	37	141

The average concentrations determined by weighing were as follows:

Table 3 Average annual concentrations (mg/l)

	I	III	V	VII	VIII
Nitrate	0.15	0.16	0.23	0.20	0.14
Ammonium	0.05	0.04	0.03	0.02	0.05
Phosphate-P*		0.001	0.001	0.001	0.001
Dissolved total P*		0.003	0.003	0.002	0.003

* three determinations only.

The average run-off amounted to $1.305 \cdot 10^6$ $m^3/km^2 \cdot a$.

2.1.2. The Lake of Alpnach

The following average concentrations were determined in eight brooks flowing from different types of land (forests, meadows, pastures and rocky land) into the Alpnacher See (a part of the Lake of Lucerne):

Table 4 Mean nutrient concentrations of brooks in the catchment area of Alpnacher See (μg/l).

	PO_4-P	Total P dissolved	NO_3-N	NH_4-N	Total anorg. N
Widibach	0.5	2.3	479	8	487
Chli Schlier	3.0	3.7	337	15	352
Grosse Schliere	1.5	4.2	237	16	253
Melbach	28	43.6	1233	49	1282
Amelioration canal	41.3	50.4	1947	68	2015
Speedway canal	16.0	25.6	1189	46	1235

2.1.3. The Lake Sarnen

Corresponding analyses effected in the Sarner See catchment area (Central Switzerland) bearing the water of brooks flowing through fertilized meadows, pastures and forests gave the following results as regards the phosphorus and nitrogen loads:

Table 5

	kg P/km^2 p.a.	kg N/km^2 p.a.
Blattibach + Rädishaldenbach	78	1425
Schwandbach	36	1106
Gerisbach	35	1180
Steinibach	41	1060
Rütibach	30	860
Leimergraben	23	690
Sigetschwandgraben	24	636
Maienbach	33	1080
Edisriedbach	59	1270
Dorfbach Sachseln	46	1130
Wissibach	35	1175
Dornibach	51	1380
Melchaa, lower course	33	1010

On the basis of correlation analysis, the following values for the loss of nutrients through leaching and erosion for the different types of land use could be determined:

Table 6

	Total N dissolved		Total P dissolved	
	mg/l	kg/km^2 p.a.	µg/l	kg/km^2 p.a.
Forests	0.6	840	3	4
Meadows without fertilizers	1.19	1650	54	74
Pastures with fertilizers	1.4	1940	74	102

2.1.4. The river system Linth-Limmat

In March 1959 at several points of the river system Linth-Limmat samples were taken continuously over a period of 24 hours. Since the upper part of the river Linth is certainly not charged with any waste water, there is an opportunity for the estimation of nutrient losses in prealpine and alpine soils. For this catchment area of 75.7 km^2 (3% forests, 5.5% mountain pastures and 91.5% unproductive land with rocks and glaciers) the following results were found as regards the loads at a specific run-off of 0.337 . 10^6 m^3/km^2 p.a.:

	µg/l	kg/km^{2}p.d.
Phosphate-P	10	0.0092
Nitrate + Nitrite	300	0.3038

2.1.5. Supply of nutrients into the Hallwiler See

The aim of this study was to measure the total supply of nutrients into the Hallwiler See and to answer the questions as to whether the nutrient load resulting from natural processes and from the agricultural utilisation of fertilizers would be low enough to prevent further eutrophication provided the inflow of wastewaters were stopped completely.

For this purpose, during one year, 60 statistically apportioned samples were taken, according to a fixed schedule, at different hours and seasons, from six affluents recognized as being the chief nutrient suppliers. At the same time, the run-off of the said affluents was determined.

The only affluent found to be suitable for the determination of the expected nutrient load was the Meisterschwander Village Stream which, in spite of its relatively large catchment area (8.1km^2), carried a weak wastewater load (0.9 km^2 of the catchment area consisted in forests and about 0.5 km^2 in constructed areas).

Minimal concentrations were always measured at 6 a.m.. AMBUEHL concluded from it that the total load may be considered as equivalent to the 'natural' load in the early morning hours. On the base of this supposition the phosphate load contributed by agriculture and forestry was calculated as follows:

$$\frac{\text{agricultural } PO_4\text{-P load}}{\text{km}^2 \text{ p.a.}} = 24.0 \text{ kg P/km}^2 \text{ p.a.}$$

Since however the run-off observed was higher than 0.098 m^3/sec in about 50% of the cases and considering that the load is not proportional to the run-off, the effective load had to be smaller than 42.0 kg PO_4-P/km^2 p.a.

According to the findings of the thorough study effected, the phosphate loss of the soil in the catchment area under observation would lie between 24.0 and 42.0 kg PO_4-P/km^2 p.a.

The nitrate concentrations were but very slightly influenced by the time of day and practically not at all by the run-off. This results, in conformity with the catchment area of the Sarner See, are in a linear dependence between the nitrate loads and the run-off (Illustration 4). At an average run-off of 0.098 m^3/sec, the nitrate load amounts to

$$20 \text{ kg N/day or } \frac{365 \times 20 \text{ kg N}}{8.1 \text{ km}^2} = 900 \text{ kg } NO_3\text{-N/km}^2 \text{ p.a.}$$

2.1.6. The Lake of Morat

Eleven rivers in the catchment area of the Lake of Morat were examined between December 1, 1954 and November 28, 1955 at intervals of two weeks.

On the supposition that about one third of the population was attached to the sewerage system and that the waste waters of the remaining two thirds had no influence on the receiving waters - or if so, only by way of the fertilizers utilized by agriculture - the contribution by agriculture to the charge of the receiving waters was evaluated as follows:

P loss of the soil: 25 - 30 kg/km^2 p.a.
N loss of the soil: 1500 - 2000 kg/km^2 p.a.

(The contribution of the population generally is assumed as to be 3 g P and 12 g N per capita / day.)

In the same study two small streams evidently not influenced by wastewaters were also examined. The nutrient loads contributed by agriculture were found to be as follows:

Table 7

Catchment area	surface km^2	PO_4-P load kg/km^2 p.a.	NO_3-N load kg/km^2 p.a.	total N load kg/km^2 p.a.
Rivière de Forel	2.0	39.5	2380	2590
Löwenbergbach	4.3	31.0	2040	2490

2.1.7. Origin of the eutrophising matter in the Pfäffiker See and in the Greifensee

In 1967 and 1968 PLEISCH made monthly samplings in 32 affluents of the Pfäffiker See and the Greifensee and at the same time evaluated their run-off in order to determine the amounts of nutrients supplied into the two lakes.

Seven of the 32 catchment areas were not or but very thinly populated, so that the nutrient load was practically due only to agriculture and forestry:

Table 8 Average concentrations and annual loads of the different catchment areas.

	PO_4-P conc. µg/l	PO_4-P load $kg/km^2 \cdot a$	NO_3-N conc. mg/l	NO_3-N load $kg/km^2 \cdot a$	NH_4-N conc. mg/l	NH_4-N load $kg/km^2 \cdot a$	anorg. N load $kg/km^2 \cdot a$
(1)	17	10	4.7	2750	0.04	23	2773
(2)	20	15	3.2	2380	0.04	28	2408
(3)	7	4.4	1.4	880	0.03	19	899
(4)	30	22.5	2.5	1880	0.13	98	1978
(5)	17	9.7	2.5	1430	0.07	40	1470
(6)	7	3.5	2.1	1050	0.07	35	1085
(7)	23	16.3	2.6	1860	0.06	43	1903

C.2.2. Recapitulation of the results

In order to permit a comparison between the results obtained by the different authors the concentrations (loads) of dissolved phosphorus compounds had to be partly evaluated from the data given for orthophosphate and total phosphorus. The following formula was applied:

$$(\text{dissolved P}) = \frac{(PO_4\text{-P}) + (\text{total P in raw water})}{2}$$

Thus calculated values are listed between brackets in Table 9.

Illustrations 5 and 6 show the specific superficial nitrogen and phosphorus loads in relation to the parts of the catchment area exploited by agriculture.

If "a" represents the specific superficial nutrient loss of the part of the area not exploited by agriculture and "b" the cultivated surfaces, the nutrient loss "Y" occurring through leaching and erosion in an area of mixed exploitation will be either

$$Y = (1-X)a + Xb \qquad \text{or} \qquad Y = a + (b-a)X\ .$$

"X" is the relative portion of surface exploited by agriculture $(X \leq 1)$.

Division into only two types of utilization, without consideration of the fertilization practices, type of cultivation (pastures, meadows, fields), climatic and topographic considerations, is of course a very rough distinction and does not correspond entirely with the effective conditions reigning in the area.

However – at least as regards phosphorus – the concordance is quite surprising. The phosphorus losses from forest areas are practically nil in the Prealps as well as in the Central Plateau.

Table 9 Type of utilization and nutrient losses from water from various areas of the Central Plateau.

Catchment area	$Q/km^2.10^6m$	utilization by agriculture %	utilization by forestry %	dissolved phosphorus µgP/l	dissolved phosphorus $kgP/km^2.a$	dissolved nitrogen mgN/l	dissolved nitrogen $kgN/km^2.a$
Hallwilersee							
Meisterschwander Dorfbach	0.38	83	11	59–103	24.0–42.0	2.37	900
Murtensee	0.655						
Le Chandon		74.2	25.8	37.6–46	25 –30	1.7–2.2	1120–1430
Rivière de Forel		95.7	4.3	60	39.5	3.95	2590
Löwenbergbach		88.8	11.2	47	31	3.80	2490
Greifensee-Pfäffikersee							
Torfrietabfluss	0.58	53	47	24	(14)	(4.7)	2733
Unterwiesbach	0.71	59	41	28	(21)	(3.2)	2408
Murholzbach	0.62	29	71	7	(4.4)	(1.4)	899
Seewiesenabfluss	0.75	100	0	35	(26.5)	(2.6)	1978
Aawiesenabfluss	0.57	85	15	22	(12.6)	(2.6)	1470
Jungholsbach	0.50	5	95	14	(7)	(2.2)	1085
Schulhausbach	0.71	67	33	28	(19.7)	(2.7)	1903

But if the catchment area is 100 % utilized by agriculture the phosphorus loss to be expected will be approximately 35 kg $P/km^2.a$ on the Plateau and approximately 70 kg $P/km^2.a$ in the Prealps. The higher Phosphorus losses from Prealpine soils are mainly due to the higher run-offs bound with more intensive erosion.

In the Prealpine areas, the nitrogen losses from surfaces utilized by forestry amount to approximately 82 kg $N/km^2.a$ and the losses from specifically agricultural soils are about 1634 kg $N/km^2.a$. As seen in illustration 6, the increase of the surfaces utilized by agriculture is bound with a more rapid increase of the nitrogen loads in the Prealpine area then on the Central Plateau (Illustration 5). Consideration should however be given to the fact that the determinations were effected at different altitudes. Taking separately the Alptal area (altitude of the area: approximately 1100–1500 m above sea level) and the

Sarner See area (500-1700 m above sea level), we find that the nitrogen losses from surfaces utilized specifically by forestry in the Alptal amount to 145 kg N/km^2·a, whereas they attain 300 kg N/km^2·a in the Sarner See area. The equation for the straight line of regression regarding the Sarner See area only would be

$$Y = 301.5 + (1547.4 - 301.5) X .$$

There is a dense scattering of the various values regarding the measures of nitrogen losses from Central Plateau soils around the calculated straight line of regression. But it is quite evident that the nitrogen losses are heavier on the Central Plateau than in the Prealpine area from surfaces assigned to the same type of utilization. The heavy straying of the values around the straight line of regression may be explained by the fact that the agricultural surfaces on the Plateau are of much more heterogenous composition (farming of various crops, seeded grassland, natural grassland, pastures) than in the Prealps (natural grassland and pastures).

For areas on the Central Plateau, the nitrogen losses from surface utilized specifically for forestry amount to about 960 kg/km^{2}p.a., whereas the nitrogen losses from purely agricultural surfaces amount to 2100 kg N/km^{2}p.a.. The higher nitrogen losses from forest surfaces at lower altitudes are due to a more intensive biological nitrogen conversion.

It may be said in conclusion that the following average losses of dissolved nitrogen and phosphorus compounds are to be expected in purely agricultural areas:

	kg N/km^{2}p.a.	kg P/km^{2}p.a.
Prealpine area	1634	69
Central Plateau	2100	35

The nutrient loads of flowing water bodies do not depend solely on the dissolved or soluble nutrients present in the soil of the catchment area, but also on the specific run-off:

load = concentration x run-off.

On the other hand, the concentration may depend (phosphorus, Illustrations 1, 2 and 3) or not depend (nitrogen, Illustrations 1 and 4) on the run-off. But it is quite certain that it always depends on the amount of dissolved or soluble nutrients present in the soil.

In order to eliminate the influence of the different run-offs in the areas examined, we have, in Illustrations 7 and 8, shown the concentration in function of the type of soil utilization. It can thus be seen that the average nutrient concentrations increase on the total surface of the catchment area as increases the portion of the area exploited by agriculture, that the concentrations of dissolved phosphorus compounds from surfaces assigned to the same type of utilization are practically equivalent on the Plateau and in the Prealpine area, and that the nitrogen concentrations on the Plateau are even considerably higher than in the Prealpine area.

If, in this case too, we should resort to linear representation to show the dependence of the concentrations from the portion of the total catchment area assigned to agricultural use, it might be that the phosphate concentrations of water bodies in surface utilized by forestry would be neglected in comparison with the phosphate concentrations in purely agricultural areas.

There are two reasons for the fact that, in spite of the less intensive use of phosphorus fertilizers in the Prealps on surfaces assigned to the same type of utilization, the phosphorus concentrations of the receiving waters are even slightly higher in this area than on the Plateau:

- The phosphorus content of the soil is but insignificantly influenced by the application of fertilizers.

- In prealpine areas, the phosphorus compounds are not only leached by precolation, but they are also carried away by erosion. This theory is confirmed by the fact that, on the Plateau, the phosphate concentrations decrease (dilution) as increases the run-off (Illustr. 2 and 3), whereas in Prealpine areas they, on the contrary, show a slight tendency toward increasing (erosion) (Illustration 1).

Since the nitrate concentrations are largely dependent on the run-off (Illustrations 1 and 4), the higher concentrations found in the Plateau streams are most probably due to a larger amount of dissolved or soluble nitrogen compounds in the soil resulting from a more intensive microbic mobilization and from a more intensive use of nitrogen fertilizers.

C.2.3. Lysimeter tests

The amount of lixiviated nutrients can be determined with the help of lysimeters. The amount of nutrients which is washed out of the soil and gets into water bodies is generally higher, the lighter (sandier), shallower and richer in nutrient the soil, the wetter the climate, the more intensive the application of fertilizers and the weaker the growth (root formation) of the plants.

2.3.1. A few results of Swiss lysimeter tests

Table 10 recapitulates the results of tests effected with a sandy and loamy soil which was poor in humus and showed a neutral reaction. Since the depth of the soil layer in the lysimeters used was only about 45 cm, the values for run-off and leaching were relatively high. It was found that plantation (of a grass mixture) considerably reduced the run-off, especially in summer, and lowered the lixiviation of nitrogen. The copious applications of liquid manure (175 m^3/ha p.a.) intensified the growth of the plants, increased transpiration and reduced the run-offs. Owing to the copious applications of nitrogen together with the liquid manure (315 kg N/ha p.a.), the lixiviations of nitrogen were somewhat increased, though they did not, by far, attain the values determined in the lysimeters without planting and without applications of fertilizers. The higher values were measured principally in the course of the second year of the tests, in places where the grass growth was impeded. The phosphorus losses were slight (approximately 0.4 kg/ha p.a.) and were influenced neither by the applications of fertilizers, nor by the planting of grass.

Table 11 shows the result of a similar lysimeter test effected however with a heavier and clayey soil. In this case, the phosphorus losses were very slight and were below the determinable limit (at the time the test was made). Owing to the higher water retention capacity of the soil, the run-offs were lower. Since the grass in the lysimeters with copious applications of liquid manure grew richly, the nitrogen leaches, in spite of the intensity of the manuring (365 kg N/ha p.a.), were rather lower than in the lysimeters without fertilizers and with grass and much lower than in the lysimeters without fertilizers and without grass. The yearly curves representing the nitrogen lixiviations in lysimeters without grass, as well as the curves representing the amounts of precipitation and percolation water and the temperature are shown in Illustration 13.

Table 10 Lysimeter tests, Oerlikon, Series I 1923 & 1924

Soil: sandy loam, pH = 7.2, 1.29 % humus,
texture: 57 % 50 µm.
Lysimeter: 50 x 50 x 50 cm, system GEERING.

Process	a	b	c
Vegetation	0	grass	grass
Fertilization (average of 2 years) commercial fert. kg/ha	0	0	136
liquid manure m^3/ha	0	0	175
Water balance (average of 2 years)			
Summer precipitations mm	627	627	627
run-off mm	364	269	203
in % of the precipit.	58	43	32
Winter precipitations mm	405	405	405
run-off mm	383	382	354
in % of the precipit.	95	94	87
Year precipitations mm	1032	1032	1032
run-off mm	747	651	557
in % of the precipit.	72	63	54
Phosphorus balance			
application of fertilizers kg/ha	0	0	20.7
depletion through grass kg/ha	0	9.8	27.9
leaching kg/ha	0,44	0.35	0.39
mg/ha	59	54	70
Nitrogen balance			
application of fertilizers kg/ha	0	0	315
depletion through grass kg/ha	0	41.0	147.5
leaching kg/ha	117.3	16.4	45.3
mg/ha	15.7	2.5	8.1

The importance of vegetation as regards the reduction of the nitrogen losses is again shown clearly in Table 12. During the main growth period, the lixiviation of nitrogen is considerably slighter in the lysimeters with grass than in the others (stable manure). This is also shown in Illustration 14.

The lysimeter tests showed repeatedly that considerable amounts of nitrogen are washed out of the lysimeters without application of fertilizers and without grass. This is partly due to the mobilization of organic nitrogen compounds in the humus ingredients of the soil. Illustration 15 shows how the mobilization of nitrogen is increased by soil loosening.

Table 11 Lysimeter tests, Oerlikon, Series II 1926 & 1927

Soil: clayey loam, pH = 5.6, 1.63 % humus,
texture: 77 % 50 µm.
Lysimeter: 50 x 50 x 50 cm, system GEERING.

Process			a	b	c
Vegetation			0	grass	grass
Fertilization (average of 2 years)	commercial fert.	kg/ha	0	0	136
	liquid manure	m^3/ha	0	0	148
Water balance (average of 2 years)					
Summer	precipitations	mm	780	780	780
	run-off	mm	338	289	138
	in % of the precipit.		43	37	18
Winter	precipitations	mm	404	404	404
	run-off	mm	320	300	262
	in % of the precipit.		79	74	65
Year	precipitations	mm	1184	1184	1184
	run-off	mm	658	589	400
	in % of the precipit.		56	50	34
Phosphorus balance					
	application of fertilizers	kg/ha	0	0	24
	depletion through grass	kg/ha	0	4.6	24
	leaching	kg/ha	traces	traces	traces
		mg/ha	traces	traces	traces
Nitrogen balance					
	application of fertilizers	kg/ha	0	0	365
	depletion through grass	kg/ha	0	26	156
	leaching	kg/ha	85.8	29.2	23.8
		mg/ha	13	5	6

Table 12 Nitrogen leachings and crop losses in the period between September 10, 1931 and November 1, 1932

Results of lysimeter tests, after GEERING (kg/ha)

Test method	without vegetation	rye	wheat
Nitrogen supply in form of stable manure	92.0	92.0	92.0
until the harvest:			
losses of nitrogen as NH_3 through percolation	12.1	11.8	12.6
losses of nitrogen as NO_3^- through percolation	92.7	15.4	36.5
nitrogen depletion through the crops	-	36.7	40.1
total nitrogen losses of the soil	104.8	63.9	89.2
Nitrogen losses through percolation before the main growth period (7 months)	30.3	19.5	27.6
Nitrogen losses through percolation during the main growth period (3 1/2 months)	74.5	7.7	21.5
Nitrogen losses through percolation after the harvest, until the end of October (3 months)	64.6	54.0	55.1

2.3.2. Discussion of the lysimeter tests

Phosphorus and nitrogen are the principal nutrients that are responsible for the eutrophication of water bodies. The contribution of agriculture toward eutrophication consists in

- commercial fertilizers
- farm manure
- wastes (silo liquor, harvest residues etc.)
- susceptibility to erosion because of the soil exploitation and mobilization of nutrients.

There are in principle two ways by which the nutrients are brought into water bodies:

a) by passing through the soil = leaching

b) by passing on the surface of the soil = run-off, erosion.

It is possible, by means of the lysimeter tests, to determine the nutrients that get into water bodies via leaching.

Table 13 Phosphorus and nitrogen amounts in the percolation water of lysimeters and in rain-water, in kg/ha, average of the years 1953 to 1956; after LOW et al.

	Lysimeter			
	Fallow	Grass	Clover	Rain-water
NO_3-N	82.0	0.7	37.0	3.1
NH_4-N	4.2	0.3	1.4	9.4
P	2.3	0.9	1.3	1.0

Table 14 Soil content in total phosphorus (mg/kg) in 1959, determined in the permanent tests at Barnfield; after COOKE et al.

Depth of the soil	Yearly application of fertilizers per ha, since 1845			
	0	35 t manure	35 t manure + 33 kg P	33 kg P
0 - 225	669	1263	1877	1206
225 - 300	453	600	753	506
300 - 375	425	498	592	475
375 - 450	412	428	474	400

2.3.2.1. Phosphorus leachings

Except in extreme sandy soils - which practically do not exist in Switzerland - phosphorus is very firmly fixed in the soil, so that very small amounts only are leached away. In the lysimeter tests effected in Switzerland the phosphorus leaching never surpassed 0.5 kg P/ha (in spite of the considerable run-offs). The influence of both manuring and cultivation appeared to be negligible. The phosphorus losses through leaching would therefore be lower than the losses caused by precipitations. According to the measures effected by LOW et al., the amount of phosphorus brought into the soil by precipitations is approximately 1.0 kg/ha.

Even an unmanured soil receives considerable amounts of phosphorus. In Switzerland, the phosphorus content in a soil layer of 120 cm can be expected to amount to about 4'000 - 10'000 kg P/ha. The additional amount of 20 - 70 kg P/ha p.a. in form of fertilizers brought into the soil in areas of cultivation might seem relatively negligible. We should not forget however that the phosphorus contained in fertilizers is much more soluble; it is relatively quickly fixed in the soil and does not penetrate very deeply into it. In this connection, the results of English tests consisting in applications of fertilizers made over an extremely long period are most interesting. The data given in table 14 for the phosphorus contents found in various depths after manuring during a period of more than a century shows that about 90 percent of phosphorus amounts introduced were retained in the upper 22 cm of the soil. Similar observations were made by GISIGER in soils under natural meadows and orchards and even in heavily over-manured garden soils (Table 15).

It may be concluded therefrom that the soil acts as an efficient barrier against phosphorus losses through leaching. Even intensive application of phosphorus fertilizers hardly increased the losses. It however remains possible that considerable amounts of phosphorus be brought into water bodies through superficial run-offs and eorsion (erosion of soluble fertilizers shortly after application, erosion of earth from the top layer of the soil enriched with phosphorus).

Table 15 Distribution of orthophosphoric acid and potash at various depths in the soil; after GISIGER

Depth of the layer cm	Garden soil		Orchard		Natural meadow	
	P_2O_5 test	K_2O mg %	P_2O_5 test	K_2O mg %	P_2O_5 test	K_2O mg %
0 – 5	165	22	25	12	21	8
5 – 10	180	20	13	5	3	6
10 – 20	160	12	10	3	2	8
20 – 30	120	4,5	7	1,5	–2	0,5
30 – 50	20	3,8	not		–1	0,1
50 – 80	0–2	0,5	determined		not determined	

2.3.2.2. Nitrogen leachings

The binding of nitrogen in the soil occurs in many different ways. The major part is organically bound to humic substances and therefore cannot be washed away. Nitrogen in form of NH_4^+ and NO_3^- is available to the plants and subject to leaching, although NH_4^+ as cation can be absorbed by clay and is therefore much less subject to leaching than NO_3^-.

Under good conditions of humidity and temperature and under the influence of biological activity, the transformation of nitrogen in the soil is intense. The organically bound nitrogen in humic substances and in dead vegetal matter is mobilized (converted into ammonium and nitrate) and then assimilated by the plants or else leached away. Nitrate can be reduced into elementary nitrogen by denitrifizing bacteria, so that it is lost for the system soil/plant. On the other hand, nitrogen binding bacteria, blue-green algae and fungi can bind the nitrogen contained in air and thus re-circulate it into the system. In addition, nitrogen compounds contained in the atmosphere are brought into the soil by rain-water or through direct ammonia absorption.

The above mentioned processes which are not necessarily influenced directly by agricultural practices should be taken into consideration in the evaluation of the contribution by agriculture toward eutrophication of water bodies as regards nitrogen. The results of the above mentioned lysimeter tests can be recapitulated as follows:

a) During the vegetation period, considerably less nitrogen is leached away from fallow land than from cultivated soils. The active roots absorb the easily leachable nitrate very rapidly.

b) Even quite heavy nitrogen manuring - as well in form of commercial fertilizers as in form of farm manure - need not result in considerable nitrogen leachings, provided that well-balanced manuring (not one-sided) procures an intensive vegetation and that the applications of nitrogen fertilizers are made at periods when the plants are able to assimilate them.

c) The nitrogen leachings under leguminous crops will be considerably more than those occurring under grass for instance, because a large amount of nitrogen is mobilized when the roots covered with nodule bacteria (nitrogen assimilation) die away.

d) Soil loosening activates nitrogen mobilization which often results in considerably increased nitrogen leachings, owing to the insufficient plant cover.

It is fortunate that optimal manuring practices in agriculture (applications made in proper doses and at proper intervals) are also optimal as regards the nutrient load imposed on water bodies. When we speak of optimal manuring practices, we mean in the first place that the doses should be adpated to the assimilation capacity of the crops and that, especially as regards nitrogen, the applications should never be made massively, but by degrees and in several portions. Nitrogen applications should never be made shortly before the vegetation pause in winter and each application should be carefully dosed in consideration of the depth of the soil layer. The risk of leachings is very great in shallow soils. It is surely not in the interest of agriculture that a part of the nitrogen fertilizers be leached away instead of benefiting the crops. In the evaluation of the contribution by agriculture toward the eutrophication of water bodies, as regards nitrogen, the amounts of nitrogen per ha which are brought into the soil by precipitations should not be neglected. According to measures effected, they vary between 5 and 28 kg N/ha and the average value would be approximately 20 kg. This lies in the scope of nitrogen losses due to percolation in areas of intensive cultivation (10 - 40 kg/ha). The nitrogen losses due to run-off and erosion should be added to the above value, for they also contribute to the nutrient load imposed on water bodies, though they cannot be determined by means of the lysimeter tests.

C.3. Relative share of the agricultural contribution in the total nutrient load imposed on some Swiss lakes, and the consequences that result therefrom

The percentual share of agriculture in the total nutrient load of lakes is influenced not only by climatic and topographical conditions, but also, to a very large measure, by the density of population and the type of agricultural utilization practised in the catchment area.

It can be seen in Table 16 and Illustration 9 that, at average population densities of 50 to 150 inhabitants per km^2, the share of the nitrogen introduced via waste water is under 35 percent, whereas the share of the phosphorus introduced via waste water amounts to 50 - 75 percent of the total nutrient load. The remaining 25 - 50 percent as regards phosphorus and 65 percent as regards nitrogen are, for the major part, leached or eroded from cultivated and natural soils.

The nitrogen losses from soils utilized by agriculture are approximately 1 630 kg N/km^2 p.a. in the Prealpine area and 2 500 kg-N/km^2 p.a. on the Central Plateau. The corresponding phosphorus losses are approximately 70 kg P/km^2 p.a. in the Prealpine area and 35 kg P/km^2 p.a. on the Plateau. In percentage of the annual amounts of commercial fertilizers brought into the soil, the losses amount to about 16 – 25 percent as regards nitrogen and 0.7 – 1.4 percent as regards phosphorus.

This data and the fact that a relatively small part of the phosphorus, but a considerable part of the nitrogen introduced into the lakes, come from soils in the catchment area, should not mislead us into giving more importance to the nitrogen load contributed by agriculture than to the phosphorus load of the same origin.

The troublesome artificial eutrophication is not an economical, but a limnonlogical problem based on the laws discovered by LIEBIG and MITSCHERLICH.

Algae, provided their growth is well-balanced, assimilate nitrogen and phosphorus in the weight ratio of 7 : 1. The N : P ratio of flowing waters varies regionally. It is approximately 30 in the Prealpine area and 80 on the Plateau. In both types of water bodies it is considerably more than 7 : 1. This means that the growth of algae in such brooks and rivers is limited by the phosphorus supply.

Thanks to their relatively high phosphorus content (50 percent of the phosphorus compounds come from detergents), the N : P ratio of waste waters is quite low, namely about 4 : 1. According to what was said previously, the growth of the aquatic plants would be, in this case, limited by the nitrogen supply.

Table 16 Share of waste waters in the total nutrient load of some Swiss lakes

Catchment area of the	density of population inh./km^2	phosphorus %	nitrogen %	Reference
Lake of Zurich	86	53	24	THOMAS cit.
Lake of Zurich		67	33	EAWAG cit.
Lake of Morat	89	52	6	EAWAG
Lake of Hallwil	125	50	5	AMBUEHL
Alpine Rhine Stream	39	53–66	26	VOLLENWEIDER
Lake of Muzzano	1000	95	80	VOLLENWEIDER
Lake of Muzzano		98	87	EAWAG
Inkwiler See	70	65	22	EAWAG
Greifensee	430	74	38	PLEISCH
Mauensee	35	50	15	EAWAG

In Illustration 10, we made an evaluation of the N : P ratio in the receiving water in function of the density of population and the type of land utilization in the catchment area, for regions in the Prealps and on the Plateau. The estimations were based on the supposition that the waste waters were discharged into the receiving water without previous purification. In the case of waste waters previously treated in a mechano-biological plant with roughly the same elimination rates for both phosphorus and nitrogen compounds, the curves would cut the 7 : 1 limit at even higher population densities. Since the algae growth in lakes is limited chiefly by the phosphorus supply, efforts are being made in Switzerland to remove additional phosphorus compounds from waste waters by subjecting them to tertiary purification. The elimination rate of such plants being 50 percent for nitrogen and 90 percent for phosphorus compounds, the N : P ratio in the effluent would increase up to approximately 20 : 1. Accordingly, the N : P ratio in the receiving water would never again fall below 20 : 1. It should moreover be noted that phosphorus compounds, particularly under aerobic conditions, are retained in the sediments of lakes to a larger extent than nitrogen compounds, so that N : P ratio in the lakes would shift even more to the advantage of nitrogen. We therefore, though by different course, come to the same conclusion as VOLLENWEIDER, namely that, under Swiss conditions and at an average population density of about 150 inhabitants per km^2 (concentrated principally on the Plateau), the minimal growth substance in lakes is really phosphorus and not nitrogen. Direct confirmation of this affirmation was found in the results of analyses effected at the Lake of Lucerne. This means that, although the nitrogen losses of the soil may be quite considerable from the economical point of view, it is the less considerable phosphorus losses of the soil that provide the major contribution toward eutrophication of water bodies. In connection with the problem of eutrophication, more importance should therefore be given to the phosphorus losses than to the nitrogen losses.

VOLLENWEIDER endeavoured to draw the limits between oligotrophic, mesotrophic and eutrophic lakes. The average depth (volume/surface of the lake) and the specific charge of the lake in bioactive phosphorus compounds (introduction/surface) were taken into consideration in these investigations. The data regarding the charge limits is shown in Illustration 11.

The phosphorus supply into a lake (P_S) is proportional to the surface of the catchment area (S_C) and the phosphorus export specific per surface unit (P_E).

$$P_S = S_C \cdot P_E \qquad (1)$$

The "environmental factor" (f_e) is a notion introduced in limnology by OHLE. It indicates how many times the surface of the lake (S_L) is contained in the surface of the catchment area (S_C).

$$f_e = \frac{S_C}{S_L} \qquad (2)$$

By dividing the equation (1) by the surface of the lake (S_L) we obtain the specific phosphorus load of the lake ($\frac{P_S}{S_L}$) as influenced by f_e and P_E

$$\frac{P_S}{S_L} = f_e \cdot P_E \qquad (3)$$

In Illustration 12, the tolerable phosphorus export specific per surface unit from the catchment area, as influenced by the average depth of the lake is noted for various f_e. This data was set up in consideration of the charge limits fixed by VOLLENWEIDER. According to VOLLENWEIDER, the phosphorus export from the catchment area in amounts liable to harm the lake is twice as much as the tolerable export.

In Table 17 the environmental factors, the average depth, as well as the tolerable and harmful phosphorus exports specific per surface unit from the catchment area, are indicated for a number of Swiss lakes:

Table 17

	f_e	Average depth m	Phosphorus export from the catchment area tolerable up to kg P/km^2·a.	Phosphorus export from the catchment area harmful over kg P/km^2·a.
Lake of Aegeri	7.1	49	34	68
Lake of Constance	20.1	100	20	40
Lake of Brienz	38.1	174	15	30
Lake of Geneva	13.6	154	38	76
Greifensee	19.4	19	7	14
Lake of Morat	25.6	22	6	12
Lake of Pfäffikon	12.1	19	12	24
Lake of Lucerne	19.6	104	20	40

Comparison of this data with the expected phosphorus losses of the soil (illustrations 6 & 7) shows that the tolerable amount of phosphorus exports in the major part of the lakes has already been attained or surpassed through the introductions from this source alone.

We however know that the phosphorus losses of the soil are only a part of the total phosphorus charge imposed on the lake. If we count 3 g P per capita and day, we obtain the following additional charge contributed by waste waters, as influenced by the density of the population (kg P/km^2 p.a.):

Table 18

Population density inh./km^2	Phosphorus elimination through: mechano-biological purification 30 %	additional treatment 85 %	additional treatment 95 %
10	7.7	1.65	0.55
50	38.5	8.25	2.75
100	77.0	16.5	5.5
200	154.0	33.0	11.0

If the waste waters are subjected to mechano-biological purification only, it must be reckoned that the noxious limit will be surpassed in most of the lakes, even, though the population density may be as low as 50 inh./km^2.

Generally speaking, the possibility of maintaining lakes in their oligotrophic state or of restoring them to their oligotrophic state in areas where the population density is higher than 50 inh. per km^2 is only given if the rate of phosphorus elimination from waste waters surpasses 85 percent. In areas where the density of population is higher than 100 inh./km^2, even the phosphorus elimination rate of 95 percent will, most often, not bring good results, unless additional measures are applied in view of a further reduction of the phosphorus losses from agricultural soils.

C.4. Consumption and application of fertilizers

The amounts of fertilizers recommended for application in Swiss agriculture are shown in Table 19. The data is taken from the Swiss Directives for Use of Fertilizers, set up by the Swiss Agricultural Research Institutes and published by the Swiss Association of Agricultural Advisors, in 1966. The nitrogen amounts are intended for soils having a medium humus content (2-5 %); the phosphorus amounts are intended for soils with, as well as without sufficient supply:

Table 19 Amounts of fertilizers recommended in case no farm manure is added. Recommended doses per ha and p.a.

	N	P (P_2O_5) sufficient supply		P (P_2O_5) insufficient supply	
Permanent grassland (Plateau)	40- 80	35-52	(80-120)	0-26	(0-60)
Temporary grassland	40- 80	35-52	(80-120)	0-35	(0-80)
Potatoes	80-120	26-35	(60- 80)	0-26	(0-60)
Sugar beet	80-120	35-44	(80-100)	0-35	(0-80)
Cereals	0-100	17-26	(40- 60)	0-17	(0-40)
Peas	0	17-35	(40- 80)	0-17	(0-40)
Tobacco	40- 80	26-40	(60 -90)	0-26	(0-60)
Maize for ensilage	140-180	30-40	(70-100)	0-30	(0-70)
Grain-maize	120-160	26-40	(60-100)	0-26	(0-60)

C.5. Possible agricultural measures to reduce the supply of nutrients into water bodies

From what has been said previously we now know that the eutrophication of our lakes and rivers is caused in the first place by phosphate compounds. We should therefore primarily tend toward reducing the supply of phosphorus into lakes.

As shown by the results of lysimeter tests, applications of phosphorus fertilizers appear to have but an insignificant influence on phosphorus leaching. Nevertheless, various observations show that the concentration of dissolved phosphorus compounds increases (Illustration 1) with the velocity of flow. This is due to erosion of the top layer of soils treated with soluble phosphorus. The following technical measures can help to reduce the phosphorus load imposed on water bodies:

- Prevention of losses due to erosion by putting plants to grow on the particular piece of ground. Fallow periods in crop farming can be avoided by intermediate cultures of fodder plants or by green manuring.

- Afforesting of all steep and easily erodable areas, particularly in the Alps.

- Avoidance of overgrazing of pastures in order to maintain the turf which protects the ground against erosion.

- The spreading of fertilizers on pastures from airplanes is not recommended, in areas where there is any chance of steep and easily erodable ground being included.

- Crop farming should not be practised on steep sites.

- Particular attention should be given to protection against erosion in intensive culture (for exemple in viticulture). Mulching, with compost for instance, or green manuring are recommended. All applications of fertilizers should be reduced to a reasonable measure, and the fertilizers should be ploughed into soil or sprayed.

- No applications of fertilizers should be made on wet or frozen soils.

The following administrative and regulative measures are moreover recommended:

- Training and advising of agricultural populations with a view to increasing their comprehension of environmental problems.

- Setting up of cultivation and manuring programmes in connection with regional planning.

- Adjustment of the subvention policy to the interests of water protection.

- Setting up of limits of tolerance for phosphorus concentrations in water flowing from agricultural areas.

- Supervision of liquid manure pits and of installations for collecting dung and silo liquor as regards their impermeability.

- All authorizations granted for livestock raising on an industrial scale should be accompanied by special prescriptions regarding the size of the liquid manure pits and the guaranteeing of a market for the liquid manure.

C.6. Final considerations about phosphorus and other plant nutrients economy

The discovery of LIEBIG and other leading plant physiologists had given fertilizer production unexpected impetus. It was hoped that the weighty task of feeding a constantly increasing world population could be solved thanks to artificial fertilizers. However, these soaring hopes were soon dashed; doubt, disappointment and finally resignation set in, for the shortcomings of artificial fertilizers had become painfully apparent. Agricultural experts had failed to pay sufficient heed to one cardinal rule, that is, that a well-balanced quantitative ratio between the various elements in the soil and the percentage of organic matter had to be maintained lest the initially obtained increase in crop yield slow down and finally even regress.

Among gardeners and farmers a movement for the application of biological farming methods was started; these circles came out against the excessive use of artificial fertilizers. This recognition gradually spread to consumers, wholesalers and finally vegetable farmers. At the same time, a vegetarian trend became felt, a development which agricultural producers were obliged to heed and cater to.

The proponents of biological farming methods forwarded guidelines for scientifically sound soil cultivation and fertilization; prime importance is given to the optimum composition of the soil's biocenosis. Biological farming methods are often doubted and even viewed with suspicion, however, indications make it more and more clear that there is much to be learnt from biological fertilization. The improvements obtained through biological farming cannot simply be shrugged off.

Another theory on the fertilization of plant cultures has now been evolved to complement LIEBIG's practically uncontested law of the requisites minimum amount of fertilizer to be used. This new theory sets a ceiling to fertilizer application and shows that excessive amounts lead to a rapid drop in crop yield as well as qualitative and quantitative damage to plants.

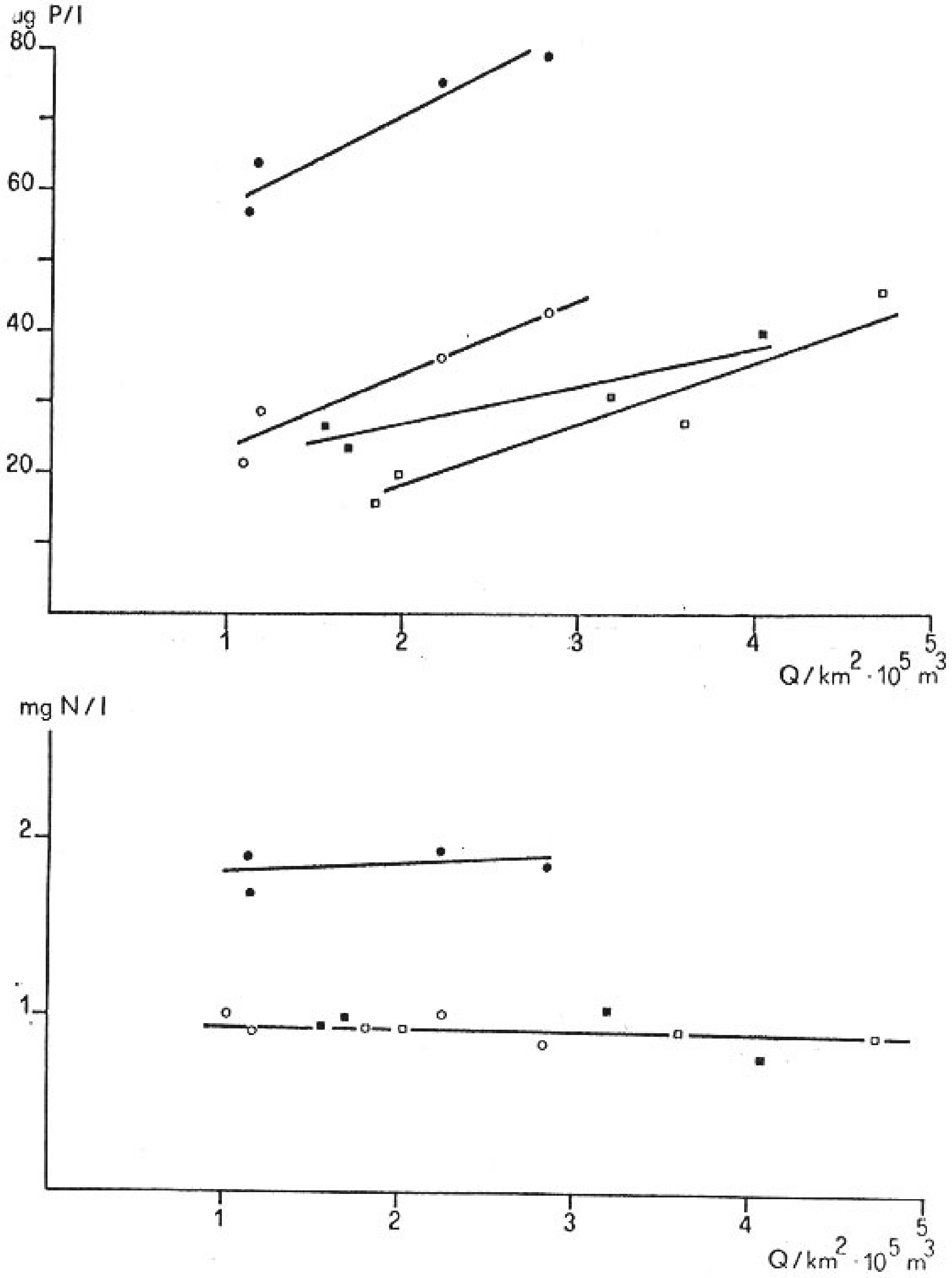
VOISIN and PH. MATILE, a plant physiologist from the Swiss Federal Institute of Technology, warned against the one-sided use of artificial fertilizer. It can therefore be expected that artificial fertilizer production and the use of phosphorus and nitrogen salts will in future lose in importance. For water pollution control, this will certainly be a welcome development.

In this report summarizing the recommendations made at the Workshop on Global Ecological Problems held in Madison in June 1971, Prof. D.H. HASLER stressed the importance of reducing world phosphorus consumption, which is mainly centered around fertilizers. In view of the fact that the rapidly increasing worldpopulation will require more food, thus placing a greater stress on fertilizer production,all available sources must be husbanded with great care. These mineral salts, which in rain washes out of fertilized soil and which act as a eutrophizing agent in surface and ground water, are taken to the sea where they are precipitated and consequently lost to mankind.

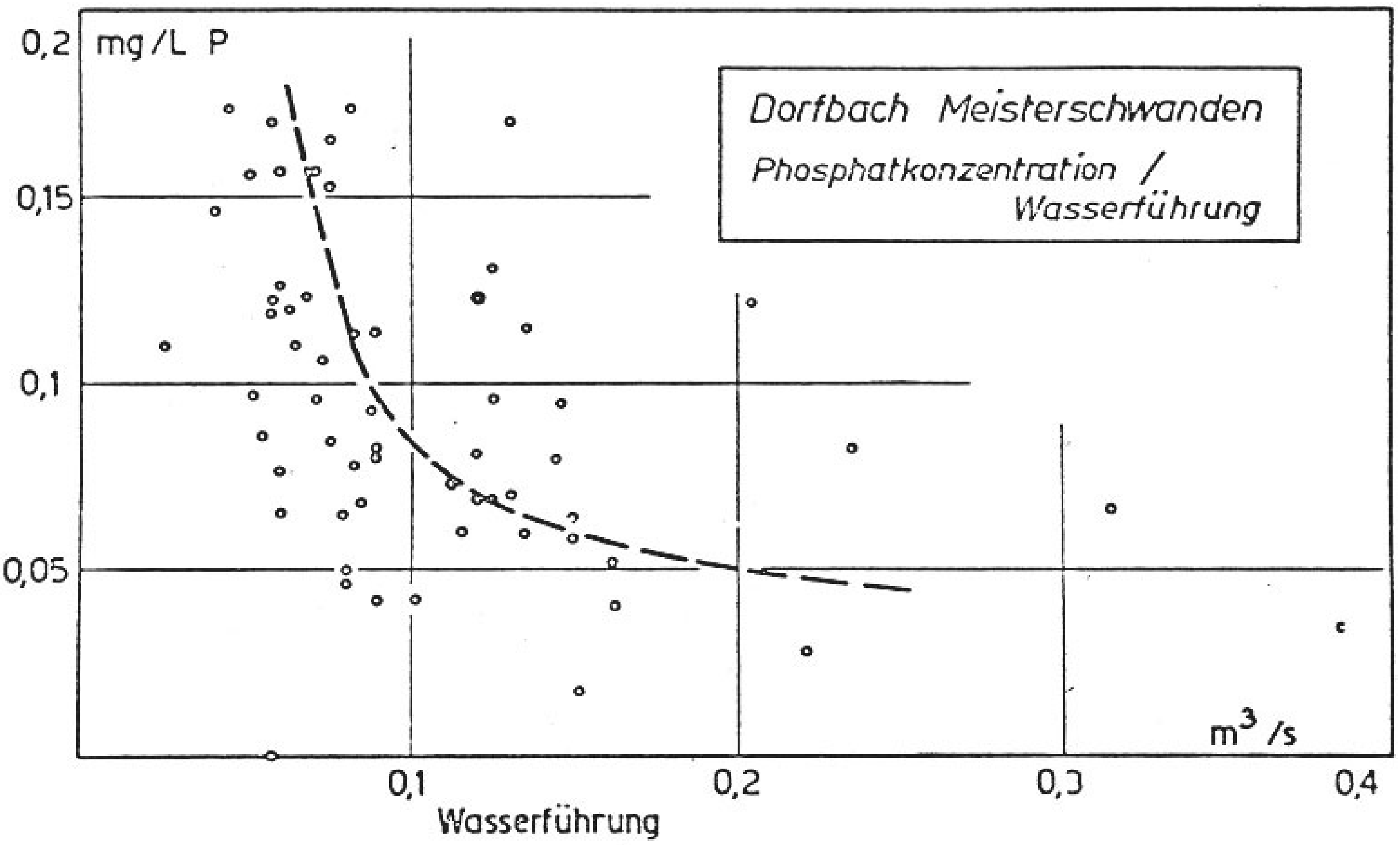
A.D. HASLER furthermore suggested that phosphorus be recycled by wastewater precipitation so that this valuable raw material is not squandered.

The participants at the workshop also calculated that the dwindling phosphorus supply will be depleted in less than 100 years. Phosphorus-bearing rock is an excellent source of this element and must therefore be protected against irresponsible exploitation.

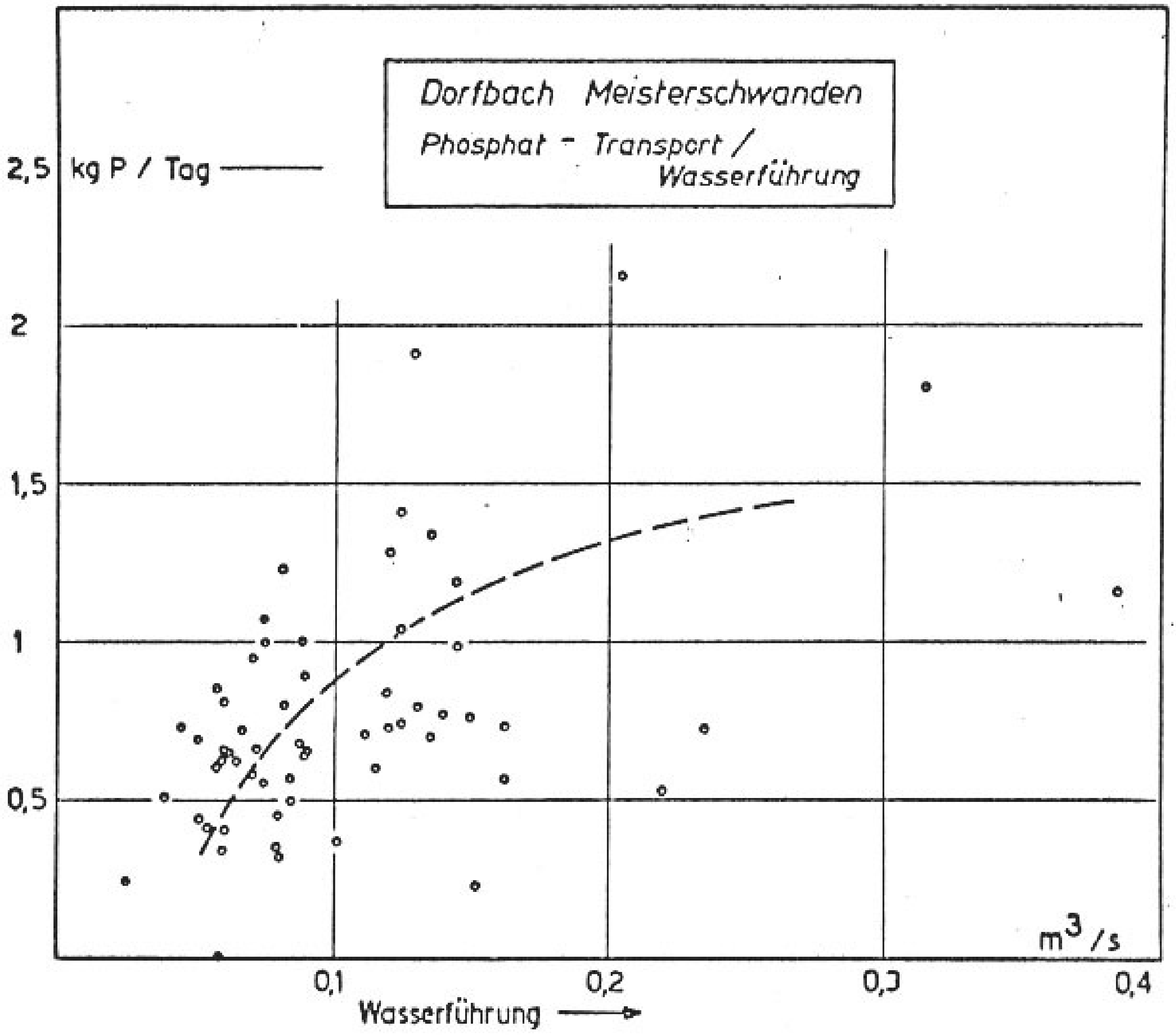
It must be borne in mind that phosphorus, nitrogen and other mineral salts will be needed for the production of synthetic detergents and fertilizers for many, many years to come.



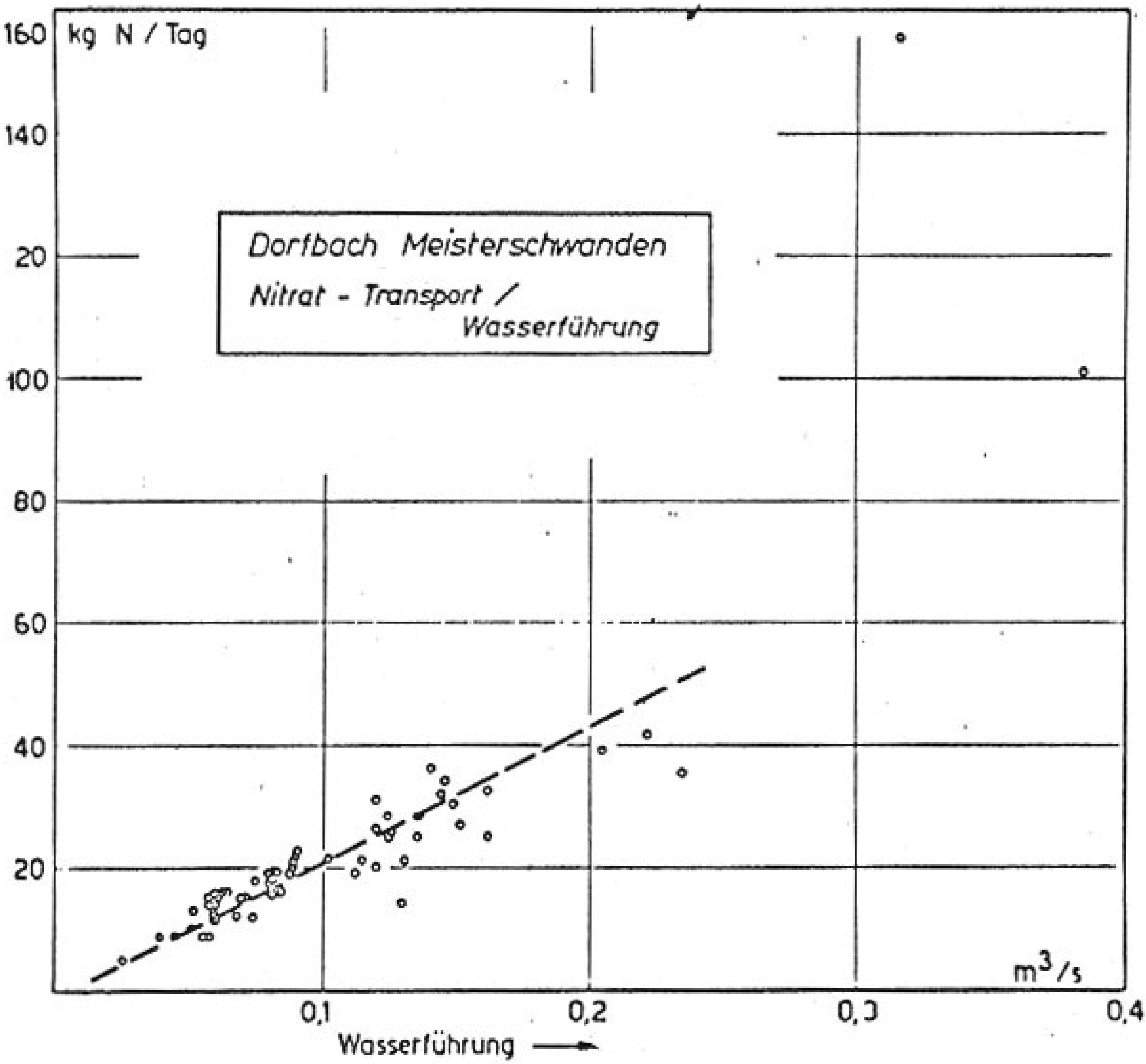
Ill. 1 Phosphorus and nitrogen concentrations of four brooks in the catchment area of the Lake of Sarnen, as influenced by the specific run-off.



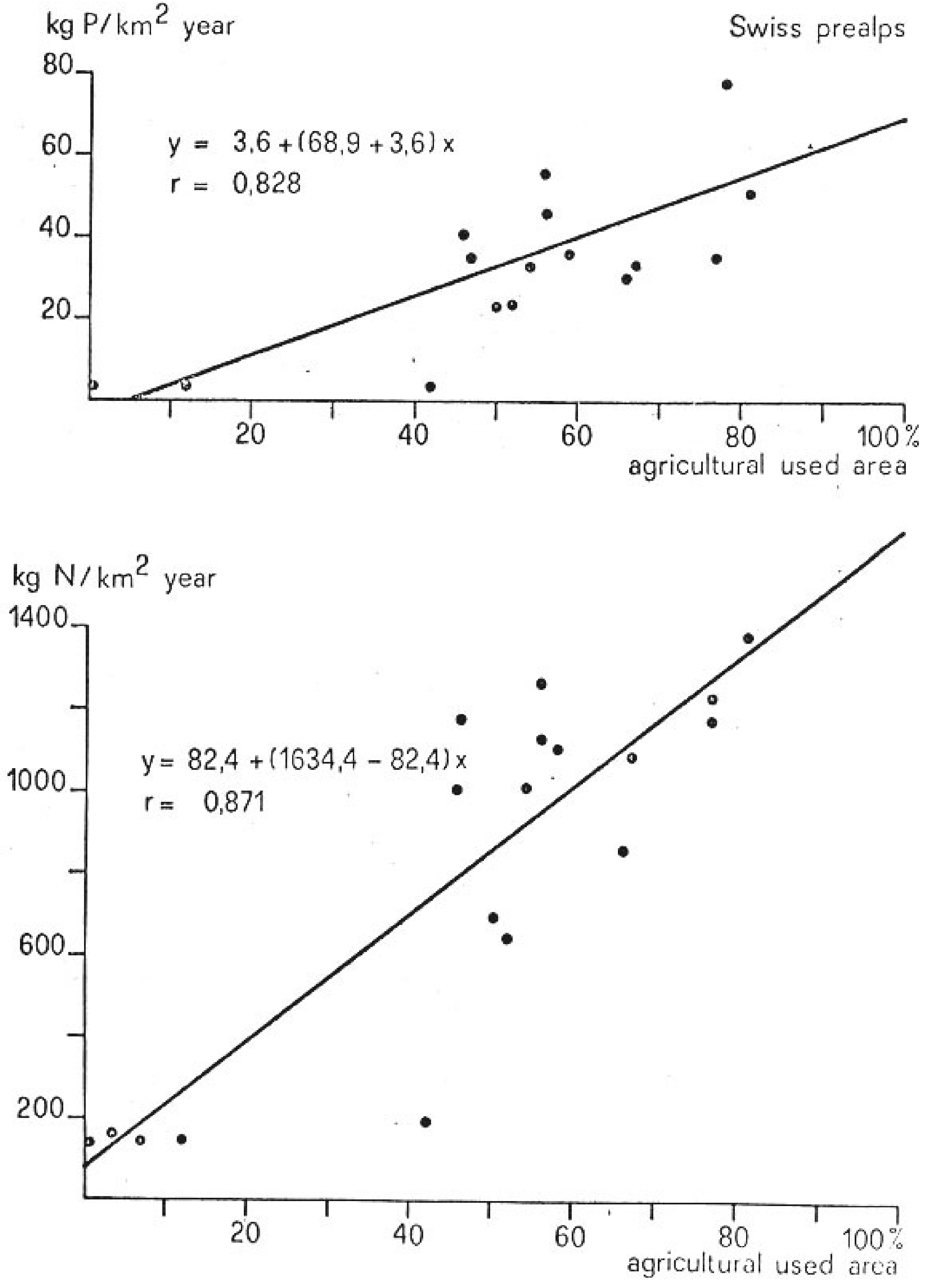
Ill. 2 Phosphate concentration of the Village Brook at Meisterschwanden, in function of the run-off.



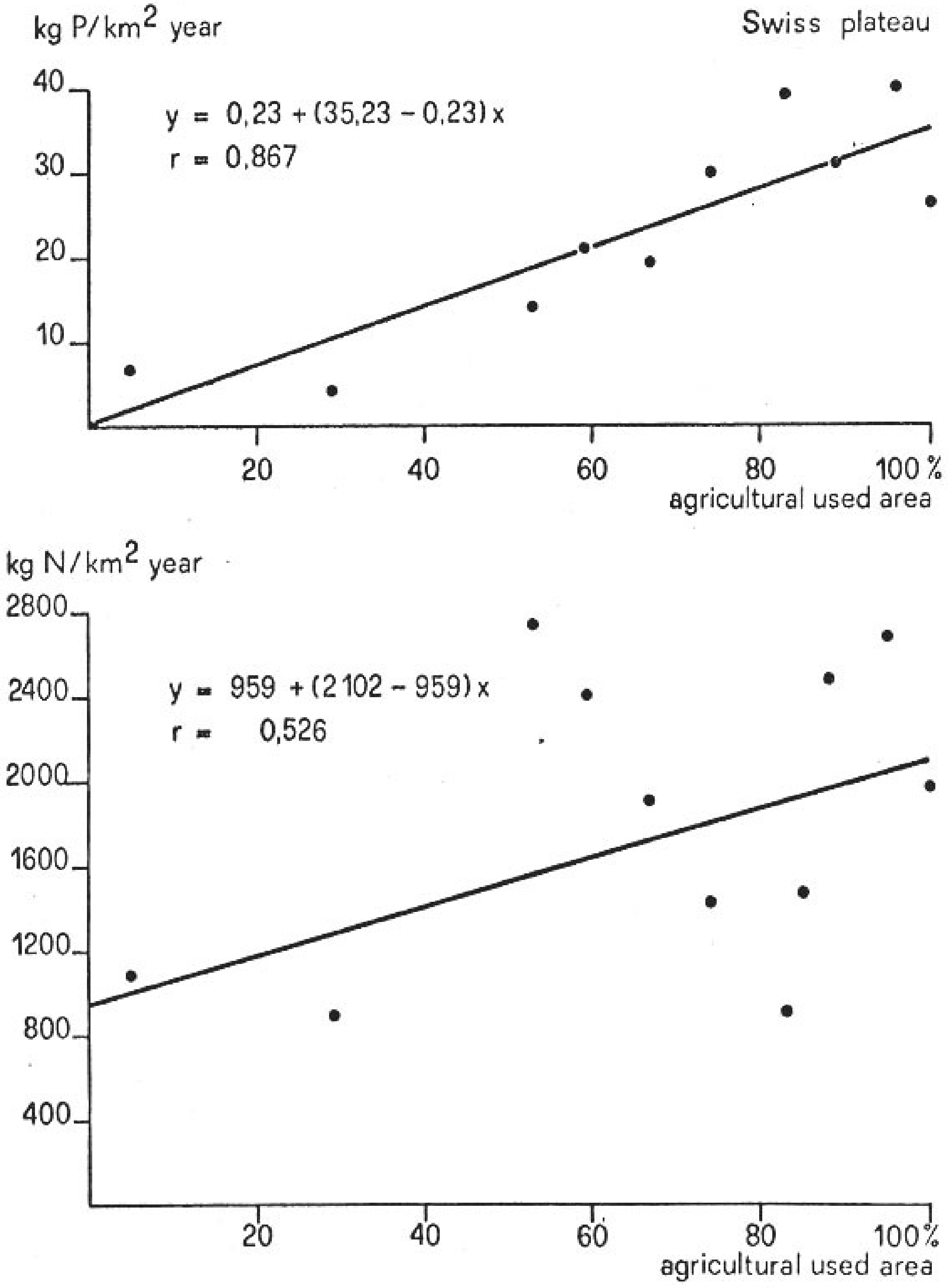
Ill. 3 Phosphate load of the Village Brook at Meisterschwanden, in function of the run-off.



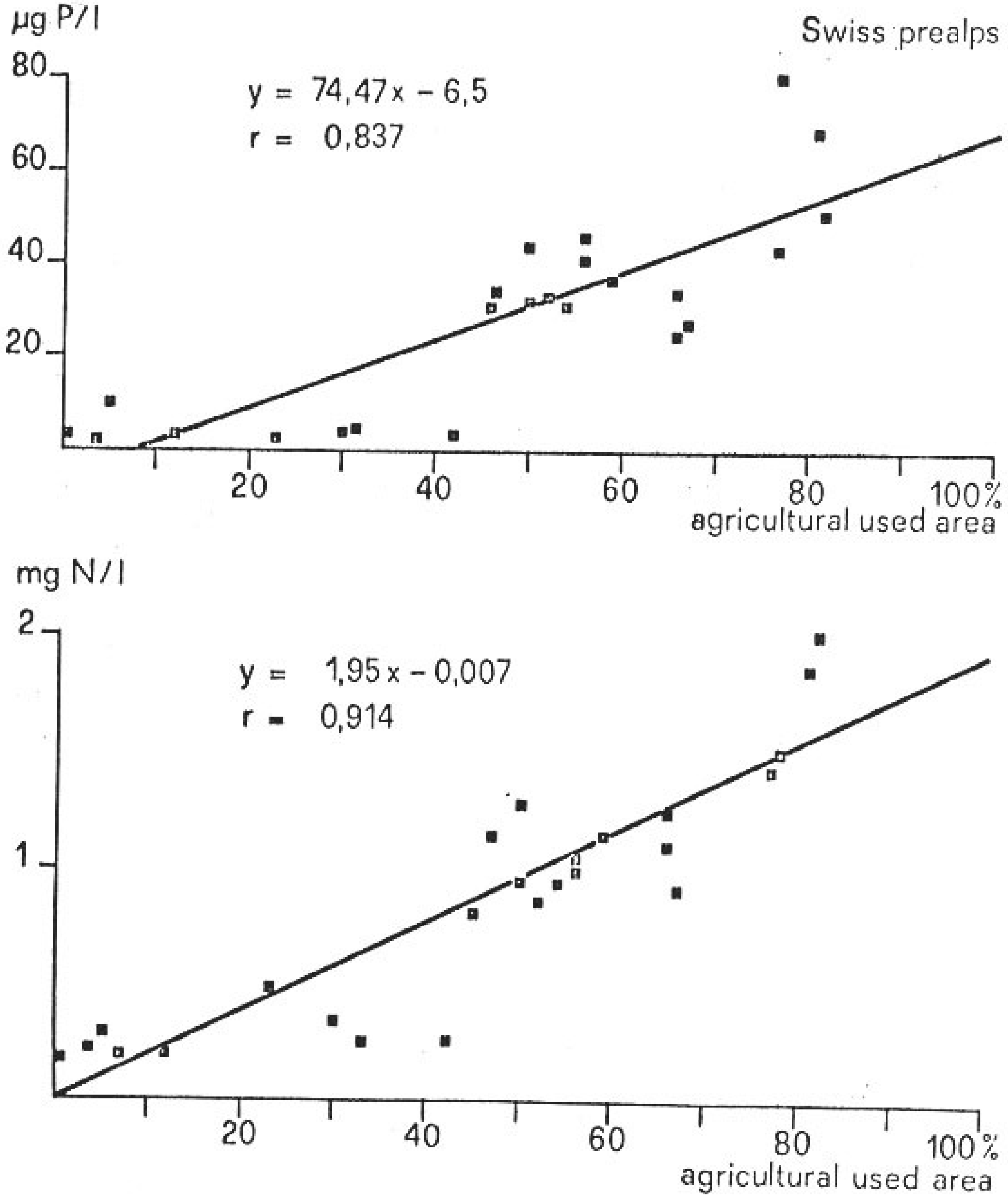
Ill. 4 Nitrate load of the Village Brook at Meisterschwanden, in function of the run-off.



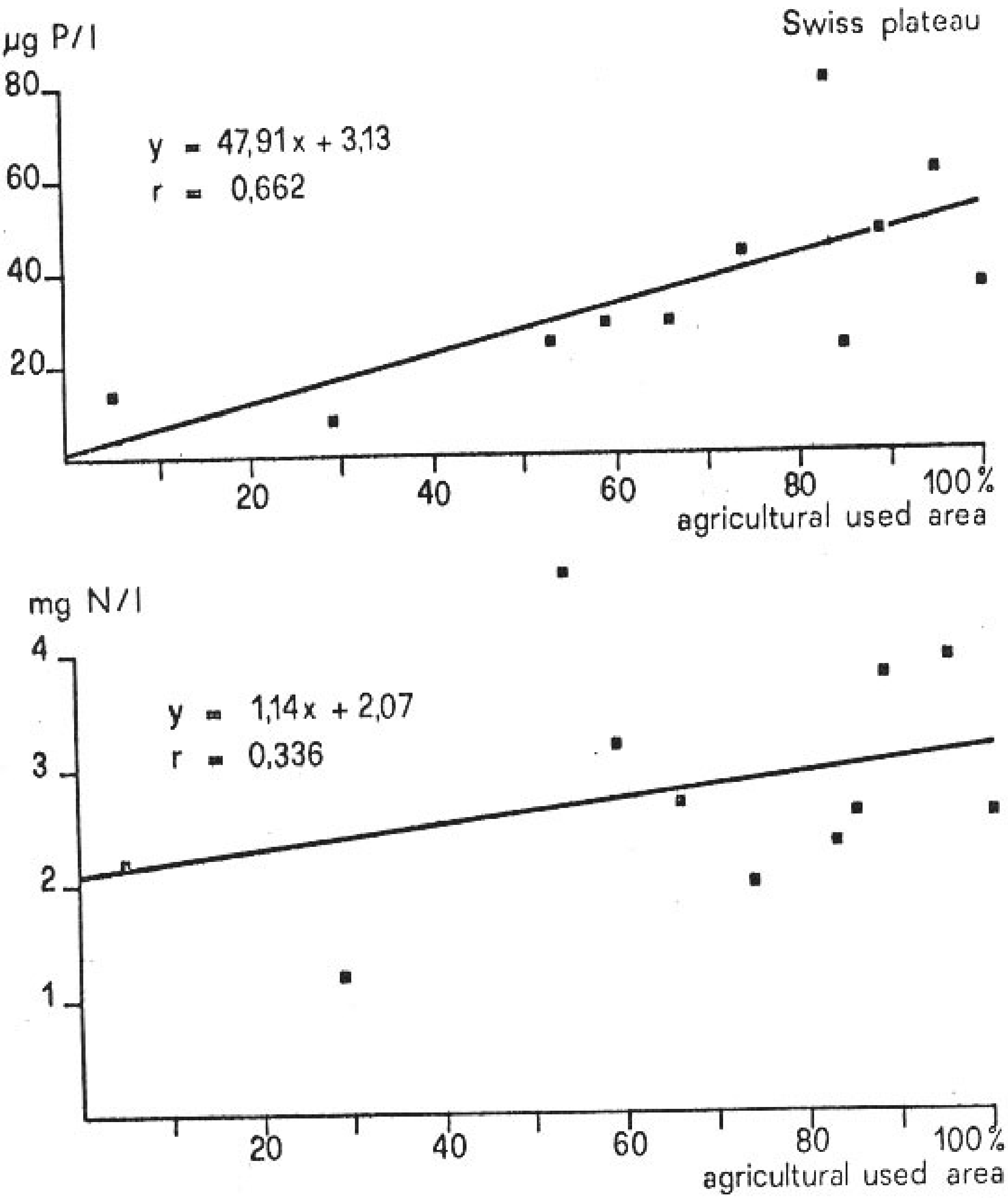
Ill. 5 Loads of dissolved phosphorus and nitrogen compounds in function of the relative share of the agricultural area in the total surface of the catchment area, in the Prealps.



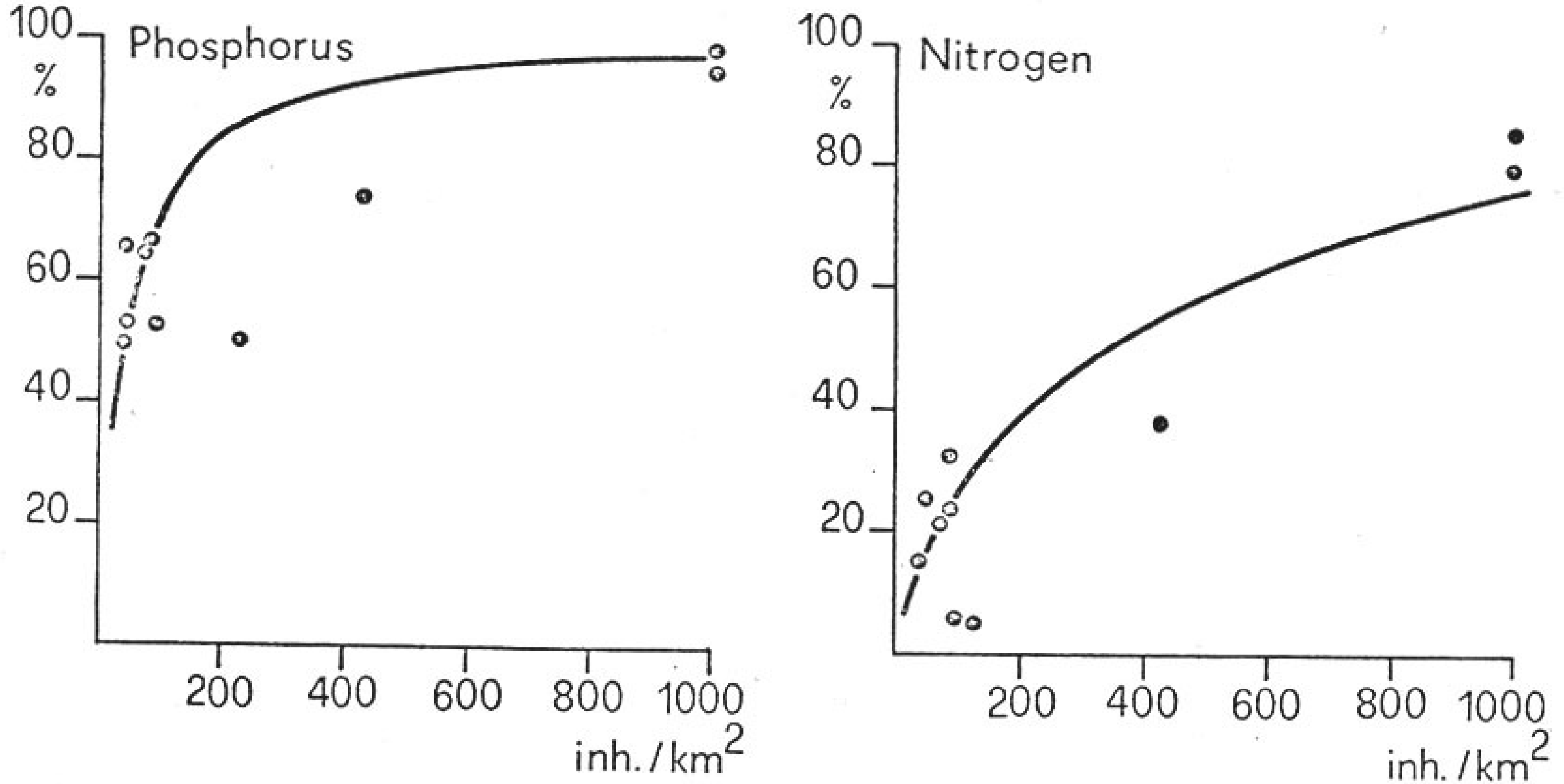
Ill. 6 the same for the Central Plateau.



Ill. 7 Concentrations of dissolved phosphorus and nitrogen compounds in streams of the Prealpine area, in function of the relative share of the agricultural area in the total surface of the catchment area.



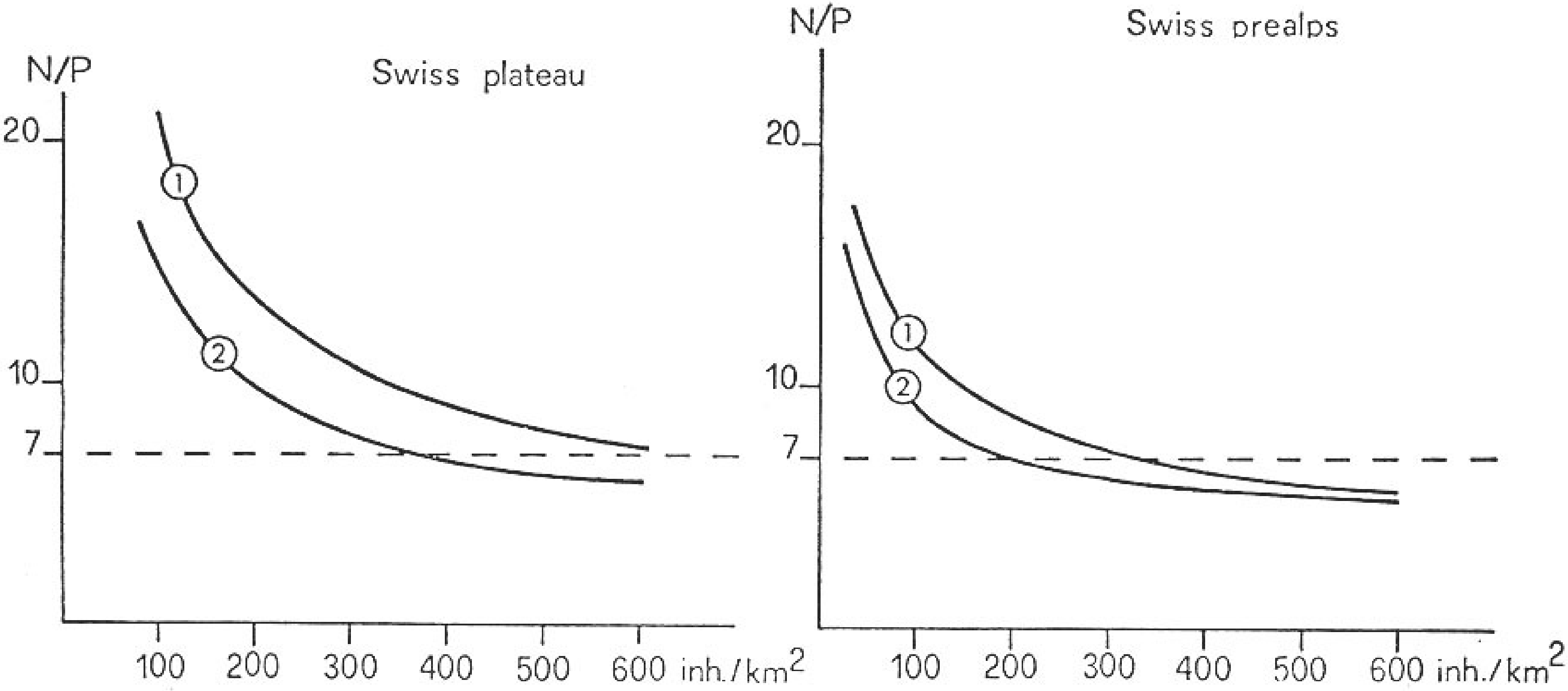
Ill. 8 the same for streams on the Central Plateau.



Ill. 9 Percentual share of waste waters in the phosphorus and nitrogen charge imposed on a number of Swiss lakes, in function of the density of population in the catchment area.

The curves were calculated on the following bases:

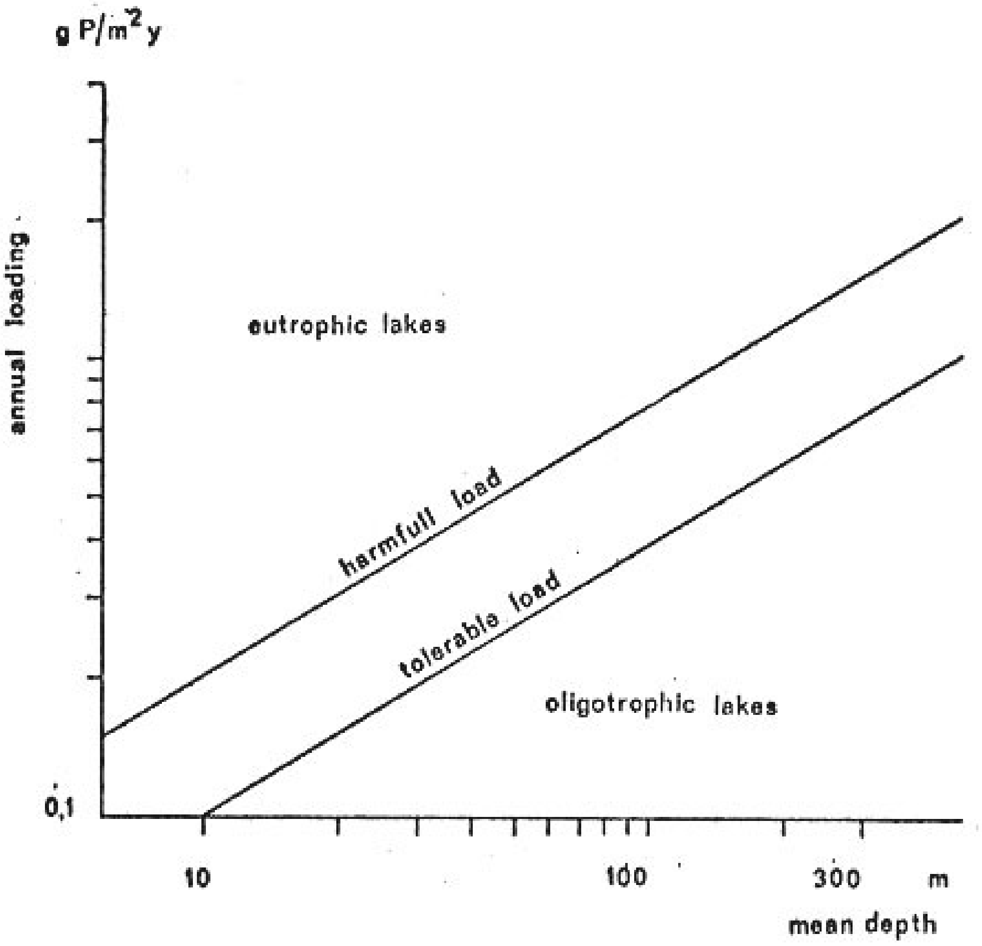
	waste waters	phosphorus losses of the soil
phosphorus	3g P/capita · day	40 kg P/km^{2}p.a.
nitrogen	12g N/capita · day	1400 kg N/km^{2}p.a.



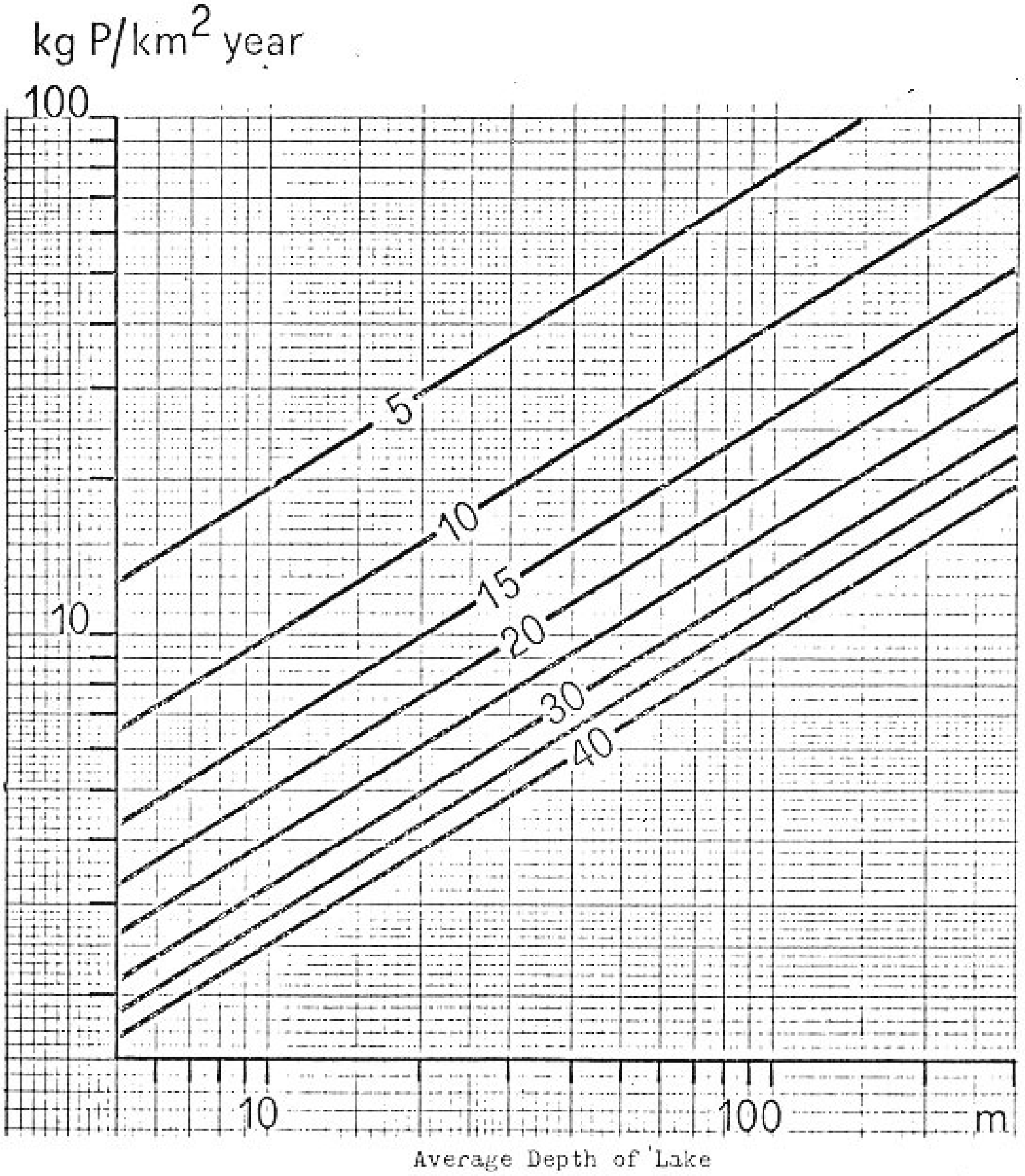
Ill.10 Expected N : P ratio in flowing waters, in function of the type of land utilization and of the density of population.

1) 90 % of the surface for agricultural utilization

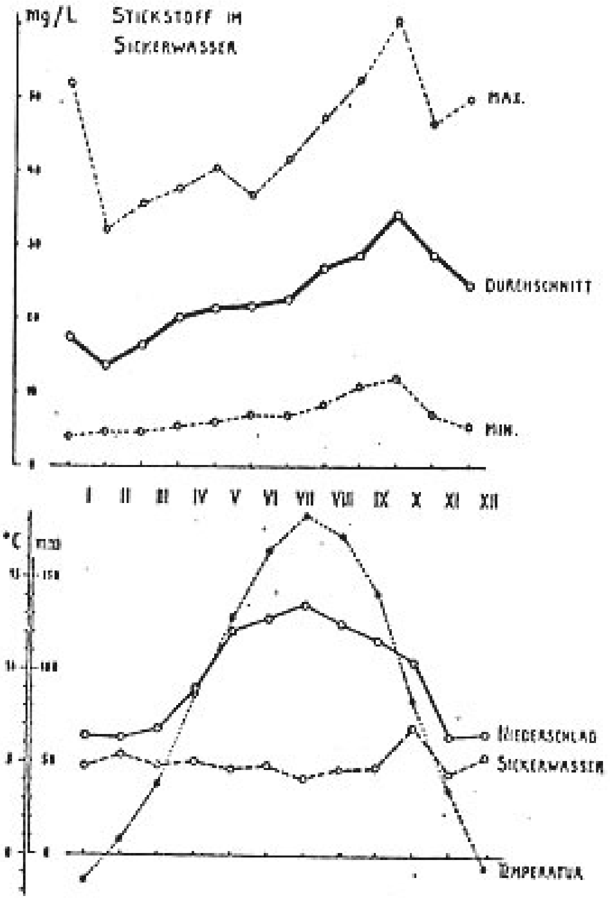
2) 50 % of the surface for agricultural utilization



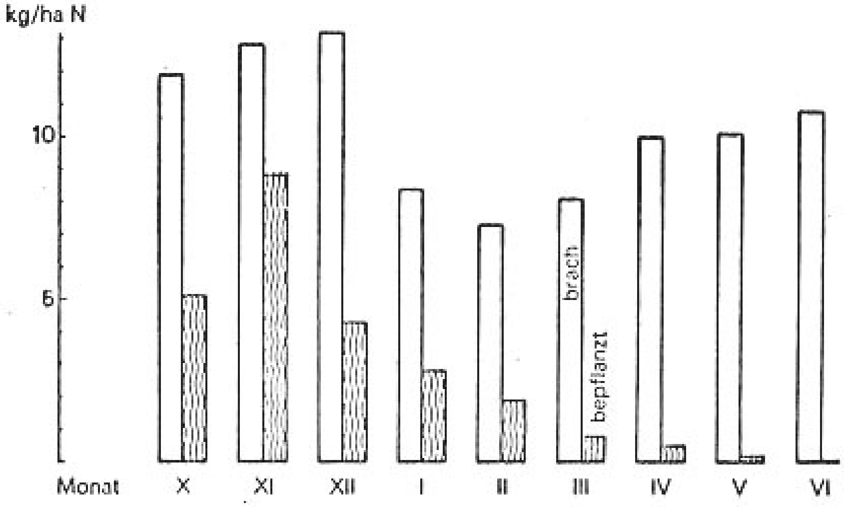
Ill.11 Charge limits for bioactive phosphorus compounds, in function of the average depth of the lake (acc. to VOLLENWEIDER).



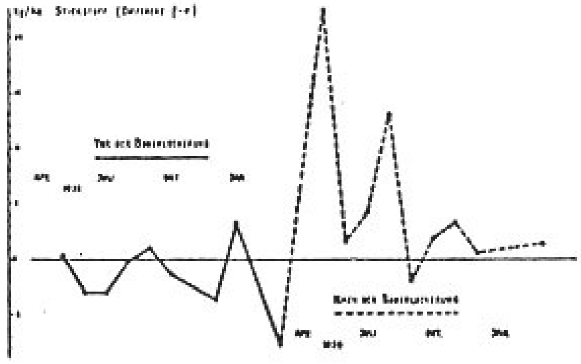
Ill.12 Tolerable phosphorus export specific per unit of surface from the catchment area of lakes, in function of the average depth of a lake. The numbers of the lines, 5-40, indicate the environmental factor, fe, as described in equation (2) in the text.



Ill.13 Upper part: Nitrogen content of the percolation water in lysimeters without vegetation (average value for a period of 13 years);
Lower part: Monthly average of the day-time temperature at Zurich, and average amounts of precipitation and percolation water.



Ill.14 Nitrogen losses in percolation waters from a soil consisting in brown earth with a low humus content. The measures were effected on one part of the soil which was left uncultivated and on another part which was planted with winter cereals. The data concerns lysimeter tests (LVR XVI/XVII, 1960 to 1962, Oerlikon). The data given for October concerns measures effected during the second part of the month (acc. to GEERING).



Ill.15 Ground loosening and nitrogen mobilisation.

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EUTROPHICATION OF INLAND WATERS WITH SPECIAL REFERENCE TO THE INFLUENCE OF AGRICULTURAL PRACTICES, INCLUDING THE USE OF FERTILIZERS

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There has been increasing public concern in recent years as to whether the present generation may be failing in its duty to posterity through excessive and perhaps irreversible pollution of the environment, particularly through the increasing industrialization and urbanization of human society. This concern has been exploited by journalists, and others, who have gained publicity by exaggerated and emotional presentation of half-truths. In this context fertilizers have sometimes been mentioned as a contributory cause of contamination of natural waters. The aim of the present paper is to give as balanced a view as possible of the facts as they are known today, based mainly on experience from Northern Europe.

It must be stressed at the outset that the amount of verifiable scientific information on this subject is limited and that continuing research is needed, involving multi-disciplinary collaboration between agriculturists, soil scientists, water authorities, analytical chemists and economists on the one hand, and environmentalists, ecologists and social scientists on the other.

There are two distinct aspects of the subject which it is desirable to consider separately: the first, which may be described under the general heading of "eutrophication", and the second, the chemical composition of surface and ground waters, with particular reference to household water supplies.

The term"eutrophication" refers to the enrichment of waters by nutrients which can directly fertilize the growth of aquatic plants and algae. This is a natural and beneficial process which occurs principally in lakes and impounded waters. A newly formed lake begins as a body of clear, nearly sterile water. Gradually streams from its surroundings bring in nutrient substances and the increasing fertility gives rise to an accumulating growth of aquatic organisms. Without nutrients there would be no aquatic life. With an excess of nutrients, or other imbalance in the ecological system, there can arise an excessive growth, or "bloom", of algae and of higher plants. This, if followed by a period of decay during which decomposing vegetable matter removes oxygen from the water at a rate faster than it can be reabsorbed, can cause unpleasant tastes and odours, death of fish and reduction in water quality, sometimes to the extent of rendering it unfit for recreational purposes and public water supply Certain algae may also themselves produce toxins.

The process of eutrophication has, in many areas, been accelerated by the intervention of man, as a result of both agricultural and industrial activities but also very largely through the rapid growth in human population. It is important to distinguish between eutrophication and direct pollution, the latter term being understood to refer to the discharge of toxic materials or those requiring excessive quantities of oxygen for their decomposition. It is important also to appreciate that the conditions for the development of algal growth are still not fully understood and that nutrient supply is not always the dominant factor. Although, for example, 0.01 mg/litre tends to be regarded as the critical level for phosphorus, many lakes with less phosphorus have "bloomed" and others with much more have not.

Moreover, some sources of nutrients exist independently of man's activities. Examples are nitrogen in rain; symbiotic fixation of atmospheric nitrogen by micro-organisms associated with the root nodules of leguminous plants and certain non-leguminous species: non-symbiotic fixation of nitrogen by freeliving soil bacteria and blue-green algae; and the release of nutrients by plant decomposition and the breakdown of organic matter in soil, which find their way into watercourses by downward leaching through the soil or by run-off or erosion. Nitrogen from these sources in lakes and rivers, except in hard rock and highland areas, is often well above the generally accepted critical level for algal growth of 0.3 mg/litre.

Agriculture contributes to eutrophication mainly through the effects of cultivation and cropping patterns on the above processes, but also through the effects of livestock husbandry and to a relatively small extent through the addition of nutrients to the soil in fertilizers and manures.

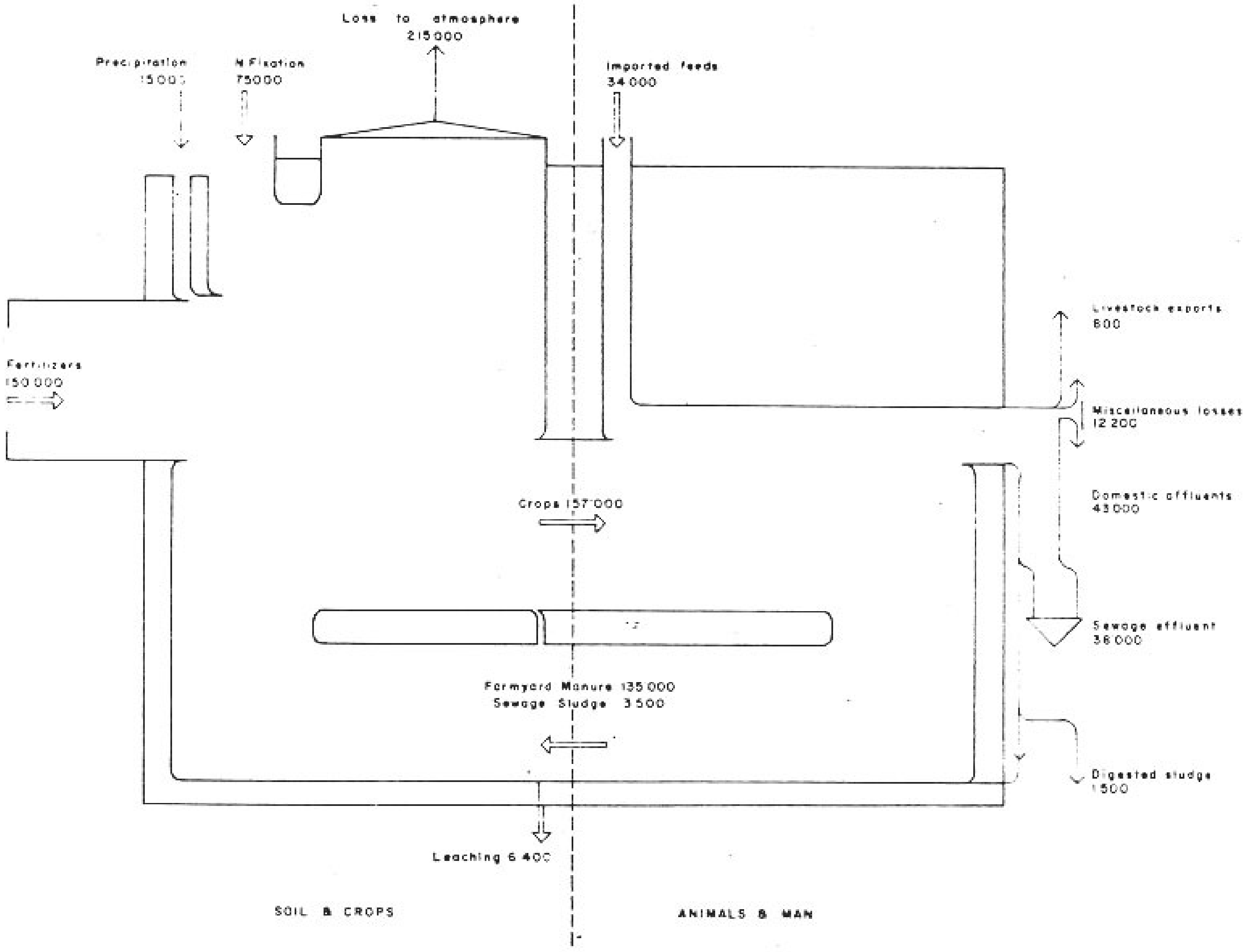
Lysimeters set up at Rothamsted Experimental Station in 1870 showed that drainage from uncropped, weed-free soil, not receiving any fertilizer, removed an average of 35 kg N/ha from 1878 to 1905, of which only 5 - 6 kg N/ha fell in rain; in 1919 the drainage loss was still averaging 23 kg NO_3-N/ha annually. During the earlier period the drainage water contained on average 9.8 mg NO_3-N/litre, ranging from 7.9 mg in February to 12 mg in September; in 1969 (the hundredth year these fallowed soils were leached) the drainage between April and November contained on average 5 mg NO_3-N/litre. Drainage from the classical Broadbalk continuous wheat experiment at Rothamsted during 1866 to 1873 contained an average of 4 - 5 mg NO_3-N/litre from unmanured plots and 12 mg/litre from plots receiving farmyard manure (35 tons/ha).

Figure 1, which is due to Dr. Nils Brink, shows in a simplified form the gains and losses of nitrogen in Swedish agriculture, which may be regarded as a characteristic pattern for a developed country. The significant feature in this diagram is that the amount of nitrogen going into natural waters was about 40,000 tons annually from sewage effluent and digested sludge but only 6,400 tons by leaching from the soil, to which 150,000 tons annually were applied as fertilizers and 135,000 tons in farmyard manure and other animal excreta. Dr. Brink's figures for phosphate similarly showed about 8,000 tons P_2O_5 annually going into natural waters from sewage disposal but only 700 tons from the soil, to which 115,000 tons annually were applied as fertilizers and 28,500 tons in farmyard manure etc. These figures apply to conditions of temperate agriculture where fertilizers were used at rates supplying around 50 kg N and 35 kg P_2O_5 per hectare of agricultural land.

Crop husbandry

Losses of nutrients from the soil to surface and ground waters arise from erosion, run-off, drainage (i.e. outflow through field drains etc.), and downward percolation to deeper layers. Losses by erosion can be minimized by the adoption of recommended soil

Figure 1.



NITROGEN BALANCE FOR SWEDISH AGRICULTURE (tons N/year) conservation practices. In areas with moderate rainfall, run-off water from well-farmed land is usually low in nutrients; though heavy rain on sloping land, shortly after application of farmyard manure or fertilizers, can sometimes cause quite serious losses by run-off. Extensive studies have been made of losses of nutrients in drainage water. In general, leaching is less from heavy soils than from light, permeable soils and depends on weather conditions, particularly the timing and quantity of rainfall. An important factor is the ability of the roots of growing crops to take up soluble nutrients in the soil as they become available from mineralization of soil's reserves or from fertilizers and manures. Losses of nutrients by leaching are greatest from freshly-tilled, uncropped soils and least from permanent grassland. Leaching losses from soils under closely planted crops with extensive root systems are less than those from soils under grapevines or fruit crops with relatively little root growth, or under widely spaced crops with inter-row cultivation. For the same reason, losses tend to be less under autumn-sown cereals than under spring-sown crops.

The correct timing of fertilizer application to tillage crops is obviously an important consideration, as too early application will result in quantities of soluble nutrients being at risk in the soil for an unnecessarily long time, unless the climatic conditions are such that leaching is unlikely during this period. It is fortunate that correct application of fertilizers in respect of quantity, method and timing is in the best economic interest of the farmers as well as minimizing the proportion of applied nutrients lost by leaching.

In the case of nitrogen, the growing of leguminous crops such as peas, beans and clovers can result in more nitrogen becoming available for leaching, and losses can be particularly high, for example, shortly after ploughing-in a clover-rich sward.

Quantitative Data on Leaching of Nitrogen and Phosphate from Agricultural Land

A comprehensive review of UK information on losses of nitrogen and phosphate from agricultural land was given by Cooke and Williams at the Symposium on Eutrophication held by the Society for Water Treatment and Examination in London, March 1970. Particular reference was made to studies of nitrates in field drainage at Rothamsted, Woburn and Saxmundham and to lysimeter experiments at Rothamsted and at Craibstone, near Aberdeen. They concluded that drainage from well-farmed arable land in England will contain on average 10 mg NO_3-N per litre; leaching of N from the decay of roots and plant residues is greatest during winter, but extra nitrate is liable to appear in drainage during wet periods in spring if fertilizer nitrogen is applied before crops are sufficiently developed to take it up. Light land loses nitrate to give drainage with larger and more constant nitrate concentrations during the year than heavy land. Loss of nitrate in drainage from productive land cannot be prevented, however, because more nitrogen will be mineralized from soil reserves and crop residues by microbial action than arable crops can take up at some times of the year. They also noted that during wet periods in summer some nitrate may occur in drainage from grazed grassland because the larger concentrations of nitrogen in urine patches may exceed the capacity of the soil and crop to absorb it.

Cooke and Williams observed that soluble phosphate fertilizers are leached down soil profiles in podzols developed from Bagshot Beds containing only 1-2% clay; phosphorus from 20 successieve years of heavy dressings of farmyard manure has penetrated into the subsoil of light land at Woburn; no other examples have been found of soluble phosphates penetrating deeply enough in arable soils to reach drainage systems, but some may penetrate over a period of years on permanent grass. Drainage from arable Chalky Boulder Clay soil averaged 0.07 mg P/l, and from Greensand soil in Bedfordshire 0.17 mg P/l. Occasionally higher concentrations have been recorded, probably from contamination by animal excreta, but were never associated with fertilizer applications.

A paper was presented at the same Symposium by Tomlinson of Jealott's Hill Research Station, on trends in nitrate concentrations in English rivers and in fertilizer use. In most of the 17 rivers studied during the period 1953 to 1967 nitrate concentrations did not increase significantly despite the substantial increase in fertilizer use. Even in those cases where significant increases occurred the increases were not dramatic. Correlations could not usually be drawn between nitrogenous fertilizer use and the nitrate content of the rivers and the author suggested that this is because most of the nitrate leached from the soil comes from the large reserves of soil N and not directly from added fertilizers.

A paper by Armitage, also of Jealott's Hill Research Station, was presented at a Symposium on Pollution Control organized by the Chemistry Department of the University of Manchester Institute of Science and Technology in January 1971, in which emphasis was placed on the experimental work at Jealott's Hill and elsewhere in the UK, using lysimeters to investigate losses of nutrients by field drainage and the effects of fertilizers on the level of nitrate in river water. Mention was made of the studies by Low and Armitage (*Plant & Soil* 1970, *33*, 393-411) in which the drainage from fallow, clover- and grasscropped lysimeters over a 4¼-year period, not receiving any nitrogenous fertilizer, averaged respectively 118, 46 and 3 kg N/ha/year. These experiments have been extended in 1971 to include all-grass swards receiving increasing levels of nitrogen up to approximately 675 kg N/ha/year.

A bibliography on loss of nitrogen fertilizer by leaching was published by the Commonwealth Bureau of Soils in May 1971 (Serial No. 1458). Earlier bibliographies related to movement of soil and fertilizer nitrogen in soil (No. 920), N and P losses from soil by leaching and erosion (No. 1089), chemical composition of drainage and groundwater (No. 1195), and rate of nutrient cycling in ecosystems (Nos. 683 and 1199).

Lysimeter studies at Ås, Norway, 1938-43, were reported by Ødelien and Vidme (*Meld. Norg. Landbr. Høgsk* 1945, *25*. 273-362). Lysimeters cropped with potatoes received approximately 59 kg fertilizer N per hectare annually or double that amount in alternate years. About two-thirds of the applied fertilizer N was recovered in the crop. Over a 5-7 year period the leaching of applied fertilizer N amounted to 5% and 0.3% respectively. The proportion that was not recovered either in the crop or in the drainage water, and therefore remained in the soil organic matter or was lost to the atmosphere, amounted to 29 to 35%.

Lysimeter studies at the State Experimental Station at Askov, Denmark, were described by Kofoed and Lindhard (*Tidsskr. Planteavl.* 1968, 72, 417-437). Grass-cropped lysimeters received calcium nitrate annually at rates which averaged 183 kg N per hectare per year over a 9-year period. Total N leached during this period, which included N from the soil reserves and from precipitation, fixation by micro-organisms etc. as well as fertilizer N, amounted to between 5 and 10 kg N/ha/year on 5 soils. This compared with uptake by the crop of 120 to 190 kg N/ha/year. Higher leaching losses averaging 31 to 43 kg N/ha/year were observed on 4 other soils, associated particularly with crop failure in some seasons on the high-moor peat and sandy soils. A reference was also made to earlier lysimeter studies in Denmark conducted by Iversen (*Tidsskr. Planteavl.*

1943, 47, 66-69). It is noteworthy that analysis of samples of drainage water from various parts of Denmark in 1969 showed an average annual loss of nitrogen by leaching from the predominantly sandy soils of Jutland of about 20 kg NO_3-N per hectare, virtually the same amount as had been observed in studies at Askov and a neighbouring farm, Jejlundgård, some 45 years earlier (Tidsskr. Planteavl. 34, 755), despite the fact that Danish agricultural production had multiplied several-fold during the intervening period and the average rate of use of fertilizer nitrogen had increased from about 5 kg to over 80 kg N per hectare.

Balance sheets drawn up by Lindhard (Tiddskr. for Landökanomi 1970, No. 2, 64-76; 1971, No. 3, 237-253) for the whole of Denmark indicate that the total of leaching loss of nitrogen from Danish soils in 1966 amounted to 54,000 tons N, comprising 27,000 tons in the drainage water and 27,000 tons downward percolation, compared with 192,000 tons N applied in fertilizers and 198,000 tons N in animal manures. Corresponding figures for the phosphorus balance in 1968 showed only 1,000 tons P leached, compared with 52,000 tons applied in fertilizers and another 52,000 tons in animal manures. The two balance sheets are summarized below:

Nitrogen balance for Danish soils, 1966 (thousand tons N)

Additions		Removals	
Fertilizers	192	Harvested crops	336
Animal manures	198	Ammonia loss	4
Seed	5	Denitrification loss	46
Micro-organisms	100	Leaching losses:	
		Drainage	27
Precipitation	45	Percolation	27
	540		440
		Balance fixed in soil	100

Phosphorus balance for Danish soils, 1968 (thousand tons P)

Additions		Removals	
Fertilizers	52	Harvested crops	50
Animal manures	52	Leaching loss	1
Seed	1		
Burnt straw	3		
	108		51
		Balance fixed in soil	57

Leaching losses thus amounted to approximately 10 percent of all additions of N to the soil and 1 percent of all additions of P.

Christensen (Hedeselskabets Tidsskr 1970, No. 3, 50-60) has pointed out that, although the surface and drainage water always contains nitrate, the ground water in Denmark contains practically no nitrate. This must be due to reduction of nitrate as the water percolates downwards through the soil.

Writing in Växt-Närings-Nytt 1966, 22 (3), 1-9, Professor S.L. Jansson of the Royal Agricultural College of Sweden estimated that in general 70% of fertilizer N applied to a cereal crop is taken up by the crop (35% in the grain, 17% in the straw and 18% in plant residues in the soil), 25% is absorbed in the soil organic matter and only a fairly small proportion, around 5% is lost by leaching, denitrification and evaporation.

Analysis of drainwater from cultivated soils in various parts of Sweden by Professor L. Wiklander showed an average of 8.5 mg N and 0.019 mg P per litre in drainage from soils in Skåne, the most heavily fertilized region, compared with an average of 1.1 mg N and 0.022 mg P per litre in drainage from soils in Norrbotten, one of the least fertilized districts. (Grundförbättring, 1970, No. 23, 117-141). Fertilizer use in 1968/69 averaged 106 kg N, 76 kg P_2O_5, 82 kg K_2O per hectare in Skåne and 24 kg N, 28 kg P_2O_5, 30 kg K_2O per hectare in Norrbotten.

Several articles on the subject of eutrophication and water quality in relation to fertilizer use were recently published in the Dutch journal Stikstof October 1971, Vol.6, No.69. Kolenbrander showed that the annual contribution of rural and urban areas to eutrophication in the Netherlands averaged 54 kg N and 16.8 kg P_2O_5 per hectare of utilized agricultural land, of which 32 kg N and 0.6 kg P_2O_5 came via the soil and the remainder from sewage and kitchen wastes. In an earlier paper Kolenbrander (Neth. J. Agric. Res. 1969, 17, 246-255) indicated the annual leaching loss of nitrogen from arable and grassland in the Netherlands, when drainage was 350 mm/year, to be 58 and 13 kg N/ha respectively, made up as follows:

	N leached (kg N/ha)	
	From arable land	From grassland
Soil	41	7
Fertilizer	12 (out of 90 applied)	2 (out of 200 applied)
Animal manure	5 (out of 100 applied)	4 (out of 100 applied)
Total	58	13

The amount of fertilizer N that was leached averaged 4 percent for the country as a whole, 2½percent for clay soils and 5 percent for sandy soils.

Results of the long-term lysimeter studies conducted for many years at the BASF Limburgerhof Experimental Station and of other experiments in the German Federal Republic have been described by Dr. J. Jung whose general conclusion is that under field conditions leaching losses of applied fertilizer nitrogen would not on average exceed about 5 percent.

Benefits from Fertilizer Use

It is hardly necessary, in view of the predominant position attached to fertilizers as an agricultural input in FAO's Indicative World Plan for Agricultural Development, to draw attention to the major role played by fertilizers in increasing world food supplies and in lowering the unit cost of production. There is perhaps, however, some advantage to be gained by considering certain other less obvious benefits arising from fertilizer use. By increasing yields of tillage crops per hectare, for example, fertilizer use enables a given level of production to be achieved from a reduced area under tillage, thus reducing the loss of plant nutrients by natural causes. Particularly on grassland, but also on tillage crops, the use of fertilizers results in an increased contribution from plant roots and crop residues to the organic matter content of the soil, thus maintaining and improving the level of soil fertility (see, for example, a literature review on this subject by D.J. Halliday in Jealott's Hill Research Station Bulletin No. 8, January 1950). Another interesting aspect, for which the author is indebted to his Belgian colleague in the Centre d'Etude de l'Azote, Mr. J. Burnotte, is the increased conversion of atmospheric CO_2 to oxygen as a result of the increased photosynthetic activity through increased plant growth. In Belgium, for example, it has been estimated that a virtual doubling of nitrogen and phosphate use, coupled with a rather small increase in the use of potash, over an interval of 15 years has resulted in the production of oxygen sufficient for an extra 3 million people and an equivalent diminuition in atmospheric carbon dioxide.

Conclusion

The present paper has indicated that the contribution of nutrients from fertilizers applied to agricultural land to inland waters and rivers is generally small in relatively heavily-populated developed countries in relation to the contribution from sewage effluents from urban areas. The contribution is smaller from grassland than from land under tillage crops and is smaller from heavier than from lighter soils. It can be minimized by applying fertilizers correctly at the right time and in the right quantity. In this respect farmer's and environmentalists' interests coincide. Against this small negative effect of fertilizers must be set the very real benefits of fertilizer use, both direct and indirect. Moreover, the increase in the nutrient content of waters which results from the use of fertilizers on agricultural land is rarley a critical factor in eutrophication, in the narrower sense of "blooms" of algae, except occasionally in hard rock and highland areas. The factors influencing these "blooms" are still not fully understood and require further study.

THE PRESENT PROBLEMS OF WASTE DISPOSAL AND THE FUTURE WASTE MANAGEMENT IN EUROPE

O. Jaag

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THE PRESENT PROBLEMS OF WASTE DISPOSAL AND THE FUTURE WASTE MANAGEMENT IN EUROPE

O. Jaag

Where people live and work, wastes are generated in a solid, liquid and gaseous form. To keep our environment healthy and enjoyable, these wastes must be disposed of in such a way that they are not objectionable from an aesthetic or hygienic point of view, or cause immissions, or harm the health and life of mankind in any way.

To provide adequate refuse removal, the cities established a collection service, and the industry provided more hygienic and more efficient collection vehicles which are still improved. A questionnaire elaborated lately revealed that in practically all European countries the duty to dispose of solid, liquid and sludgy wastes in a non-objectionable way rests with the communities and industries.

1. How to tackle the solid wastes problem

The duty to protect our habitat involves the following particular and inevitable measures: the protection and, where necessary, the purification of our waters by treating the sewage from residential areas and industries before it is discharged into a receiving water body; the elimination of solid wastes, i.e. domestic refuse, street refuse, waste oil, various industrial waters, animal carcasses and confiscates without harming the human environment, and finally the raw and digested sludge that accumulates in the sewage treatment plants; the protection of air and soil against excessive noise and other immissions of all kinds.

The need for order and cleanliness has, with the passing of time, undergone various changes. Thus our task must be adapted to the circumstances, particularly in times like ours, where on the one hand the need for amenities is extremely great and seems to be increasing, and on the other hand, the mass production industry floods the market with commodities of all kinds, kitchen dishes, radio and television sets, washing machines, refrigerators and cars of various makes. This entails unimaginable waste that the communities and regions must deal with in an economical way and, if possible, without polluting the human environment. The rapid economic development that became apparent after the last world war, as well as automation and the accelerated growth of the population brought about a new avalanche of waste, the end of which cannot yet be foreseen.

During the last 15 years, the volume of domestic refuse has doubled or even tripled. This development is due particularly to an abundance of packaging material in town and country.

This means that the way to treat solid waste must be adapted to the changing requirements and the given circumstances. This pre-supposes that the competent authorities adapt their policy to the rapid development of science and technology to the advantage of all those involved. This however requires continuous information, documentation and discussion in order to choose the best technical means that competition offers.

The problem of waste disposal is a very important one, because we must take decisions about the organization of the collection, the treatment, the processing for re-use and finally the complete disposal of the useless remaining material.

For collection and transportation, the municipal cleansing departments have found solutions which for their purposes were practicable. The problem of the disposal of collected waste is already a much more difficult one. In this respect, we have several, fundamentally different possibilities: a) Open dumping, b) Controlled tipping (sanitary landfill), c) Composting, d) Incineration.

The principal factors to be considered in determining future needs for solid wastes management are industrial development, population growth and land planning. Forecasts are usually developed on a regional or inter-regional basis.

At all events close cooperation between the authorities engaged in water and waste water management and those occupied with solid waste disposal is indispensable.

Figure 1 represents a survey on the processing channels in wastes disposal.

The first task consists in determining thoroughly the amount of municipal, industrial and agricultural waste to be disposed of per year or per week in the course of the different seasons.

Industrial wastes surveys have to be carried out in accordance with typical production programmes and every effort must be made to obtain data on production rates as well as data on wastes generation.

Wastes from agricultural activities indicate strong seasonal variations and change in quantity from one year to the other.

2. Planning of waste disposal facilities

The usual design periods for waste disposal facilities vary from 10 to 40 years. In order to make the best of the invested money it is advisable to secure the area necessary for the treatment of the refuse after 20 years. The surface for a second furnace and/or a second composting installation being already at hand, the enlargement of the plant can be projected in time. Furthermore, two sets of treatment machines are preferable in order to ensure the running of the plant in case of a breakdown of one set.

Methods for sampling procedures, determination of the moisture content, separation into waste fractions, refuse components analysis, heating-value determination are the most important parameters which determine the choice of the final method of treatment.

The heating value increases with the growing percentage of cardboard, paper and especially of plastics in the refuse. Polyvinyl-chloride (PVC) very rapidly increasing in volume in the refuse often causes corrosion damages on boilers. Combustion residues from incineration should not contain any fermentable matter and the water soluble compounds should be sintered in the slag.

3. The main systems of solid wastes disposal

3.1 Open dumping has become a very widespread method in recent years, which often contaminated and disfigured the countryside and even polluted the air with smells from such dumps. It has been generally recognized that this method of waste disposal can no longer be applied.

3.2 A further step in waste disposal has been taken in France and in Great Britain with the system of controlled tipping or sanitary landfill. This method is more complicated and more costly, since it requires special machines and personnel, but it protects the deposit surfaces and the surroundings from practically all immissions, and moreover, it uses land which has so far been unproductive.

3.3 Composting As far as wastes management is concerned we live in a closed environment, which comprises soil, water and air. Disposal of wastes means discharging them into one or more of these sectors of the biosphere. Thus, proper wastes management involves deciding which of these sectors can accept refuse without detriment. 40 to 80% of domestic refuse consists of fermentable matter, which can be transformed into compost. Unfortunately these plain relations are not as simple as they may seem. The technical,

Processing Channels in Wastes Disposal

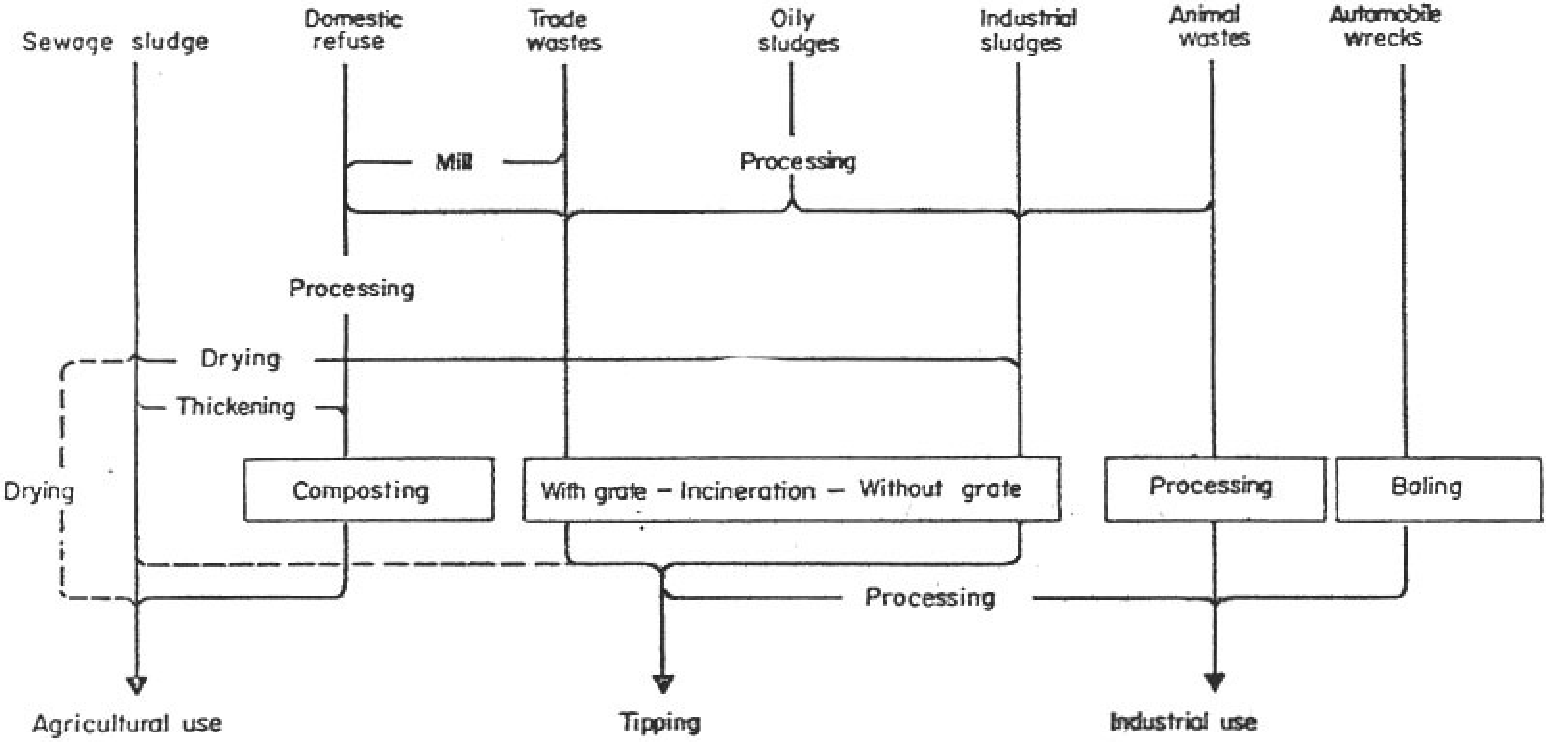


Figure 1

biological and marketing problems were often underestimated and led to subsequent disillusionment.

Mature compost, applied properly, has a manifold influence on cultivated soil, for example preventing water and wind erosion, retaining soil moisture during dry periods and many other positive effects.

The best known and most thoroughly tested field of compost application is that of viticulture. Since the vines are often cultivated on a slope, prevention of erosion plays a very important part. Furthermore compost is welcome in horticulture, cultivation of vegetables, fruit culture, tree nursery and forestry.

A very interesting use for waste compost is pig breeding. Pigs are often anemic. In Holland specially treated compost has been given to piglets for some time already as a source of iron. According to the results obtained by adding compost mixtures with various preparations rich in iron, the anemia and diarrhoea in piglets can be prevented and weight increase stimulated more effectively and cheaper with mature compost than with other preparations tested.

Composting has caused much disillusionment for many reasons, but after all it still represents the most significant possibility for the use of waste if done properly. Indeed we all know that agriculture is in need of humus, and there is no way of producing humus more economically. A reasonable selling price covers part of the expenditures, and compost treated grounds may absorb a certain percentage of toxic industrial mineral refuse, which cannot be disposed of otherwise, but marketing must be planned on a long-term basis.

3.4 Incineration. It has been recognized at a very early stage that big cities, particularly when they are situated in densely populated conglomerations cannot apply the above mentioned methods for their waste problem. Therefore, they chose the most radical way of waste disposal, i.e. incineration. In fact, numerous cities all over the world have opted for this method, which was to their advantage. This development has been considerably promoted by the availability of incinerators and powerful machinery. Suppliers of several countries have for decades been engaged in a healthy competition with each other of this market.

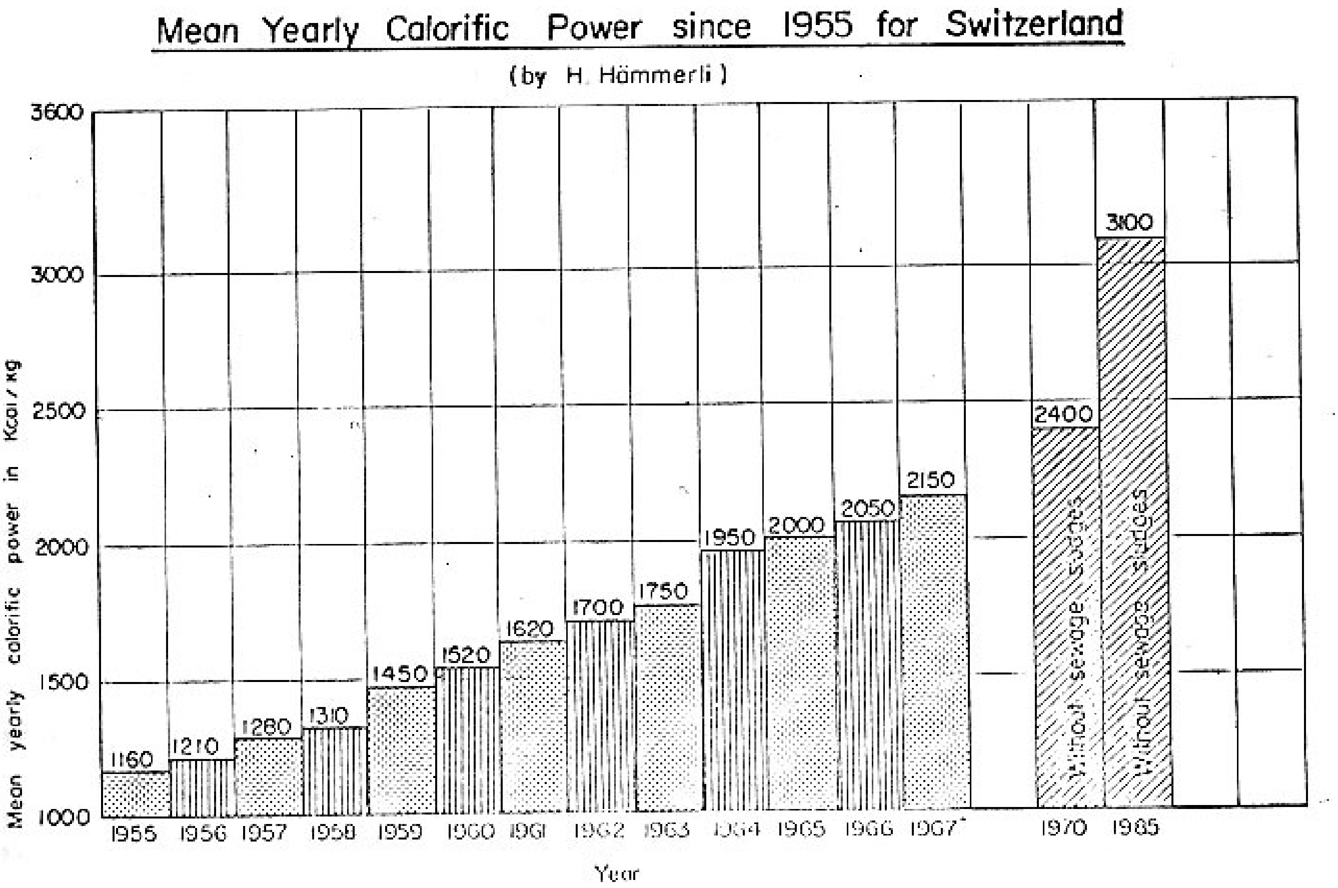
Depending on the local and regional circumstances, the competent authorities are left with the choice of incineration with or without utilization of the energy generated. This energy can be used for the production of heat, steam of electric power (Figure 2).

The fact that there are several possibilities of waste disposal serves our purpose extremely well, since the amount of waste produced today could hardly be absorbed by agriculture.

We have to seek the optimal solution for each individual case and its special circumstances. This requires research in various fields as well as publication of its results in the authorized groups.

Concerning the characteristics of combustibility the three component water, ash and combustibles determine the heating value of waste. The three-component diagram (Figure 3) shows inside the hatched area the range of refuse composition in which combustion can be maintained without additional fuel, but in fact, incineration will never be a profitable business. Indeed, the proceeds derived from the sale of the waste heat does not cover the prime costs of the incineration plant disregarding the collecting service. This fact is relevant even for the biggest plants.

If heat recovery is not economical the heat produced by incineration must be destroyed. Plants of this character are frequently used for incinerating the screen residue of composting installations and municipal incinerators with capacities below 100 tons per day.



Mean Yearly Calorific Power since 1955 for Switzerland

(by H. Hämmerli)

Figure 2

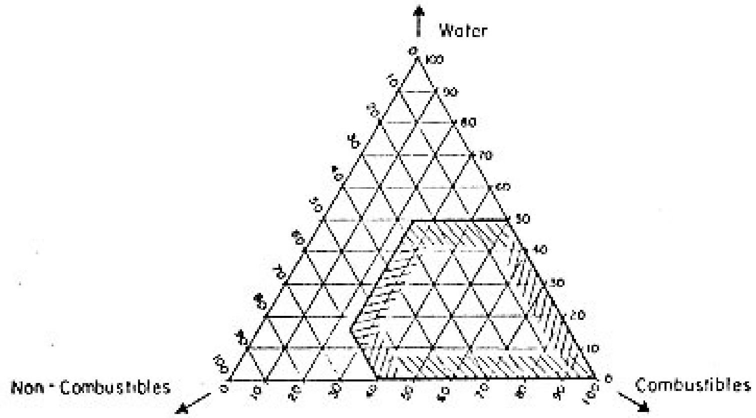


Figure 3

Refuse incineration with heat recovery will probably never be self-supporting. When comparing the results of wastes disposal by incineration with those by composting, it is obvious that the soil conditioner "compost" cannot be replaced by any other means, whereas heat is produced cheaper and easier from fuel.

The decision of whether an incineration plant should be built with or without heat recovery depends chiefly on the local conditions. The most favourable conditions for heat recovery are given when the incineration plant can be established within the premises of a power station.

The most convenient way to deliver thermal energy for industrial purposes is to locate the incineration plant in the neighbourhood of a heat-taking industry. The heat must be taken all year round and the incineration plant ought to be built very close to the industry. Another possibility of using the heat produced directly is the feeding of a long-distance heating system.

Instead of using the thermal energy produced for the generation of electricity, heating purposes or instead of wasting the heat, the resulting energy may be used for drying the sludge generated in a sewage treatment plant. For this purpose a hearth furnace, where municipal and industrial refuse, pumpable sewage sludge and waste oils may be incinerated simultaneously, is suitable.

Sewage sludges turn to solid wastes when they are dewatered or thickened. - The combussation of waste oil, slaughterhouse wastes and dead animals presupposes special mechanical devices in the furnace. - As to industrial sludges and further noncombustible wastes like galvanic residue, lacquers, varnish removers etc., it has been shown that these substances are absorbed to a certain degree in the composting process, although it has not yet been proved whether compost with the addition of industrial sludges is suitable for cultivating food-plants.

4. Costing and conclusion

Much data have been collected to find a common denominator for comparing the investment and operating costs between the three main ways of waste disposal, i.e. landfilling, composting, incineration.

Taking into consideration the numerous constituents which interfere in the various technical systems and the different local conditions it has shown that mean values can hardly be set up even for one single country. How many more difficulties must arise in evaluating these costs on an international basis. Each of the above mentioned three possible ways of waste management should be calculated separately, taking into account that the totality of wastes must be disposed of.

Until recently in Europe any suggestion of re-using refuse was thought of as unreasonable, reminiscent of war times. But more and more it has become a particular concern to all the people of our generation which is inevitably compelled to keep our environment clean and prevent disaster later.

5. New concepts

New concepts in waste water treatment and combinations of conventional and physical-chemical processes will have a decisive influence on the treatment and disposal of municipal and industrial sludges. Its qualitative and quantitative consequences cannot at present be evaluated. We are still forced to rely more on conjecture than on facts.

This chapter covers a review of the present state-of-the-art in sludge disposal. A discussion of future problems of sludge disposal is based on this and foreseeable new treatment methods.

5.1 Possibilities of sludge disposal

Anaerobic stabilization (digestion) of municipal sludges and subsequent application of stabilized sludge to agricultural land are still the most commonly used treatment and disposal methods. This practice is not only economical but also most reasonable from a biological point of view since wastes are reintegrated in a natural cycle. If reuse of liquid, or possibly pasteurized, sludge in agriculture is not feasible the following alternatives may be taken into consideration:

- disposal in suitable sites
- combined composting in both municipal refuse and sewage sludge
- processing to fertilizer
- sludge incineration or combined refuse/sludge incineration

The operating costs of all these alternatives, however, are considerably higher because sludge must be dewatered or even dried. The same processes used for municipal sludges can be applied in the treatment of non-toxic organic industrial and trade wastes. Dewatered inorganic sludges are disposed of in special disposal sites.

5.2 Influence of hardly or non degradable organic compounds

A distinction must be made between the effects of non degradable organic carbon compounds on the one hand and inorganic compounds, i.e. metallic salts on the other hand.

Very little is known about the effects of hardly degradable organic carbon compounds upon aerobic and anaerobic environments, soil and plant growth. Experience has shown that other soluble materials interfere with the digestion process. As these substances are only partially broken down during digestion, operating difficulties can be expected in dewatering and possibly in the agricultural use of such sludges.

Just as little is known about the influence of detergents. Newly developed, aerobically degradable detergents do not cause the wellknown problems of "hard" detergents. But it has been shown that these soft detergents are as resistant to anaerobic digestion as hard detergents. Therefore, the possibility of digestor problems still exists. Furthermore the influence of soft detergents on dewatering and the possible effects on agriculture are unknown.

These few examples evidently lead to the assumption that aerobic sludge treatment processes,such as wet oxydation might be used instead of anaerobic processes in the future. Experiments have shown that most organic carbon compounds can be broken down. In addition, such sludges are easier to dewater especially after thermal conditioning.

5.3 Influence of Inorganic Compounds

As regards inorganic materials, the discussion is restricted to metallic salts that are discharged (after insufficient in-plant treatment) into municipal waste water systems and ultimately into open water bodies. The ever increasing amounts of metallic salts in municipal sludges cause digestor problems and, eventually, difficulties in agriculture. Promising processes for the elimination of metallic salts have been developed by Sontheimer. Elimination should not be carried out in waste water treatment plants, but at the source, i.e: in industrial plants and factories, as concentrated waters are much easier to process than dilute ones. Consequently, more restringent requirements for industrial effluents will be necessary in the future. In the light of long-term effects we cannot tolerate toxic materials from industry in municipal sludges since the treatment and re-integration of these domestic sludges into a natural cycle would be made difficult or even impossible, thereby becoming an unjustifiable burden for the taxpayer.

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EUTROPHICATION FROM AGRICULTURE WITH SPECIAL REFERENCE TO FERTILIZERS AND ANIMAL WASTE

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1. Introduction

Eutrophication is the nutrient enrichment of waters which frequently results in an array of symptomatic changes, such as increased production of algae and other aquatic plants, deterioration of fisheries, general deterioration of water quality and other responses which are objectionable or impair water use.

Among the plant nutrients responsible for eutrophication, phosphorus and nitrogen have been found to be the most important elements. The general view is that phosphorus is generally the limiting factor. However, Legge and Dingeldein (1970) are of the opinion that carbonaceous material is also a dominant factor.

We shall in this report not enter into the question of limiting factors which is a problem for limnologists.

With phosphorus and nitrogen as main factors in eutrophication it is obvious to think about agriculture in highly developed countries, using high amounts of nitrogen and phosphorus in crop production as a main source of increasing eutrophication.

In this report it will be attempted to give an (quantitative) analysis of factors with respect to the contribution of agriculture.

2. Present Fertilizer Consumption

In Canada, Finland, Norway and Sweden a very small part of the total area is cultivated land, (3-8%). This contrasts with the United Kingdom where 80% of the total area is farmland. About 70% of the Member countries of the O.E.C.D. have an area of cultivated land of about 45-70% of the total land area.

From the F.A.O. report Fertilizers (1969) it can be calculated that cultivated land in the O.E.C.D. countries receives an (weighted) average amount of 25 kg N/ha/y and 10 kg P/ha/y.

However, in many cases permanent grassland is not fertilized. Therefore, it is of more interest to know fertilization on arable land[1/], which also can be calculated from the F.A.O. report. It was found that 65% of the arable land receives 0-80 kg N/ha, 25% receives 80-120 kg N/ha and 10% receives 120-160 kg N/ha. The second group (80-120 kg N/ha) represents approximately an optimum for tillage land.

When on tillage land more nitrogen is applied (120-160 kg N/ha), here is an indication for the presence of temporary grass in the rotation because in modern grassland management amounts of 175-225 kg N/ha are possible as shown by Table I. Also phosphorus application (see Table I) encompasses a wide range in West Europe running from 15-80 kg P/ha. However, the average application in a four-year rotation of cereals, potatoes and sugarbeets of 128 kg P/ha is in reasonably good agreement with removal in harvest of 108 kg P/ha.

For grassland, the removal depends strongly on the type of grassland management. The P-application here is sufficient for a production of 10 tons/ha dry matter.

From these results it is evident that actual nitrogen fertilizer consumption in agriculture in comparison with the optimum is relatively low and that average phosphorus application is in a reasonably good agreement with removal in harvest.

1/ including temporary grass

Table I

Annual Nitrogen and Phosphorus Application on Tillage Land and Grassland

Country	Region or System	P kg/ha/y				N kg/ha/y grass	
		Cereals	Potatoes	S.beet	Grass	Temporary	Permanent
Canada	Prairie Prov.	13	-	-	-	-	-
"	Ontario	25	-	-	25	-	30
"	Alberta	-	-	-	75	-	-
"	Atlantic Prov.	50	105	-	-	-	90
Belgium	Barrage Nisramont	38	35	35	35	60	50
France	Average (3)	26	29	44	15	40	11
"	Nord	-	-	-	-	184	62
"	Limousin	-	-	-	-	14	2
Netherlands		18	42	33	20	-	225
Sweden	Southern Centre	-	-	-	-	-	180
"	North	-	-	-	-	-	120
Switzerland		15	21	30	32	-	60
United Kingdom	Strip Grazing	-	-	-	-	215	175
"	Extensive Grazing	-	-	-	-	88	75
"	Arable Land	23	80	53	24	-	-
Average application (1)		24	41	39	25	100	96
Average removal (2)		20	24	44	14		

(1) Excluded Canada

(2) Removal calculated on a yield of 4.6 t/ha cereals, 40 t/ha potatoes, 50 t/ha sugarbeet and one cut of hay of 5t dm/ha

(3) Phosphorus data from : Feivy

3. Future Trends in Fertilizer Consumption

With Hebert and Graffin (1971) we may expect that on tillage land with a nitrogen fertilizer level of 80-120 kg N/ha there will not be any spectacular increase in fertilizer consumption because the optimum yield has been reached already. Only higher yields can be obtained by improvement of varieties and state of health or by preventing logging by the use of C.C.C. This might increase the nitrogen consumption in the long term.

But 65% of the land [1] received 0-80 kg N/ha. Here are good possibilities for increasing yields and fertilizer consumption, when natural conditions are not limiting factors. In dry regions, for instance, irrigation has to be developed first.

While there is under ideal conditions on 65% of the tillage land a possible mean maximum increase of about 60 kg N/ha (from 40-100 kg N/ha), in grassland the increase will be much higher. Cooke (1971) is of the opinion that 350 kg N/ha in leys is a real possibility and 250 kg N/ha on grassland grazed by dairy cows. Alberda (1971) comes to the conclusion that grass production of 20 tons dry matter per ha is even possible at about 500 kg N/ha/y, and without serious losses by leaching.

However, in estimating fertilizer need, especially of phosphorus and potassium, we also have to keep in mind that a certain amount of plant nutrients is imported in the concentrated feed used for livestock. These amounts are found back in farm yard manure and urine and used in crop production and will reduce the need for fertilizer. In The Netherlands the annual import of phosphorus in concentrated feed is already of the same order as the use in fertilizer!

The weighted average annual increase for the O.E.C.D. countries over the period 1964-1969 has been calculated for nitrogen at about 7%, for phosphorus at 3.5%. Over a period of five years that is about 20 kg N/ha and 2.5 kg P/ha.

Hebert and Graffin (1971) estimated for France for the next few years a growth of 3.9% for N and 5.4% for P. Cooke (1971) expects for the United Kingdom over the next 30 years a mean annual increase of 3% per year for nitrogen but with no more P needed than at present. In The Netherlands experts of the nitrogen industry are expecting an increase on tillage land from 100 to 125 kg N/ha/y in the next 30 years and on (temporary and permanent) grassland from 225 to 275 kg/ha/y. This is a growth of 22-25% or 0.75% per year up to the year 2000. For phosphorus a decrease in fertilizer use may be expected.

It is obvious that all these expectations will be influenced to a great extent by political, economic and agricultural factors.

4. Leaching Losses

4.1 Amount of Drainage Water

The amount of plant nutrients leached each year depends on the amount of drainage water produced and the concentration of nutrients in the soil moisture. The amount of drainage is determined by rainfall and rate of evapotranspiration, neither of which are man-made phenomena.

From data by Mohrmann and Kessler (1959) it appears that rainfall in Western Europe ranges from 200-1200 mm per year with an average of 700 mm. The water surplus ranges from 0-500 mm with an average of about 250 mm/y.

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[1] tillage

4.2 Leaching Loss of Nitrogen

Kolenbrander (1969) made a systematic study of N and P leaching by means of lysimeters. In view of the large effect of drainage on the leaching losses of nitrogen, Kolenbrander (1969) started from a linear relation between annual drainage water production (mm/y) and annual nitrogen loss (kg N/ha) up to about 600 mm drainage.

From this study it became evident that a distinction has to be made between a loss originating from soil organic matter and a loss by fertilizer. Further, that soil type and type of crop are very important in relation to nitrogen leaching losses.

4.2.1 Tillage Land

4.2.1.1 N Loss from Soil Organic Matter

Table II shows the N losses on cropped tillage land originating from soil organic matter at a drainage water production of 250 mm/y, at different clay contents of the soil. It appears that nitrogen loss is inversely proportioned to the clay content. This difference in leaching loss between different soil types is due to differences in rate of denitrification as a consequence of difference in pore-size distribution.

It is clear that the N-losses in sandy soils are high (45 kg N/ha) and that this will result in higher nitrogen concentrations in subsoil than in clay soils, where nitrogen losses are much smaller.

A reduction of these high losses on sandy soils will be only possible by "mining" the soil organic matter the next fifty years. But this soil organic matter is precisely the foundation of soil fertility and crop production in agriculture.

4.2.1.2 N-Loss from Fertilizer

Table III shows the nitrogen losses by leaching as a function of applied nitrogen fertilizer and soil type. Once again it is evident that losses on light soils are much higher than those on clay soils, but also that nitrogen losses increase as the amount of applied fertilizer increases. This effect of soil type on leaching loss will also be the result of differences in rate of denitrification.

We can make a rough estimate of the average leaching loss on cropped tillage land from fertilizer. Starting from the supposition that distribution of applied nitrogen as found in paragraph 2. on all soil types will be the same and that distribution of soil type itself will be as given in Table IV, it is found that an average N fertilizer application of 60 kg N/ha/y a leaching loss of about 2 kg N/ha is reached or 3.5% of the amount applied.

This is in good agreement with the 8% nitrogen loss calculated by Kolenbrander (1971) for tillage land in The Netherlands at a fertilizer level of 100 kg N/ha and about 50% sandy soils and the data of Hebert and Graffin (1971) for France which we calculated at a loss of 80 kg N/ha on tillage land.

Table II

N Losses by Leaching from Soil Organic Matter on Cropped Tillage Land at a Drainage Water Production of 250 mm/y (lysimeter exp.)

Heaviness of Soil 16 μ clay	N Loss kg/ha/y	N. Conc. mg/l
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

Table III

Nitrogen Losses by Leaching in kg N/ha/y at Different Clay Contents of Soil and Rate of Fertiliser Application on Cropped Tillage Land at 250 mm Drainage 6 Lysimeter Experiments

N Fertiliser Applied Kg N/ha/y	% Clay Content < 16 μ			
	0-10	10-20	20-30	30-40
0	0	0	0	0
30	1	0.5	0	0
40	2	1.0	0.5	0
50	3	1.5	0.5	0
60	4	2.5	0.5	0
70	6	3.5	1.0	0
80	8	4.5	1.5	0
90	11	6.5	2.5	0.4
100	14	8.5	3.5	0.5
110	19	12.0	5.0	0.8
120	24	16.0	7.0	1.2

Table IV

The Weighted Mean Nitrogen Loss by Leaching on Tillage Land

Soil Type	< 16 µ clay	Estimated Frequency	Soil org. Matter	N-Fertiliser	Total N Loss
Sandy Soil	0 - 10%	10%	45kg N/ha	5.7kg N/ha	51kg N/ha
Light Clay soil	10 - 20%	20%	30 "	3.3 "	33 "
Clay Soil	20 - 30%	40%	18 "	2.2 "	20 "
"	30 - 40%	20%	10 "	0.2 "	10 "
Heavy Clay Soil	40 - 70%	10%	5 "	0.0 "	5 "
Weighted Average		100%	20 "	2.1 "	22 "

However, the loss from soil organic matter is much higher (20 kg N/ha/y) thus about ten times that of fertilizer.

When all the tillage land would be fertilized optimally (<100 kg N/ha), average loss of fertilizer would increase 5% of the amount applied.

4.2.2 Grassland

The losses of nitrogen on grassland have also been studied by Kolenbrander (1969). Here the losses are much lower than on tillage land. At 700 mm rainfall the loss from soil organic matter was about 5 kg N/ha/y and from fertilizer (250 kg N/ha) only 2 kg N/ha/y or 1%. Also, Kofoed and Lindhard (1968) found a total N loss on grassland of 5-10 kg N/ha at a fertilizer level of 183 kg N/ha/y.

On clay soils Low & Armitage (1970) found 1 kg N/ha from soil organic matter and Bolton et al (1970) only 0.3 kg N/ha. The average N-loss from soil organic matter on grassland can be estimated at about 3 kg N/ha/y, that from fertilizer at about 1% of the fertilizer annually applied.

The explanation for these low losses in grassland is the high rate of N uptake, the long growth period of the grass, the absence of fallowing and the fact that the total amount is given in 4-6 separate applications during the growing season only.

4.2.3 Crop Rotation

Leguminous plants fix nitrogen from the air. When plowed under in Autumn a part of this nitrogen will be leached. From unpublished data of Maschhaupt quoted by Kolenbrander (1971) and results of Low & Armitage (1970) and Karraker et al (1950) we calculate an extra nitrogen loss of about 45 kg N/ha/y. However, after peas, harvested in the beginning of August, Maschhaupt found an extra nitrogen loss by leaching of about 125 kg N/ha. From these results it becomes clear that a large part of the biologically fixed nitrogen in the root nodules of pulse crops and leguminous plants is not used by the next crop, also when this is a "cover" crop sown in autumn.

In this respect grass as green manure crop should be preferred.

4.2.4 Time of Application

Nitrogen applied during autumn and winter is much more vulnerable to leaching than that applied in spring or summer. Kolenbrander (1969) found with grassland on sandy soil that nearly 40% of the fertilizer nitrogen applied at the beginning of November proved to be lost, while there was no loss at all in spring.

Under practical conditions fertilizer application is restricted to the growth season but much nitrogen is applied in autumn and winter as farm yard manure and liquid manure which will result in extra losses by leaching and run off.

4.3 Leaching Loss of Phosphorus

4.3.1 Type of Soil

Table V is a summary of P losses from lysimeter experiments, or calculated from drainage water analyses (Henkens (1971), Cooke and Williams (1970)) and soil moisture analyses (Munk (1972)). From this table it can be estimated that the average loss by leaching on cropped farmland is about 0.22 kg P/ha/y at 250 mm drainage water. This P loss is increasing linearly with drainage water. This P loss is increasing linearly with drainage water amount (Kolenbrander 1971).

Pfaff (1963) found with clay soils much higher values running from 2 to 4 kg P/ha/y. This is possibly caused by losses of clay particles, which can absorb high amounts of phosphorus. The amount of clay particles in the drainage, therefore, will cause great fluctuations in the total P loss by leaching with the tendency that the P loss on clay soils may be higher than on sandy soils.

On peat soils the phosphorus loss by leaching is much higher. From data by de Vries and Hetterschij (1936/37), Wilson and Staker (1937), Henkens (1971), Eggelsmann and Kuntze (1972) and Munk (1972), it was estimated that an annual average loss of 2 kg P/ha at 250 mm drainage water is likely. Partly this is phosphorus in organic form.

4.3.2 Effect of P-Fertilizer Application

In contrast to nitrogen, no relation was found between the amount of P-fertilizer applied and the loss of P by leaching in lysimeters with a depth of 1 m.

In view of the low phosphorus concentration in the drainage water (about 0.08 mg P/l (Cooke and Williams (1970)) strong absorption in the profile must be assumed.

The absence of a clear relationship between P-applied and P-lost by leaching makes it very difficult to reduce the phosphorus losses by leaching. Here again, as with nitrogen only "mining" of the soil organic matter the next fifty years would be a theoretical possibility in decreasing these P losses.

The conclusion must be that nitrogen and phosphorus loss by leaching can hardly be reduced by activity of man without a serious loss in soil fertility and crop production.

The losses of fertilizer nitrogen on tillage land are small, except in light sandy soils. On grassland they are negligible.

Table V

Leaching Losses of Phosphorus in Cropped Soil

(Lysimeter exp. and drain water analyses)

	Arable Land		Grassland	
	Loss kg P/ha/y	Drainage mm/y	Loss kg P/ha/y	Drainage mm/y
Baltin et Al (1970	0.72	250	0.30	250
" "	0.48	250	-	-
Coppenet (1969)				
Quimper	0.13	250	-	-
Versailles	0.28	250	-	-
Cooke and Williams (1970)	0.13	?	0.20	250
Holtan (1971)	0.07	?	-	-
Kolenbrander (1971)	0.06	250	0.20	250
Low and Armitage (1970)	-	-	(1.23)	250
Minderman and Leeflang (1968)	0.05	250	-	-
Henkens (1971)	0.07	250	-	-
Munk (1972)	0.11	250	-	-
Average	0.21	250	0.23	250
Average Concentration mg/l	0.084	-	0.092	-

5. Soil Erosion

There are two types of soil erosion:

a. erosion by wind

b. erosion by water

5.1 Wind Erosion

Wind erosion occurs in different countries during dry weather periods on sandy and peat soils. Wind tunnel experiments showed that a sandy soil was blown at a rate of 50 tons/ha/hour (= 5 mm soil/hour) when wind speed was equal to 15 m/sec (Peerlkamp, 1971).

Cooke and Williams (1970) mention that wind erosion may remove 10 mm of soil containing perhaps 1500 kg total nitrogen and 150 by total phosphorus from 1 ha.

Much of this soil is deposited locally and ditches are filled. A part of the N and P in the dust must also enter streams, rivers and lakes, but to what extent is difficult to estimate.

5.2 Water Erosion

In Western Europe water erosion is not generally a problem. In the Western part of the U.S.A. it is. Also in Canada 0.1% of the soils are severely affected by water erosion (loss in productivity > 35%). This severity of erosion is related to topographic features such as hill areas or river valleys.

In regions of erosive soils 25-75 tons/ha/y are delivered to streams if vegetation is poor. Most material in transport by erosion is in suspension and is in the silt and clay size range. Water erosion is, therefore, a silt transport problem.

Besides the length and steepness of the slope, intensity of rainfall is an important factor. Erosion starts with a rainfall intensity of about 25 mm/h. Ripley et Al (1961) found on a 10% slope a soil loss of 12 ton/ha which is about equivalent to 1 mm of top soil.

Holt et Al (1970) remark that sediments carry relatively large amounts of total nitrogen and total phosphorus into the surface water, but in both cases only a small proportion of its total is readily available to the biosystem.

It is evident that N and P loss by erosion will vary within wide limits, depending on climatic and topographic conditions.

In the United States the annual contribution by soil water erosion has been estimated on 5-50 kg total N/ha/y and 0.5-5 kg total P/ha/y (Armstrong and Rohlich, 1970).

Cooper et al (1969) point out the highly significant inverse correlation between crop yields and soil and water losses from sloping land. The beneficial effects of a high level of soil fertility reduce erosion losses by inducing a more rapid early spring growth, denser canopy, enlarged rootsystem and more organic residues to enhance soil tilth, infiltration and biological activity.

Wadleigh (1968) is of the opinion that by erosion control measures losses can be reduced by 75% and more.

5.3 Run-Off

Even when soil erosion by water is prevented, run-off will be a factor in eutrophication. Run-off can take place on flat soils in winter when soils are frozen and snow is melting. Also, in spring when rain follows fertilizer application, run-off can contribute considerable amounts of N and P to the surface water, but this will be only incidental cases.

Table VI shows total nitrogen and phosphorus contribution of watersheds to surface water. In these watersheds pollution by industry and population are excluded. A small effect of rural living may be possible, but it is very difficult to estimate these amounts.

It appears from Table VI that the total contribution of phosphorus including drainage water is small (0.35 kg P/ha) when serious pollution by annual waste is excluded. Still this loss is higher than that found in lysimeter experiments where run-off is excluded (0.22 kg P/ha).

Gächter and Furrer (1971) are of the opinion that a high value of 0.70 kg P/ha is due to run-off.

In summary, the effect of run-off from Table VI can be estimated to be from 0 to 0.5 kg P/ha/y. The upper limit of 0.5 kg P/ha/y is the lower limit estimated for soil erosion.

6. Pollution by Animal Waste

6.1 Direct Pollution of the Surface Water

Direct discharge of animal waste with a high content of organic matter, nitrogen and phosphorus, causes a serious pollution problem.

Under normal practical conditions the farmer will use the animal waste as manure for his crops. When, however, for economic reasons the number of livestock per ha has to be increased, liquid manure tanks become impractical and it will be cheaper to discharge a part of the urine to the surface water.

However, in "industrial" farming which means: "the highest number of livestock on the smallest area possible", the animal waste becomes a considerable problem for the farmer and a discharge to the surface will be a way out.

It is not difficult to calculate the total amount of N and P produced annually by livestock. But it is difficult to estimate which part is really discharged to the surface water.

Kolenbrander (1971) estimated on balances from different watersheds a direct discharge of 0.2 kg P/ha/y and 5 kg N/ha/y, which is equal to 1% of the faeces production plus 10% of the production of urine. In regions where "industrial" farming has been concentrated the direct discharge may be a factor 7-8 times higher.

Harmeson et al (1971) estimated for the Kaskaskia River region (Illinois) that about 7% of the nitrogen has its origin in animal waste while Baumann and Kelman (1970) postulate a rough estimate of 25% for Iowa.

From these data it is clear that estimates range widely. But even a direct discharge of 7% is in the order of the contribution of soil erosion.

In order to reduce eutrophication it will be necessary to restrict "industrial" farming in this uncontrolled fashion.

Table VI

Total Loss of N and P from Catchment Areas, Excluding Effects of Urban Living and Industrial Pollution

Country and	Source	100% Forest or Prairie		100% Cultivated Land		Type Exploitation
		N kg/ha	P kg/ha	N kg/ha	P kg/ha	
Canada	Owens/Johnson	-	-	5	0.26	-
MacLean (1971)	Campell/Webber	0	0.01	-	-	Prairie
France	Rupt de Mad	-	-	2	-	
Netherlands	N. Veluwe	-	-	-	0.40	Grassland
Kolenbrander (1971)	Flevoland	-	-	24	0.16	Arable
	Hupselsebeek	-	-	56*	0.52	Grassland
	Hierdensebeek	-	-	22	2.49*	Grassland
	Langebroekerw	-	-	-	1.37*	Grassland
Sweden						
Brink (1971)	Uppsala reg.	2	0.06	6	0.35	Arable
Switzerland						
Gächter/Furrer (1971)	Préalpine reg.	1	0.03	16	0.70	Grassland
	Midlands	6	0.03	23	0.35	Mixture
United Kingdom						
Owens (1970)	Great Ouse	-	-	12	0.06	-
U.S.A.	Lake Monona	-	-	6	0.36	-
Sawayer (1947)	Lake Wambesa	-	-	6	0.39	-
	Lake Kegonsa	-	-	8	0.41	-
	Average	2	0.03	12	0.35	
Lysimeters (250 mm)		0.5	0.12	5-60	0.22	Arable or Grassland

* excluded from average (animal pollution)

6.2 Dumping and Irrigation with Animal Waste

When direct discharge to surface water has to be prevented, the farmer may start dumping his animal waste on his agricultural land in amounts much higher than is necessary for crop production. Crop production may even become a secondary factor!

From the study of Stout and Burau (1967) it becomes evident that any fertile sandy soil has an inherent potential nitrate supplying power of about 22.5 ppm N ($\approx$ 100 ppm NO_3) which value is in good agreement with that found in lysimeter experiments for sandy soils in Table II. However, this concentration of 22.5 ppm N is the maximum concentration recommended by the International Water Supply Association in 1952 (Trines, 1952) in relation to "infant methemogloinemia". The American Drinking Water Standards quote a maximum level of 10 ppm N (= 45 ppm NO_3).

It is evident that dumping of high amounts of animal waste in excess of crop need will increase the amount of nitrate which in turn will increase basic leaching. On light soils this may result in nitrate concentrations of groundwater above the standards for drinking water. In countries where drinking water from public water supplies is predominant this will not be a problem because a decrease by denitrification in deeper layers may be possible (Kolenbrander, 1971, Hebert and Graffin, 1971, Cooke and Williams, 1970, Stewart et al (1967)).

In the foregoing we have seen that applied fertilizer phosphorus was not leached in mineral soils. Only in very light sandy soils with a low phosphorus fixing capacity and high water penetration it may be possible that fertilizer phosphorus can move slowly downward and reach the water table after a great number of years.

However, when phosphorus is in a form not easily absorbed into the soil complex, in contrast to fertilizer phosphorus, there is the possibility that the displacement of the phosphorus into the subsoil will be much faster and result in increased phosphorus concentrations in groundwater. Rietz (1969) found at a depth of 40 cm after sewage application a content of 9 mg P/l, van Geneijgen and Scheltinga (1970) at 60 cm 2.6 mg P/l and Kuelleker and Miner (quoted by Black, 1970) at 122 cm 0.5 mg P/l, after irrigation with livestock waste. This value of 0.5 mg P/l seems to be considered as a minimum value in sewage effluent, also after chemical treatment of sewage water (Notes on Water Pollution, 1968). It may be an indication that this phosphorus is in organic form and has to be mineralized first by bacterial activity before it will be absorbed.

Results of Vetter and Klasink (1972) with high amounts of slurry show a 2-3 fold increase in phosphorus content in subsoil (60-90 cm) after 20 years. Van Geneijgen and de la Lande Cremer (not yet published) found an increase even within a year of total P at 1 m depth after dumping eight times 30 tons of slurry on a sandy soil in a few weeks.

These results indicate that phosphorus from organic manure can move to a greater or lesser extent to the subsoil. This process will be stimulated by irrigation of high amounts of waste with low dry matter content. Resulting phosphorus concentrations are higher than those normally found at this depth (1 m) due to fertilizer phosphorus (about 0.08 mg P/l).

The determining factor is not the rate of reduction of the P concentration in the waste water but the phosphorus content in the effluent or ground water. An important factor is clearly the depth of the water.

In reducing nutrient enrichment of surface water, N pollution of subsoil has to be prevented, which will be possible by limiting irrigation with high amounts of waste with low dry matter content on light soils and dumping of high amounts of solid waste.

7. Evaluation of Agricultural Contribution

The relation between phosphorus discharge per ha catchment area (P_D) and the surface loading factor for lakes (S_L) from Vollenweider (1970) is:

$$P_D = S_L \cdot \frac{A_L}{A_C}$$

The value of S_L as given by Vollenweider is ranging from 0.7 kg P/ha/y at a mean depth of the lake of 5 m to 6.0 kg P/ha/y at an average depth of 200 m. The ratio A_L/A_C represents the ratio between the area of the lake (A_L) and the area of the watershed (A_C). The value P_D will be small for small lakes in large watersheds and for lakes that are shallow (decrease of S_L).

From data of Gächter and Furrer (1971) for Swiss lakes (Table VII) a relation has been calculated between the discharge factor P_O and the percentage of lakes for which this discharge is permissible or dangerous.

From these figures it is clear that the P loss found under forest conditions (see Table VI) is permissible to all lakes. The P loss from leaching (lysimeters) of 0.22 kg P/ha is permissible to about 60% of the lakes and dangerous to 10%. The total P loss including run-off (0.35 kg P/ha) is only permissible to 10% and dangerous to 35% of the lakes.

It appears that there is already an unstable situation in the smaller and shallower lakes when only drainage water from agriculture is discharged, and that the danger limit will be very easily crossed by pollutions of any other kind such as run-off erosion, animal waste and sewage water of population.

In evaluating the contribution of agriculture, we can consider its contribution to the total phosphorus flow to the surface water. This is possible by input balances of watersheds. Table VIII shows four balances in which it is striking that contribution of agriculture in The Netherlands is only 4% in rural run-off and groundwater whereas this is 42% in the U.S.A. The most important factor influencing the results is the low population density in the U.S.A. The lower this density the higher the contribution of agriculture. A second factor is that for The Netherlands the contribution of phosphorus in agriculture is estimated to be 0.4 kg/P/ha and in the U.S.A. at 2.77 by P/ha due to the important effect of soil erosion. At high population densities urban living will be a very important source of eutrophication (Owens, 1970).

8. Legal Aspects

In nearly all countries new laws or additions to older ones are promulgated concerning the protection of the environment against pollution. Discharge of waste (fluid, solid or gas) to water courses is forbidden or restricted to a license containing financial and technical conditions on discharging. The authorities must balance the advantages to society and the costs for the polluter.

However, these legal measures in environment protection relate at best to the oxygen content of the surface water which is depressed by direct pollution with organic matter and ammonium nitrogen and not to eutrophication. The use of fertilizer as a source of pollution is not restricted in any country. One does find restrictions on feed lots in some provinces of Canada and in some states in the United States. The conditions are that adequate land or other facilities must be available for disposal of waste, preventing run-off to surface water and the provision of storage facilities for manure. In The Netherlands "natural" run-off is not considered as an artificial pollution!

Table VII

Relation between Phosphorus Discharge Factor P_D and Percentage of lakes to which this is Permissible or Dangerous

Phosphorus Discharge Factor P_D Kg P/ha/y	% of the Lakes	
	Permissible to	Dangerous to
0	100	0
0.10	97	0
0.15	90	1
0.20	70	5
0.25	50	12
0.30	25	23
0.35	10	35
0.40	2	50
0.45	0	63
0.50	0	75
0.55	0	87
0.60	0	95
0.65	0	98
>0.70	0	100

Data of Gächter and Furrer (1971) and Vollenweider (1970)

Table VIII

Estimated Amounts of Nitrogen and Phosphorus reaching Surface Waters

	Netherlands		Wisconsin		Lake Mendota		U.S.A.	
	N	P	N	P	N	P	N	P
Rainfall (2)	8 %	7 %	9 %	1 %	20 %	3 %	2 %	1 %
Urban Living (3)	27 %	74 %	36 %	68 %	16 %	53 %	14 %	28 %
Rural Run-Off	5 %	2 %	12 %	28 %	11 %	42 %	60 %	42 %
Ground Water	29 %	2 %	42 %	2 %	52 %	2 %		
Non-Agric. Land	-	-	-	-	-	-	8 %	29 %
Industry	31 %	15 %	2 %	1 %	-	-	7 %	-
Ratio : Urban living Rural Sources (1)	0.77	21	0.67	2.3	0.25	1.2	0.21	0.4

(1) Rural run-off + ground water

(2) Only in surface water area

(3) Including private sewage systems and urban run-off

9. Possible Remedies

Starting from the general point of view, control of eutrophication implies a strong reduction of the P and N discharge to surface water. Agriculture has in principle the following possibilities for reducing P and N discharge:

1. Reducing soil erosion by better soil conservation management;
2. Fertilization from aircraft or steep slopes should not be allowed;
3. No manuring activity in autumn and winter;
4. Sufficient storage capacity for all waste from the farm;
5. Preventing fallowing in autumn and winter by use of a cover crop (preferably not a leguminous crop);
6. Over-manuring (dumping and over-irrigation of soil have to be limited particularly on light sandy soils;
7. Separate treatment of solid and liquid animal waste will open better possibilities than production of slurry;
8. Factory farming has to be restricted to licensed operations;
9. Restrictions in P and N fertilizer use will have little or no effect in reducing eutrophication;
10. Decrease P and N loss from mining soil organic matter will result in a strong decrease in crop production and increase of food prices;
11. At high nitrogen fertilizer levels, it is advisable to give a number of small applications rather than a single large one.

10. Summary

The contribution of agriculture to nutrient enrichment of drainage waters is about 0.22 kg P/ha/y. This amount is dangerous to 10% of the lakes and permissible to 60%.

Contribution of run-off is estimated to be 0 -0.5 kg P/ha/y. The average total discharge in drainage water and run-off is about 0.35 kg P/ha and permissible to 10% of the lakes and dangerous to 35%.

However, it is not easy to reduce this contribution of agriculture because there is no relation between applied fertilizer phosphorus and P leached at 1 m depth. Only by "mining" soil organic matter during the next 50 years will it be possible to reduce this P loss, but this will result in a serious loss of crop production which is impossible in view of our ever-increasing world population.

The contribution of nitrogen depends on the type of soil and ranges for soil organic matter from 45 kg N/ha/y on sandy soils to 5 kg N/ha/y in heavy clay soils. The difference is due to loss by demitrification.

The total leaching loss from fertilizer N was calculated to be 3.5% at a level of 60 kg N/ha on tillage land. On grassland the N loss is still smaller and is ranging for oil organic matter from 0.3 - 5 kg N/ha/y and for N-fertilizer at 1% at an application level of 250 kg N/ha.

The contribution of soil erosion is much more important than from fertilizer and is ranging for P from 0.5 - 5 kg P/ha/y and for Nitrogen from 5 - 50 kg N/ha/y.

The contribution of animal waste was estimated to range from 1 - 25%. Because of its serious effect on pollution and eutrophication, factory farming must be restricted by licenses.

Use of fertilizer is not restricted by law, while "factory farming" is in some countries.

Nutrient enrichment due to waste is not restricted by any law. Discharge of "organic" waste in relation to the oxygen content of the surface water however is.

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NUTRIENT CYCLES AND AGRICULTURAL RESOURCE MANAGEMENT [1]

Considerations for Decision Making

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In terms of land area and value of natural resources, agriculture and forestry constitute the largest environmental complex on earth. Although the problems associated with this complex may differ from region to region, one can safely say that at least for the so-called developed nations its major problems are sediment and dust, plus organic wastes from livestock and the food and forestry processing industries.

Sediment burdens from agricultural lands in the United States are estimated at two billion tons per year, as is the quantity of livestock wastes produced. Both are immense problems, and would be very costly to handle even if the will and the technology existed. Fortunately the amount of sediment has been reduced during the past generation due to efficient crop production methods which have permitted several millions of marginal acres of U.S. crop land to be retired from cultivation. With sustained effort during the 1970's, sediment should be brought under reasonable control on both farms and forests. In passing one might note that sediment from highway erosion and urban and industrial growth is also about two billion tons a year, but as of now prospects for rapid improvement in the U.S. are not bright.

Livestock numbers in the U.S. are on the increase and the volume of wastes is growing faster than disposal technology. Many people today say that disposal of manure is agriculture's greatest problem. They believe that the only solution lies in spreading more and more of it on rural lands. It appears quite likely, therefore, that the U.S. soon will see some shifting away from the huge feeding operations where thousands of cattle are turned out annually, to smaller ones with lower-density stocking. Such a shift will facilitate control of runoff as well as getting manure spread on the surrounding land. The cost will appear to be high because of reduced efficiency and because the value of the nutrients will not pay for the labor required. Thus, one can anticipate added food costs or increased taxes, and these must be evaluated in terms of enhanced environment.

City tax burdens are already great in the U.S. and are skyrocketing for handling of human sewage and urban wastes. A number of joint city and federally sponsored experimental projects are currently under way to find out how much organic matter or sludge can be accommodated by spreading on a given area of land, at what cost, with what social objection, if any, and with what toxic effects on plants, if any.

Because most streams in the U.S. already are overburdened with organic matter, not only is the demand for improved treatment technology imperative, but it appears that we must look to land disposal to provide relief for streams and lakes in the near-term future. Hopefully, for the long-term, new technology will develop economic techniques for dissipating oxidizable carbon so that streams can handle urban effluents with no adverse effects. Hopefully, too, new techniques will provide similar means of handling livestock wastes to protect streams from oxygen depletion.

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Unfortunately certain rather recent cropping pattern changes in the U.S., and particularly in the midwestern states, have not led to improvement in stream quality. Today millions of acres of land (1) are devoted to soybeans whereas formerly they were used for barley, oats, wheat and hay, crops which provided considerable soil protection, especially during periods of heavy snow melt and spring rainfall. This is in marked contrast to the lack of snow melt and spring rainfall. This is in marked contrast to the lack of protection now provided by dead and shredded residues from the soybean crop. Residues from the vast acreages of corn are handled similarly, and provide little protection. It would surely follow, therefore, that adjacent streams are receiving much greater amounts of water runoff (1), containing organic matter and plant nutrients, leached out of the crop residues.

FERTILIZERS BLAMED

Recently fertilizers have been blamed for deterioration of water quality in U.S. streams through contribution of nutrients. I am not yet convinced that this is serious because there is very little conclusive evidence based on a check or natural background area for comparison. According to Dr. Frank G. Viets (15) of the U.S. Department of Agriculture, some of the best information to date on the effect of fertilizers was obtained in Canada on a Brookston clay soil. Here the experiments included various crops on fertilized and unfertilized plots. The amount of nitrogen and phosphorus fertilizer applied is referred to as "higher than normally recommended".

The 7-year average composition of the tile drainage water was:

	PPM	
	NO_3-N	P
Fertilized	8.1	0.21
Unfertilized	6.4	0.18

Although the amounts of nitrogen and phosphorus from both the treated and untreated plots are relatively small, they are very much more than those required for support of plant growth in aqueous systems. The same can be said for the results of all other similar work I have observed, as for example, the data reported by Viets (15) for different types of land use, which values average from 7.4 to 13.4 ppm of NO_3-N reaching a water table at a depth of 20 feet.

Extremely interesting to reflect on at this point is a publication by Drs. Stout and Burau (17) in which they calculated the nitrate concentration in leachates from U.S. prairie soils due to a century of cultivation. If the soils contained 0.1 percent organic nitrogen in the top foot, and if one fourth was lost during 100 years of cultivation, and one-hundredth was lost as nitrate in 12.6 inches of percolate annually, the water would contain 28.6 ppm of NO_3-N. This leads me to the belief that in the early years of cultivating these soils, when rate of organic matter destruction was quite high, waters naturally must have been considerably higher in nitrate than is true today.

The above data cited by Viets and lines of reasoning by Stout and Burau seem to lend strong support for looking beyond plant nutrients, and instead considering organic matter as the pollutant, rather than its nutrients. Perhaps only when nutrients are present to the degree of causing an undesirable toxic salt effect should they be looked upon as pollutants. Water can contain all essential nutrients in the best possible balance for plants and yet be a sterile medium. Unless energy is provided for bacteria, little life will ensue. In the laboratory, unless air (carbon dioxide) is bubbled through the medium, very limited production of algae occurs until organic matter builds up. Dr. H.S. Swingle of Auburn University found this out more than 20 years ago when he obtained negative results from fertilizing fish ponds. He soon reasoned that bacteria would be necessary to generate enough carbon dioxide for the photosynthetic plants such as algae, if they were to serve

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as the base for the food chain for fish production. It was only after he supplied energy sources, as cottonseed meal or soybean meal, that he got good yields of phytoplankton, zooplankton and fish.

More recently, scientists of the Tennessee Valley Authority fertilized paired coves over a two year period to see if nutrients would cause increased algae-growth for fish production. They found that the addition of soluble inorganic nutrients produced no measurable effects on phytoplankton or on inorganic nutrients produced no measurable effects on phytoplankton or on fish. Had they included a readily available source of organic carbon, I'm sure profound effects would have occurred immediately, and that these effects and ensuing ones would still be evident in terms of species of aquatic plants.

In nature, where organic matter is nearly always present, it is well established that very small quantitites of nitrates and mineral nutrients will sustain luxuriant growth of aquatic plants, and that certain rooted plant species obtain nutrients through their roots (10). Upon plant decay, these nutrients, plus those added by wildlife and transient waterfowl (5) are cycled over and over by bacteria, algae and other plants and animals. I cannot, therefore, envision a situation in nature where man-induced inputs of these nutrients are necessary for eutrophication; otherwise how can one account for the earth's vast coal, oil, and peat deposits? Likewise I cannot envision any existing situation where removal of a nutrient other than carbon from effluents could have any measurable effect on the receiving stream or natural body of water. To be effective the principle of nutrient removal surely will have to be applied to the body of water itself (7). And, if and when it is, it likely will be bzsed on the removal of one or more of the micronutrients, as by chemical precipitation, plus harvesting of algae or other plants at certain intervals.

Slowing the process of accelerated eutrophication will indeed be difficult because the input of both organic and inorganic carbon must be controlled. The present tremendous volumes of human and livestock wastes dictates that control over the organic carbon input should take first priority, not only for sanitary reasons, but because it offers a means of partial control over accelerated eutrophication. But, until the inorganic carbon input can also be controlled, there is little hope of bringing eutrophication under reasonable control, especially near airports and cities.

BETTER COMMUNICATIONS ESSENTIAL

Regardless of what part of the world you are from, I's sure each of you here is aware that considerable effort is going forward in the U.S. to remove phosphorus from sewage, prior to its discharge. Unfortunately both the people and the political decision-makers were led to believe that this would halt eutrophication, whereas it can lead only to wasted effort and money (7). Repetition of this type of error must be avoided by the developing nations, and this will require skillful attention to communications.

Actually communications of elementary information on pollution sources should not be too difficult because there are only a few major ones of significance:

1. Sediment, dust, and inorganic industrial wastes.
2. Organic matter:
    a. Domestic animals, human, and wildlife wastes,
    b. Industrial wastes,
    c. Plant and animal remains,
    d. Improperly used chemicals.
3. Energy wastes:
    a. Transportation,
    b. Heating and power.

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On the other hand, communications of information on how to bring pollution sources under control is quite something else and much more difficult. All too often factual data are lacking or not yet conclusive enough for decision making. This is the area of speculation now occupying efforts of the "phophets of doom", who rarely let the absence of facts keep them from talking and writing.

Two basic conditions now are evident, however, and these should not be difficult to communicate to the lay community and its decision makers. These are:

1. The human population eventually must be balanced against resources and the abivility of a country or region to cope with the wastes of its society.
2. People of every nation must prepare to meet the high cost of disposing of their organic and energy wastes while at the same time preserving the productivity of their lands.

ESSENTIALS OF NATURE AND AGRICULTURE

The remainder of this paper is devoted to a few simple, although often overlooked, situations and facts of nature and agriculture which need to be understood by decision and policy-making people, both in the developed and less developed nations, if costly mistakes are to be avoided.

Simplified View of Nutrient Cycles

A simplified view of the earth is that the chemical elements at or near the surface and in the air are in a continuing state of movement, or subject to forces which can cause movement. The outstanding characteristic is that outgo of inorganic elements (including plant nutrients) from land to water greatly exceeds input over most land surfaces of the earth. The same degree of negative balance does not apply, however, to the non-mineral nutrients, carbon, nitrogen, oxygen and hydrogen. With them, there is a turn-over through the atmosphere, land, organic matter, and water, with outgo from land almost being balanced by inputs, except for agricultural areas of the world where crop and livestock removals are causing a deficit and for lake shorelines, swamps and bogs where plant remains are accumulating.

Nitrogen - the Mobile Element

Fortunately, man has learned how to fix nitrogen from the air into forms that he can handle and use to nourish crops. If this had not been true, he might already be on the verge of extinction. It is fortunate, too, that most crop plants have the ability to synthesize more protein as their supply of soil nitrogen is increased by additional fertilizer or other means.

It has been estimated (3) that 90 million metric tons of nitrogen are fixed biologically on the earth every year, largely through algae in water and bacteria on land, and that an additional 10 million tons are added by rainfall. This 100 million tons is almost four times the 25.6 million metric tons of fertilizer nitrogen consumed in world agriculture in 1970. It is only in the more advanced countries that synthetic sources of nitrogen play a key role in food production. These countries fix three-fourths of the world's nitrogen, but contain only one-fifth of the world's people (13).

In 1968, C.C. Tanner (14) confirmed earlier studies that the (Fertilizer) Nitrogen Equivalent of Diets (FNED) is generally related to per capita income. Tanner's work has been confirmed by FAO studies. The dietary method has been used to supplement other techniques for projecting future needs for nitrogen.

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Based on projected dietary protein and other needs of the world in the year 2030, when population will be 12 billion people (4 times the present level), more than 200 million tons of nitrogen will be required to grow food and fiber. Most of this nitrogen will have to come from the fertilizer factory.

Because nitrogen looms so great in man's future, and because vast quantities of it are constantly moving about in our environment, a few facts should be kept in mind. Even though the atmosphere contains about 35,000 tons of nitrogen over each acre, this represents only about 2% of the earth's supply of the element, the major portion being in minerals, rocks, and soils.

According to a recent review (6), the United States (exclusive of Hawaii and Alaska) receives 10 million tons from biological fixation. Add to this amount the 5 million reaching United States soils and waters in rainfall, 7 million tons from fertilizers, and some 7 to 8 million tons from combustion of fuels (17) in factories, autos, and homes, 10 million in livestock wastes, and 8 million tons which go down the sewer every year from the food consumed in the U.S., and it is obvious that the amount of nitrogen transient in the environment is indeed very great. Still an additional source of transient nitrogen is the 20 million tons arising from the yearly decay of organic matter in soils of the United States, including forest lands. About half of this is utilized each growing season by plants and soil organisms, and recycled (12). Actually, the total or net loss is lower today than formerly. The first 25 years of cultivation of land in the Midwest destroyed about 25 per cent of its original nitrogen. During the next two 20-year periods losses amounted to approximately 10% and 7%, respectively (11).

But, many of these same soils still contain up to five tons of nitrogen per acre plow-depth. In terms of nitrate, this is equivalent to 45,000 pounds per acre. Such soils obviously could lose 100 pounds of nitrate per acre per year for a half century and still have at least 2.5 tons of nitrogen remaining. The soils' reserve of nitrogen, however, should be no less then than now because profitable cropping practices will be adding large quantities of crop residues. In spite of this, even then our best lands likely will not be able to supply enough nitrogen during the growing season for optimum yields unless nitrogen fertilizer is used.

Dr. Stanford of the U.S. Department of Agriculture (12) has emphasized that little movement of nitrate occurs below the root zone of a properly fertilized crop, and then only when rainfall or irrigation water is supplied in excess of that used by the crop and retained in the soil profile. Under most farming conditions in Europe and America there is little opportunity for nitrogen loss by leaching during the growing season. This likely will not hold true, however, in the tropics and needs to be studied. No doubt new slow-release sources of nitrogen will be economically essential.

Because nitrogen is present everywhere and because it is such a mobile nutrient in water, land, and air, it has received very wide attention in recent years with respect to excessive growth of unwanted aquatic plants, especially algae. However, if one remembers the above figures, and considers that rainfall contains from 0.5 to 1.0 ppm of nitrogen and that 40 some species of algae get their own nitrogen from the air as needed, it does not appear likely that nitrogen from fertilizer is generally increasing aquatic plant growth. It must be remembered, too, that only 0.3 ppm of nitrogen, or half that in ordinary rainfall, will support growth of algae.

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Phosphorus Non-Mobile

Phosphorus, unlike nitrogen, is highly immobile in soil. Nevertheless it is receiving a great deal of attention in connection with pollution. Like nitrogen, however, it is an essential constituent of every plant and animal cell and thus a major component of the human diet as well as that of livestock, pets and wildlife. Because phosphorus is ever-present in both soil and water, and always will be, there is little cause for concern over it, especially when less than 0.01 mg/l (10 ppb) of it in a lake is enough to support algal blooms. Underwater deposits of organic matter, silt, and clay will provide enough available phosphorus for decades to come to grow many aquatic species of vegetation because certain rooted ones obtain their supply of mineral nutrients through their roots (10). Upon death of the plants, their nutrients are released and are subject to being cycled over and over again by countless forms of aquatic life.

The soil sediment that reaches lakes and coastal waters contains phosphate molecules tightly adsorbed on the surfaces of the clay and colloidal particles. The amount of phosphate thus adsorbed may amount to 1.0 ppm. Distinction must be made, however, between adsorbed phosphorus and phosphorus in true solution when one considers growth of algae. To control algae by controlling the amount of phosphorus in true solution means that the quantity of such phosphorus must be maintained below 0.01 mg/l and this would seem to be impossible in most situations (7, 8, 9).

Thus it is difficult to envision a water environment in nature, let a one find one, where growth of algae, for example, could be inhibited because of lack of phosphorus.

Regarding nutrient input-output relationships, the study of nutrient budgets for continents, or watersheds such as the Nile or Mississippi, seems rather useless except for knowing the seriousness of the occurring losses. On a smaller scale, however, nutrient budgets may serve a useful purpose for areas such as a dairy farming region (4), a livestock feeding area, or a small watershed.

Carbon has Great Significance

Over thousands of years great stores of carbon were fixed by plants and are still held in soil organic matter, peat, muck, coal, and oil deposits. The stores in soils of many areas of the world are being depleted by poor farming practices, and our fuel sources are being dissipated for heat, power, and transportation.

Although biologists and ecologists recognize how important carbon is to life processes on earth, most have yet to recognize that at times it may be the controlling (18) or most limiting factor for plant growth.

Consider first a soil-grown crop, and look at the major nutrients required to grow 150 bushels of corn grain per acre, (including tops, grain, and roots):

N	385	lbs.	to	the	acre
P	66	"	"	"	"
K	255	"	"	"	"
Ca	70	"	"	"	"
S	42	"	"	"	"
Mg	60	"	"	"	"
Oxygen	5	"	"	"	"
Carbon	8	"	"	"	"
Water	4,000	"	"	"	"

Plus small amounts of micronutrients.

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The earth's atmosphere over one acre, at sea level, weighs about 47,000 tons. This weight is composed largely of nitrogen and oxygen, but contains also carbon dioxide, hydrogen, water vapor and inert gases in small amounts. The major components of interest are:

Nitrogen	37,500	tons over each acre
Oxygen	9,500	" " " "
Carbon dioxide	21	" " " "

The 21 tons of carbon dioxide contain 5.7 tons of carbon, or only three-fourths of the 8 tons used by the crop.

Then consider pure water which contains and can supply much less carbon dioxide than air. For such, many scientists now believe that carbon is the plant nutrient most likely to control rate of growth of aquatic plants. Impurities of sewage, organic industrial wastes, waterfowl excrements or decaying plants and animals furnish energy for growth of bacteria in water which release the carbon dioxide necessary for massive growth of aquatic vegetation.

Almost always overlooked is the fact that algae require 100 to 200 times more carbon than phosphorus. One ton of algal tissue (dry matter basis), which can grow in two months per acre of lake area, will contain 1000 pounds of carbon and only 5 to 10 pounds of phosphorus. The latter can be supplied by almost any body of water from fresh organic inputs (5) plus the vast phosphorus stores which have accumulated over centuries in bottom muds and organic deposits.

But, were does the 1000 pounds of carbon come from? Ordinary water contains only 0.40 to 1.00 ppm of carbon dioxide, or the equivalent of 0.10 to 0.25 ppm of carbon. Pure water in equilibrium with normal air could not possibly grow one ton of dry algae tissue per acre in two months.

This point is so important that it warrants further detail and review. Organic matter, such as sewage, is utilized by bacteria, which evolve the carbon dioxide for growth of algae. Once the process gets going, it is difficult to control, because the algae release oxygen to stimulate bacteria and when both die, their carbon is consumed by more bacteria, which, in turn evolve more carbon dioxide to grow more algae (20). As yet, all of the details of the complex "symbiosis" are not fully understood. Enough is known, however, to realize that removing phosphorus or other nutrients from city effluents (7) will not control growth of algae in natural or man-made bodies of water (unless inputs of carbon also are controlled).

Algae often Useful

Without algae to fix nitrogen and to convert carbon dioxide into oxygen around the world, animal life never could have developed. Nor would we have our vast coal, oil, and peat deposits. Even today algae are, perhaps, the most versatile form of life on earth. According to Steward (13), the more extreme the physical conditions are, the more likely one is to find blue-green algae, provided that light, water, and carbon dioxide are available at some period. He cites two examples: In Antarctica, on rock and soil surfaces, Nostoc species fix nitrogen alone, or in lichen symbiosis, at low temperatures. Nostoc accumulates in such areas to depths of 15 cm. as algal peat. In Yellowstone Park, USA, the color of large thermal areas is due largely to blue-green algae, where nitrogen fixation occurs at temperatures up to 55°C.

Historically, blue-green algae have been beneficial in helping produce rice, the staple food for over half of the world's population, because they fix from 30 to 50 kilograms of nitrogen per hectare per year under paddy conditions.

How Pure Need Water Be?

What degree of purity do we need, and can we afford?

Even remote mountain streams are not pure in the sense of being sterile. Excreta from wildlife and fish, and decaying plant and animal remains keep these streams constantly polluted in warm weather. Wild ducks use certain flyways and frequent numerous lakes and reservoirs. A government report (5) for a lake in Illinois indicates an addition of 12.8 pounds of nitrogen and 5.6 pounds of phosphorus per acre per year to water from the transient duck population.

Runoff from urban streets, sidewalks, rooftops, highways, and playground areas is high in chemical nutrients. Even rainfall itself is not pure when it reaches ground level but contains many types of chemical compounds and substances.

So, we must ask ourselves, "What is pure water and where do we find it?" We don't. What we have in the future will depend upon the use to which it is to be put and the cost each use will justify.

SUMMARY

While it is relatively easy to determine the contribution of a city or of a factory to the pollution load of a stream, it is much more difficult to do so for a farming or forested area. Chiefly, this is because of the large number of variables plus some unknown factors.

Rainfall averages about 0.7 of a part per million of nitrogen. Near livestock feedlots, cities, and certain types of industrial plants, considerably larger amounts of nitrogen in such forms as nitrogen oxides and ammonia occur in the rain. Nitrogen oxides going into the atmosphere in the USA from automobile exhausts, homes, factories and power plants and being returned to land and water surfaces with rainfall is about 17 million tons a year (16). All too often the natural and artificial atmospheric inputs are overlooked and a portion may end up by being assigned to the agricultural sector. Also, changes occur from time to time in lakes and reservoirs causing inversions and stepped-up release of nutrients from the bottom deposits. Where situations have worsened in recent years, due chiefly to cities and industry, agriculture has received too much of the blame (for example - Lake Erie in the U.S.).

When farmland is maintained in a high state of fertility with plants growing as much of the year as possible, very small amounts of nutrients are lost to surface or underground water (12). To date there is no conclusive evidence that proper fertilizer use has increased the nitrate level of streams or wells (18) in the U.S. Over the past decade many towns, cities and factories have added waste treatment facilities and others have improved their degree of waste treatment before dumping effluents into streams. This has greatly reduced the organic food for bacteria, and in turn reduced the biological oxygen demand (BOD) on the stream (15). The result is that both the nitrate and oxygen levels should now be higher than when the stream was overburdened with decomposing organic matter. Obviously, when the BOD is great, bacteria will use oxygen and nitrate as they become available, and neither will be present in a medium (unless a toxic substance or other condition prevents growth of bacteria).

Paired watersheds under study by the U.S. Department of Agriculture (19) throw further light on agriculture's small contribution. One watershed in Ohio is farmed and fertilized, and the other is in forest. The amounts of nitrogen and phosphorus being released annually from both watersheds are almost the same, and very small, but enough to support aquatic plants. Similar results have recently been reported from Canada (2), where the amount of nitrogen in Canal Lake coming from rainfall exceeds that coming from surrounding farm lands.

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Scientists realize that they lack sufficient information to determine agriculture's exact contribution. It will require several years of tedious work in numerous watersheds by skilled soil scientists and hydrologists to obtain this information.

Research programs, although meager, are seeking new techniques for disposing of organic wastes and more effective means of conserving soil and keeping it from blowing and washing away. When land is properly farmed and otherwise handled, little sediment gets into streams and lakes. Unfortunately there is yet a long way to go in most countries until all land is properly maintained and adeuqate protection provided.

Before man and his civilization appeared on the scene, forests and prairies released enough nutrients to streams, lakes, and coastal waters to support eutrophication and to support marine animal life. If this had not been so, there would have been no fish or other marine animal life. The world's peat and muck soils, coal, and oil deposits are monuments to the process of eutrophication (19). In North America, one has only to fly from Minneapolis to Winnipeg on a clear day to observe all stages of this process over vast areas practically untouched by man, and certainly untouched by agriculture.

People in all lands need to understand that although man has not been on the scene very long, he has greatly accelerated the process of eutrophication by organic waste products from his sewage, factories, livestock and pets. He is learning how to treat and handle waste from such sources. In due course, but at high cost, man's contribution likely will be controlled.

People everywhere also need to be aware that both intensive research and extensive action programs are going to be required, and although these will appear to be costly, in reality they will return untold dividends because only fertile soils will support man in the future and because it is twenty-fold cheaper to keep soil in place than it is to dredge it out of reservoirs and lakes.

If water or health problems are likely to occur from use of fertilizer, surely they would have been evident before now in Holland, Denmark, and Japan, where fertilizer usage is older and more intense per unit of area, for example, than in the United States.

The Appendix to this paper is intended to provide answers to some of the more frequent questions about agriculture and the environment. While the answers express the views of the author, they are based largely on the writings of the persons cited below, most of whom have published a number of additional important papers.

APPENDIX

Answers to Commonly Asked Questions

ARE HEALTH PROBLEMS ASSOCIATED WITH NITROGEN FERTILIZERS?

A repeated warning is that of associating blue baby disease (cyanosis or methemoglobinemia) with use of nitrogen fertilizers. Records of the U.S. National Institutes of Health and of various state departments of health, do not reveal a single instance associated with fertilizer use. Nor is there a case on record where a child has become afflicted with the disease from eating processed baby foods.

Ruminant animals reduce nitrate to toxic nitrite and thus are susceptible to excessive intake of the nitrate ion in their diets. Certain crops are high in nitrate and if consumed under certain conditions, (as on a low energy diet), the animals will develop toxic symptoms and may die. In fact, death of cows was once a common occurrence in Wisconsin due to high-nitrate weeds in pastures, and in the Dakotas from grazing small grains prior to the time fertilizer came into use.

Frost or drouth during the growing season to stop protein synthesis may cause high nitrate in plant tissue, and grazing is to be avoided.

Water-related or health problems involving fertilizers are not likely to occur in the United States because none has yet developed in Holland, Denmark, or Japan, where fertilizer use is much greater per acre, covers a much higher proportion of total land area, and goes back over a much longer period of time.

DOES FARMING CONTRIBUTE TO THE LEVEL OF NITRATE IN STREAMS AND LAKES?

Results of the most conclusive agricultural nitrogen study to date have recently been published by the U.S. Department of Agriculture for the Upper Rio Grande River Valley. During the past 30 years, when use of fertilizer increased 35- to 100-fold in the Rincon, Mesilla, and El Paso Valleys, no increase occurred in the nitrate content of the river waters.

Analyses of Midwest streams tend to confirm that their nitrate level has not increased in recent years even though use of nitrogen fertilizers and livestock feeding have more than doubled. Where exceptions may be cited, there appear to be other circumstances such as unusually heavy spring runoff from fields standing over winter in corn and soybean stubble. Soluble nutrients from these decaying plants no doubt contribute nutrients to the runoff water. But, where crops are well fertilized and managed, soil loss is minimal, as is the loss of nitrogen.

DO NITROGEN FERTILIZERS GET INTO WELLS?

Nitrate fertilizers sometimes are listed as contaminants of farm wells. Extensive studies of 6000 wells in Missouri, and studies in certain other states, have uncovered no conclusive evidence associating fertilizer use with high nitrate in wells. The major findings thus far are that wells with high nitrate are usually shallow, poorly constructed, near to a feedlot, farmyard, or septic tank, often contaminated with organic matter and bacteria, or located in areas of sandy soil.

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DOES NITROGEN CAUSE EXCESSIVE GROWTH OF ALGAE?

Although nitrogen is an essential constitutent of every living cell, it happens that there is enough of it available in rainfall to support algae growth, besides the fact that 40-some species of algae can fix their own nitrogen. Thus, no further input is necessary, as from fertilizer, unless one's objective is to grow enough phytoplankton for fish production. Here a program of fertilization is usually essential to get enough plankton to shade out rooted water weeds.

DOES USE OF NITROGEN FERTILIZER UPSET THE NITROGEN CYCLE?

Less than 10 per cent of the seven million tons of nitrogen applied to United States soils is in the nitrate form. Even if all of it were applied in the nitrate form, however, the end result would be no different than if all of it came from organic matter. It happens that plants do not know whether their nitrate, or other nutrients, arise from an organic or an inorganic source. Fortunately, fertile agricultural soils readily convert organic nitrogen into nitrate, whether the source, for example, is urea fertilizer or barnyard manure.

Soils in midwestern U.S., for example, release an average of about 80 pounds of available nitrogen* per acre from organic matter every growing season, while total loss from all U.S. farm soils amounts to more than 20 million tons of nitrogen a year. About 10 million tons of nitrogen enter our environment from nitrogen-vising bacteria and algae, five million tons from the atmosphere, 10 million tons from livestock wastes, and eight million tons (in sewage) from the food we eat. When added to the nitrogen coming from food and fiber processing industries, the total amount of it moving about in our environment is vast, indeed. In comparison, the seven million tons of fertilizer nitrogen used to nourish growing plants last year in the U.S. is but a very small part.

HAS IMPROPER FERTILIZER USE DAMAGED SOILS?

Long-term experiments in Illinois, Missouri, Pennsylvania and England prove to the contrary.

Plots of soil, depleted of organic matter and tilth because of no fertilizer, or improper fertilization, during a century of experimentation responded immediately to good fertilizer and lime treatment once applied according to crop need. In fact, yields were restored almost to normal the very first year of adequate fertilization.

Neighbouring plots, receiving good fertility treatments during this time, showed no decline in yielding ability, regardless of whether the fertilizer nutrients came from manure or inorganic fertilizers. Also, there was never any discernable difference in quality of wheat or corn produced regardless of the source of nutrients, i.e., organic or inorganic, so long as the amounts were the same.

WHAT IS EUTROPHICATION?

Chemical nutrients at or near the earth's surface are subject to movement by water and air. In nature there is a continual downhill movement of these nutrients into streams, lakes, and oceans.

When man entered the geological picture, this movement (or water-enrichment process) became more active because of working the soil to grow food. This caused more soil particles and organic matter to move into water bodies. These substances, for ages of time, have been accumulating under water along the shorelines of the world.

Thus, eutrophication may be looked upon as nature's age-old geological process of supplying waters with chemical nutrients. Without this process, there would be no coal, oil, or muck deposits on our planet. Nor would there be marine life.

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WOULD EUTROPHICATION BE SPEEDED UP IF USE OF FERTILIZERS WAS CURTAILED?

Yes, because agricultural land soon would be unable to support protective vegetation and would be subject to nature's wind and rain storms. Besides millions of additional acres would have to be cultivated.

WHY ARE ALGAE SOMETIMES CALLED THE KEY TO LIFE?

Because certain algae can utilize atmospheric nitrogen, they are regarded as the early "base of life" for the storing of vast amounts of carbonaceous matter or energy on earth.

Algae also are important because of the link they provide in the food chain for animal life in aquatic environments.

Surely, if it were not for algae and other green plants, man would perish because the process of photosynthesis maintains carbon dioxide as a level he can tolerate in the air he breathes.

ARE LAKES PERMANENT OR DO THEY DISAPPEAR?

No lake or body of water is permanent. Each has four stages of life: birth, existance, old age, and disappearance. Examples of all stages can be found in the United States, Canada, Alaska, Siberia, Brazil, and Africa, in surroundings practically untouched by man and certainly never touched by agriculture.

Although the aging process has been accelerated by virtue of man's activities, one must not overlook the contribution of sewage and other organic waste products. More than 1000 communities in U.S.A. still discharge all of their wastes into water without treatment of any kind. An equal number of cities employ primary treatment which removes from 30 to 40 per cent of pollutants.

Many authorities agree that organic matter in sewage and livestock manures, when added to soil sediments, constitute our greatest water pollutants. Until and unless these are controlled, tax dollars spent for water quality improvement cannot result in the quality of water desired.

HOW DOES ORGANIC MATTER CONTRIBUTE TO ALGAE GROWTH?

In Lake Erie, for example, organic matter from sewage, waterfowl, fish and rooted water plants provides food for bacteria to multiply. They give off carbon dioxide, which, along with water and sunlight, are among the essential ingredients for growth of plants. When carbon dioxide is plentiful, massive growth of algae occurs when light, temperature and nutrients are adequate. The process is difficult to control because the bodies of dead algae and other plants furnish food for more bacteria to evolve more carbon dioxide to grow more algae. This is why removal of phosphorus (phosphate), as from detergents, cannot be expected to control excessive growth of unwanted plants. Control measures must be aimed at eliminating energy by destroying organic matter, but even this will not provide the desired control in most situations, as near to an airport or city where carbon dioxide is plentiful.

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IS PHOSPHATE (PHOSPHORUS) THE CAUSE OF EXCESSIVE ALGAE GROWTH?

Phosphorus, an essential constituent of every living cell, is utilized by plants and animals mainly in its phosphate (oxidized) form.

In believing that phosphorus is the key to growth of algae, and the cause of the death of lakes, people overlook the fact that algae require 100 to 200 times more carbon than phosphorus, depending on the particular algae species. One ton of algal tissue, dry weight basis, which can develop in six weeks of good growing conditions, in an acre of lake area, will contain approximately 1000 pounds of carbon but only five or six pounds of phosphorus. The latter can be supplied by the water because of the recycling of organic phosphorus from decaying rooted plants, animal remains, waterfowl excrement, and often from sewage and industrial wastes. Even without these sources, the vast stores of phosphorus from decaying rooted plants, animal remains, waterfowl excrement, and often from sewage and industrial wastes. Even without these sources, the vast stores of phosphorus laid down in the bottom muds and organic deposits over ages of time are sufficient to satisfy demands for it.

WHAT IS BALANCE IN NATURE?

When speaking of "balance of nature", a frame of reference and a time in history are needed. Dinosaurs did not survive. Certainly, the early American Indians, who lived as close to nature as humans have at any time in history, had but a very short natural life span. Was nature in balance during those times?

Until man found out how to grow plentiful and nutritious food and to combat diseases and insects with modern-day chemicals, his own life span was very short.

Dr. Cecil H. Wadleigh, former science advisor for Natural Resources, U.S. Department of Agriculture, has said: "Make no mistake! Nature alone could not sustain the World's population for one day -- not in food, not in clothing. Truth is that nature never maintained a balance in favor of man, or other animals, and never will."

In the days of the buffalo, vast regions of our river and streams were muddy wallows and polluted beyond description. Range lands often were devoid of vegetation because of overgrazing. Today, most of these same lands and waters are in much better condition.

IS WATER PURE?

Mr. D.A. Williams, former administrator, United States Soil Conservation Service, and one of America's most ardent conservationists, made this statement in 1969.

> "Water vapor is pure, but when it condenses and falls into the earth's atmosphere, it becomes a solvent for many substances. Pure water is seldom found anywhere in nature. Falling rain dissolves gases, including oxygen, nitrogen, and carbon dioxide, and carries them into the soil.
>
> "Water dissolves chemical nutrients in the soil and carries them into plants. This is not pure water, but a solution containing hundreds of different chemical compounds and substances.
>
> "Today, man has the knowledge to enrich this soil solution through proper use of commercial fertilizers so as to produce his food and fiber in higher quality and in greater quantity than at any time in the world's history. Today, man also has the knowledge of soil conservation techniques to maintain agricultural lands in a high state of productivity with practically no loss of sediment and its nutrients to streams and lakes. Unfortunately, we have some way yet to go before all of our land is protected. But, we do know that vigorous plant growth and good ground cover, often made possible with adequate fertilization, provide a most effective deterrent to soil erosion and its pollution of lakes and streams."

WHAT FERTILIZER FACTS SHOULD EVERYBODY KNOW?

Chemical fertilizers are purified or upgraded products of nature, being recycled back through nature by man for crop and livestock production.

There is no discernible difference in nutritional quality of crops grown with fertilizers, manure, or human wastes. Once in the soil, organisms free organic nutrients by releasing them into inorganic forms for plants to use.

Without commercial fertilizers, upgrading of diets for the growing populations in the developing nations would in no way be possible, and the standard of living in the more advanced would decline at a rapid rate.

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EFFECT OF SOIL ENRICHMENT WITH MINERAL ELEMENTS AND FERTILIZERS ON SURFACE WATER AND PLANTS

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1. Introduction

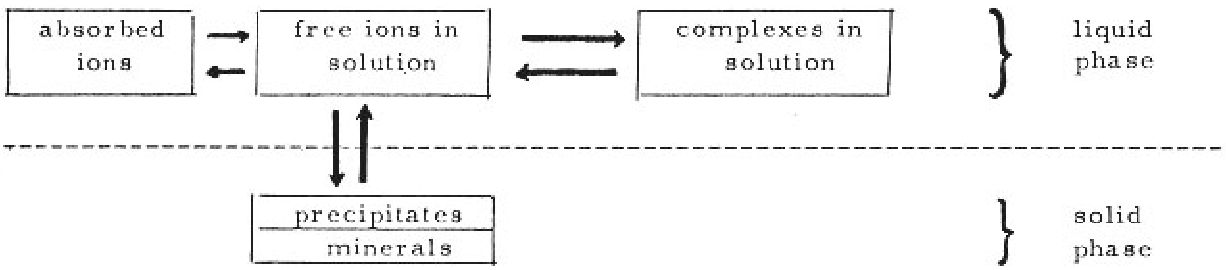
Intensive fertilizer use has resulted in Belgium to a considerable increase of the chemical fertility level of agricultural soils. Therefore, a direct quantitative crop response to fertilizer application or omission is rarely observed, except for nitrogen.

The question whether this enrichment of the soil with fertilizer salts contributes to environmental pollution needs systematic observation and research. If intensive fertilizer use should affect the environment, its first symptoms will concern soil and surface water, as well as the growing plants.

On the other hand chemical soil pollution has occasionally been observed as a consequence of an increased content of elements such as Zn, Pb, Ni, Cr etc., which are normally present as traces, and which cause toxicity to plants at higher levels. The following pages summarize some observations with respect to this problem.

2. Soil and soil water relationship

Every chemical which is introduced in the soil is distributed over different more or less distinct fractions. Phenomena of dissolution and precipitation, adsorption and exchange, as well as complexation, lead to an equilibrium status which may be represented by the following scheme:



The possibly polluting action of an element is function of its mobile fraction or the quantity of it, which is capable of being transferred from the solid to the mobile pool. If we consider the normal Fe-content of a soil, being of the order of 5% (50 000 ppm), only some 5 to 10 ppm of this total quantity is normally present in the solution phase. A small part of the iron in the solid phase is able to be transferred, due to the chelating action of organic matter, to reduction of Fe(III) to Fe(II) and to pH decrease. In order to estimate the influence of fertilizer application on the composition of soil water and water drained away from the fields into brooks and canals, field observations and systematic experimentation is being carried out as described below.

2.1. Soil and Water Analysis

- A series of samples were taken from soils before and after dressing and analysed for the fraction of fertilizer elements which are complexed, adsorbed and which remain in solution. Therefore the soluble cations were determined in water extracts (soil/water: 1/5). These soluble ions consist of free ions and soluble complexes. To determine the soluble complexes, a cation-exchange resin Dowex 50 W (Na-form) was used. The resin is able to fix the free ions, while their soluble complexes remain in solution. For the determination of adsorbed Ca^{++}, Mg^{++}, K^{+}, Zn^{++} and Mn^{++}, the samples were percolated with 1 N NH_4OAc of pH 7 (Schollenberger & Simon, 1945), while adsorbed Cu^{++} and Fe^{++} were determined after percolation with 1 N NH_4OAc of pH 3 (Jackson, 1958).
- Another series of samples were taken before and after a period of heavy rainfall from brooks, where the water from the surrounding fields is gathered.
- In a laboratory experiment different soils received two doses of N-P-K fertilizers. After equilibration the soils were percolated with water, and the leached fertilizer elements analyzed.

2.2. Results and discussion

2.2.1. Incorporation of the fertilizer into the soil

The origin of the soil samples and the applied fertilizers are given in table 1.

Table 1: Origin of the samples and kind of applied fertilizers.

Origin of sample	Nr.	Kind of applied fertilizers	Texture class
Watervliet	198	undressed	heavy sandy-loam
	190	N P K (15-15-15)	
Astene	172	undressed	loamy sand
	173	N P K (13-13-20)	
Meilegem	168	phosphate slags, K, Magnesia lime,	sandy loam
	169	phosphate slags, K, Magnesia lime + CaNCN	
Bottelare	176	undressed	loamy sand to sandy loam
	177	N P K (13-9-20-5)	
St. Laureins	187	undressed	loamy sand
	188	KCl	
Ophasselt	183	undressed	sandy loam
	182	N P K Mg	
Wetteren	191	undressed	light sandy-loam
	192	N P K MgCa (6-8-14-14-22)	
Dikkelvenne	170	Farm yard manure + phosphate slags	sandy loam
	171	Farm yard manure + K	

In complement to the already mentioned analysis, the conductivity of the extracts, the total N-content and the pH of the soils were also determined. The results are given in table 2.

Table 2 : Results of the chemical analysis of the dressed and undressed soils.

Nr. sample	pH H_2O	Conductivity micro mho per cm	Ca in ppm			Mg in ppm			K in ppm			N in mg/100g soil
			S	SC	A	S	SC	A	S	SC	A	
189	5.85	120	57.5	0	977	5.8	1.35	48.5	38.5	0	97.7	170.2
190	5.32	168	100.0	0	651	3.6	0.05	30.0	42.2	0	78.2	145.6
172	5.70	195	120.0	0	1037	10.9	0.05	50.0	25.2	0	78.2	150.4
173	5.40	770	562.5	0	863	30.8	1.35	27.0	263.7	7.25	117.3	156.3
168	6.12	301	150.2	0	1037	22.8	0.25	113.5	109.5	1.0	200.4	122.3
169	6.72	439	270.0	0	1528	24.2	1.35	108.0	182.5	2.0	205.3	151.8
176	6.30	230	130.0	0	1292	10.6	0.13	87.5	53.5	1.0	141.7	121.1
177	6.40	305	185.0	0	952	13.9	0.18	58.0	81.5	1.0	136.8	126.4
187	6.48	117	70.0	0	701	9.5	0.12	58.0	26.5	0	39.1	123.7
188	6.31	292	130.0	0	1177	20.3	0.25	103.5	90.0	0.5	97.7	152.1
183	6.25	76	52.5	0	1037	4.0	0.22	55.0	21.7	7.25	88.0	114.8
182	6.90	341	207.5	0	1583	19.0	1.59	117.0	42.2	0.50	152.5	148.2
191	6.95	148	72.5	0	1352	8.9	0.07	134.0	73.0	1.0	235.6	113.1
192	6.25	520	320.0	0	1157	60.6	0.38	156.5	195.0	4.5	234.6	128.3
170	6.95	230	170.0	0	1217	13.5	0.63	107.0	38.5	0	141.7	121.6
171	7.00	252	192.5	0	1648	11.0	0.03	79.0	35.2	0	141.7	116.4

S : total amount as soluble ions,
SC : soluble complexes. The soluble free ions can be found as the difference between S and SC
A : adsorbed fraction

These results show that:

1.- the electrical conductivity is higher in water extracts of soils which received a fertilizer-treatment, than in the undressed soils.

2.- soluble Ca increased notably in all dressed soils. This is due to the fact that this element is present in most fertilizers.

3.- the K-content in the soils, treated with a K-fertilizer, is much higher than in the undressed soils. Relative high amounts of this element are present as free ion in solution.

4.- Mg, present in the fertilizers, is recovered as well in the free solution as in the adsorbed fraction.

5.- except in one soil (no. 190), the quantities of N found after N-fertilization were higher than in the undressed soils.

The increase of the mobile contents of all elements under study in soil water indicates the possibility of their enrichment in drainage and effluent water.

2.2.2. Drain water

Drain water from an horticultural soil receiving intensive fertilization, showed the following composition in comparison with the normally used irrigation water:

	irrigation water	drain water
conductivity (μmho)	263	1340
Total salt (mg/l)	140	725
SO_4^{--} (mg/l)	45	385
Cl (mg/l)	22	65
NO_3^- (mg/l)	0.6	200
NH_4^+ (mg/l)	0.5	1
Na (mg/l)	7.4	26.8
K (mg/l)	4.5	26.8
Mg (mg/l)	3.3	38.4
Ca (mg/l)	41	197
PO_4, Mn, Fe	traces	traces

Table 3 shows the analytical results of water samples, taken at three different places in a brook where drainwater from the surrounding fields is gathered.

Table 3 : Chemical analysis of brook water samples before and after heavy rainfall ("Lieve" canal)

Nr Sample	Before rainfall			After rainfall		
	1	2	4	1	2	4
pH	7.40	7.75	7.80	7.85	8.13	7.52
Fe-content in mg/l	1.28	0.16	1.28	1.28	8.13	7.52
Mn-content in mg/l	0.51	0.50	0.60	0.90	0.30	1.04
PO_4^{--} in mg/l	1.60	5.40	18.30	1.30	4.10	4.20
NO_2^- in mg/l	0.10	0.32	0.06	14.20	0.92	0.32
NO_3^- in mg/l	3.80	4.20	4.40	1.80	1.80	trace
NH_4^+ in mg/l	5.30	2.70	15.60	4.10	8.00	33.00
Na^+ in mg/l	25.00	142.7	35.00	13.50	78.30	198.00
K^+ in mg/l	9.30	17.70	59.80	18.60	15.70	39.00
Mg^{++} in mg/l	14.00	15.80	17.40	11.40	12.58	9.36
Ca^{++} in mg/l	33.50	121.50	35.00	130.00	120.50	102.50
Conductivity in microMho per cm	800	1180	2780	880	1120	1820
Salt content as mg NaCl/l	435	640	1650	480	604	1000

Considering the results given in table 3, it appears that :

1. - The Na^+, K^+, Mg^{++} and Ca^{++} content of the water samples taken after rainfall is generally smaller than before rainfall, due to dilution.
2. - The NO_2^- and NH_4^+ contents increased after rainfall, while the NO_3^- content was decreasing.

2.2.3. Laboratory experiment

Nine different soils were treated with the following doses of N, p and K-fertilizers.

Fertilizers	% N, P_2O_5, K_2O	Dosis 1 in units/ha	Dosis 2
NH_4NO_3	26 % N	100	200
superphosphate	18 % P_2O_5	100	200
K_2SO_4	50 % K_2O	150	300

The pH, carbon content and C.E.C. of the soil samples are given in table 4.

Table 4 : Characterisation of soil samples

Soil Nr	Origin	pH H_2O	pH KCl	% C Walkley & Black	C.E.C. in meq/100g of soil	Texture
71GV156	Herentals	4.85	3.95	2.35	7.50	sand
70GV142	Waarschoot	5.60	4.60	2.52	11.87	loamy sand
70GV144	Peruwelz	6.25	5.50	1.30	8.30	light sandy loam
71GV157	Glabbeek	6.45	5.25	1.38	10.25	light sandy loam
70GV141	Merendree	6.30	5.05	2.23	11.55	sandy loam
70GV160	Proven	7.75	6.90	0.65	14.75	sandy loam
70GV145	Wannegem-Lede	5.65	4.75	1.54	9.37	heavy sandy loam
71GV159	Kieldrecht	7.85	7.20	2.23	19.50	heavy sandy loam
70GV143	Ath	6.50	5.75	1.42	11.25	light loam

Of each soil 100 g were mixed with the N, P and K fertilizers as mentioned (+ blanc). The treated samples were brought into percolation-tubes, the soil-column having a length of 20 to 30 cm. After percolation with 100 ml of deionized water, N P and K were determined in the effluent (see table 5).

Table 5: K, P and N contents of percolation water.

Nr soil sample	K in ppm			P in ppm			N in ppm		
	Blanc	Dosis 1	Dosis 2	Blanc	Dosis 1	Dosis 2	Blanc	Dosis 1	Dosis 2
156	13.2	33.0	65.0	1.5	2.2	1.3	18.2	36.4	63.0
142	5.7	7.7	10.4	4.8	4.1	3.3	21.0	21.0	39.2
144	12.0	12.5	18.7	2.6	5.2	4.8	25.9	18.2	26.6
157	60.0	72.0	131.0	11.5	10.2	13.3	20.3	18.2	19.6
141	3.2	3.6	4.7	2.0	3.9	2.2	15.8	21.0	36.4
160	8.3	10.5	11.4	1.7	1.5	2.8	16.1	18.2	23.8
145	25.5	30.2	49.0	3.5	3.5	3.3	17.5	15.4	30.1
159	31.0	42.2	41.5	0.9	1.5	–	16.8	36.4	39.2
143	19.2	36.5	36.5	3.7	3.7	2.4	16.8	36.4	36.4

With these figures the percentages of the applied K and N, respectively retained by the soil and leached, were calculated (see table 6).

Table 6: Percentages of applied K and N, leached and retained by the soil.

Soil nr.	Dosis 1		Dosis 2		Dosis 1		Dosis 2	
	% leached	% retained by the soil	% leached	% retained by the soil	% leached	% retained by the soil	% leached	% retained by the soil
156	39.50	60.50	51.75	48.25	54.6	45.4	57.2	32.8
142	4.10	95.90	4.75	95.25	0	100	27.3	72.7
144	1.15	98.85	7.30	92.70	0	100	1.0	99.0
157	24.00	76.00	71.00	29.00	0	100	0	100
141	2.80	97.20	2.50	97.50	12.6	87.4	29.4	70.5
160	4.30	95.70	3.10	96.90	6.3	93.7	11.5	88.5
145	9.50	90.50	23.50	76.50	0	100	18.9	81.1
159	22.50	77.50	11.50	88.50	58.8	41.2	33.6	66.4
143	34.55	65.45	17.30	82.70	58.8	41.2	29.4	70.6

These figures show that the quantities of elements being leached are very different in function of soil properties, such as texture, humus content and pH. It has been shown by Kolenbrander (1970) that distribution factors, calculated from column experiments are not valid in field conditions, however, the observed differences may be usefull in comparing different soils and acting parameters.

3. Plant reaction to chemical soil enrichment

Through intensive fertilizer use the upper part of the well known Mitscherlich curve is often reached and yield decrease may even occur due to non equilibrated nutrient supply or toxic accumulation of some elements.

Direct toxicity phenomena are however most observed with regard to trace elements or non essential elements, introduced by external pollution, or eventually as plant nutrients. The reaction of plants to such situations is largely depending upon the element and the pH of the soil. Different observations showing injury to plants and accumulations of elements, such as Pb, Cr and Zn in their tissues are not caused by intensive fertilizer use, but occurred in industrial zones and were sometimes also observed in urban gardens. The case of Pb enrichment in pasture crops along highways was also confirmed; but showed to be restricted to small distances, seldom reaching 20 meters.

Soils, exposed to temporary inundation with polluted water, often show harmfull effects, as described in the following two examples.

a.- A soil, flooded with brook water containing 120 to 560 ppm Cr and 9 to 23 ppm Ni as a consequence of industrial pollution, showed a 0.5 N HNO_3 extractable content of 78 ppm Cr and 23 ppm Ni, while the grass was enriched to 15.3 ppm Cr and 29.6 ppm Ni.

b.- On a meadow having a pH-H_2O of 5,9 flooded with water of the river Schelde, three cows died within a few days, while the analysis of soil and plants were as follows: (in ppm):

		Fe	Mn	Zn	Cu	Pb	B	Ni	Cr	Mo	Co
Soil extracted with 0.5 n HNO_3	flooded	2500	92	569	29	-	-	8.2	15	2.5	2.5
	normal	590	42	10	7	20.5	-	traces			
grass	flooded	>2000	939	689	71	52	62	>125	>100	6.7	15
	normal	200	80	40	7	4	16	traces			

3.1. Pot experiments

Since trace element toxicities were often presumed in recent times, a series of systematic experiments was set up in order to observe the plant reactions towards highly increased soil contents of trace elements at two pH levels. Therefore one part of an acid sandy soil was treated with lime in order to increase the pH with ± one unit.

After equilibration with increasing levels of B (as $Na_2B_4O_7.10H_2O$), Mn (as $MnSO_4.4H_2O$), Zn (as $ZnSO_4 7H_2O$) and Cu (as $CuSO_4.5H_2O$), successive cuttings of Italian ryegrass were grown in pots containing 1 kg of soil. The results of these experiments are given in tables 7 to 10. In all cases, the leaf contents of ryegrass with the element under consideration increased very much in function of the treatments, especially where no lime was applied.

While liming also influenced favorably the dry matter production, a consequent yield decrease was only observed in function of the high trace element treatments with Cu and Zn. If we judge the toxicity of an element in function of this yield decrease, the toxic tissue concentration levels might be estimated for Cu at the range of ± 20 ppm and for Zn at ± 1000pmm (dry matter), while the toxic level seems not to be reached in the experiments with B and Mn. These figures however do not correspond with any estimation concerning the eventual toxic effects of the produced crops towards animals.

Table 7: Boron experiment: treatment and results of plant analysis.

Soil	B treatment (in ppm)	dry matter produced (in g)		B content in plant dry matter (ppm)	
		1st cut	2nd cut	1st cut	2nd cut
acid (pH-H_2O 4.6)	0	2.74	3.28	18.2	22.1
	0.5	2.69	3.63	85.0	46.9
	1.0	2.69	3.42	110.0	48.1
	1.5	2.82	3.32	155.0	66.9
	2.0	2.46	3.41	193.3	72.5
limed (pH-H_2O 6.2)	0	3.99	1.29	19.0	31.0
	0.5	3.67	1.31	31.4	47.0
	1.0	3.92	1.29	59.4	64.5
	1.5	4.60	1.17	76.9	93.5
	2.0	3.93	1.23	107.5	109.5

Table 8: Mn experiment : treatments and results of plant analysis.

Soil	Mn treatment (in ppm)	dry matter produced (in g)		Mn content in plant dry matter (ppm)	
		1st cut	2nd cut	1st cut	2nd cut
acid (pH-H_2O 4.22)	0	2.5	1.8	47.7	75.6
	250	2.4	1.9	72.1	136.2
	500	2.2	1.7	112.5	103.4
	750	2.2	1.4	134.2	165.6
	1000	2.2	1.5	149.4	167.7
limed (pH-H_2O 5.28)	0	2.9	2.4	15.3	23.2
	250	2.7	2.0	26.0	33.1
	500	2.6	1.7	41.2	84.4
	750	2.8	2.2	52.5	98.0
	1000	3.1	2.0	65.2	125.5

Table 9 : Zinc experiment : treatments and results of plant analysis.

Soil	Zn treatment (in ppm)	dry matter produced (in g)		Zn content in plant dry matter (in ppm)	
		1st cut	2nd cut	1st cut	2nd cut
acid (pH-H_2O 4.42)	0	1.27	2.47	181	186
	200	0.78	1.00	2100	2890
	400	0.17	-	-	-
	600	-	-	-	-
	800	-	-	-	-
limed (pH-H_2O 5.22)	0	1.38	1.78	117	108
	200	1.22	1.57	585	700
	400	1.08	1.63	1040	1150
	600	1.20	1.45	1500	2230
	800	1.04	1.05	2080	3440

Table 10 : Copper experiment : treatments and results of plant analysis.

Soil	Cu treatment (in ppm)	dry matter produced (in g)		Cu content in plant dry matter (in ppm)	
		1st cut	2nd cut	1st cut	2nd cut
acid (pH-H_2O 4.09)	0	1.10	0.31	17.1	
	25	0.92	0.44	18.3	
	50	0.69	0.14	26.2	
	75	0.31	0.05	53.4	
limed (pH-H_2O 5.25)	0	1.55	1.31	9.2	12.6
	25	1.47	0.97	11.9	13.9
	50	1.30	1.78	16.9	17.6
	75	1.40	1.70	21.7	21.5

Former systematic experimentation has shown (Cottenie A. et al, 1970) that the essential trace elements may be classified as follows:

1. B and Mo , the concentration of which in the plant tissue reflects quite truly their presence in the soil.
2. Mn and Zn , which may also be found in very variable concentrations in the plants, but for these elements, soil pH seems to be the most important acting factor.
3. Fe and Cu, are less variable elements in plant tissues.

This means that toxicity to plants caused by one of these elements will correspond with a different uptake pattern. For example B or Zn toxicity corresponds with highly increased concentrations of these elements in the plants, while Fe or Cu toxicity may cause an important yield decrease without the same enrichment of the plant tissues with these elements.

3.2. Neubauer experiments

Similar experiments were carried out using the Neubauer seedling method (Nair, K.P.P. & Cottenie, A., 1967). Therefore 100 barley seedlings were grown during 15 days in 100 g of soil mixed with 50 g of pure sand.

3.2.1. Visual symptoms

Observation of visual symptoms on the growing plants and arrest of proper vegetation growth reflecting in a lower dry matter production, were the criteria with which toxicity effects of the treatments were estimated. The experiment with iron showed observable reduction in vegetative growth and toxicity symptoms at 200 ppm with a gradual intensification till 500 ppm.

With zinc, the reduction in growth gradually intensified from 100 to 600 ppm. In the experiment with manganese, where the treatments ranged from 0 to 600 ppm, there appeared a slight evidence of manganese toxicity on vegetative growth by way of growth reduction in the beginning of the experiment. Toxicity symptoms in the form of leaf tip browning and yellowing, were observed at the 500 ppm level.

A first experiment with boron, where the treatments ranged from 0 to 200 ppm, showed acute toxicity symptoms. Browning of leaf tips appeared at the 20 ppm level. Yellowing of leaves leading to a papery white appearance, coupled with stunting of vegetative growth, started at the 40 ppm level with a severe intensification till the highest level (200 ppm). In a second experiment with boron, where the treatments ranged from 0 to 20 ppm, there was no observable reduction in vegetative growth corresponding with the treatments.

Sparse leaf tip browning was observed at 2,5 ppm level and later at 1,25 ppm also. However, maximum leaf tip browning was observed at 20 ppm level.

3.2.2. Uptake of trace elements

Uptake of trace elements in µg per g of dry matter was obtained as a multiplication product of content in ppm in dry matter and yield of dry matter in g. Iron uptake showed relatively small variations, while the toxicity symptoms and reduction in vegetative growth started from the 200 ppm level (table 11).

Table 11 : Iron treatment effects on Fe-uptake.

Doses	Fe-uptake (in microgram)
control	85.90
100 ppm	95.58
200 ppm	83.66
300 ppm	83.58
400 ppm	87.28
500 ppm	78.16

The effect of zinc additions has clearly reflected in uptake. At the 400 ppm level there was a marked reduction in uptake coupled with a correspondingly marked reduction in vegetative growth (table 12).

Table 12 : Zinc treatment effects on trace element uptake.

Doses	Mean uptake by dry matter averaged over 3 replications (in microgram)				
	Zn	Al	Cu	Mn	Fe
Control	46.95	15.72	16.53	164.51	86.66
100 ppm	124.51	20.33	17.41	215.48	90.93
200 ppm	492.21	14.21	25.37	354.81	147.82
300 ppm	1000.43	11.05	27.40	422.37	133.08
400 ppm	908.58	16.98	24.28	240.96	133.37
500 ppm	826.75	4.67	14.64	153.16	101.27
600 ppm	499.56	3.03	11.80	147.10	70.40

In the experiment with manganese there were no observable growth differences, but the treatments strongly influenced the Mn uptake (table 13).

Table 13 : Manganese treatment effects on mean uptake of Mn and Fe

Doses	Mn uptake (in microgram)	Fe uptake (in microgram)
0	222	103
50	507	-
100	910	88
200	2186	99
300	2506	82
400	3516	91
500	2946	73
600	2787	70

In the first experiment with boron, discernible differences in uptake corresponding with the reduction in vegetative growth could be observed. In the second experiment, despite the absence of perceptible growth differences, a significant difference in uptake was observed (table 14).

Table 14 : Boron treatment effects on B uptake.

1st Experiment		2nd Experiment	
Treatment (ppm B)	B uptake (in microgram)	Treatment (ppm B)	B uptake (in microgram)
control	31	control	11
20	449	1.25	70
40	627	2.5	69
80	474	5	223
120	280	10	319
160	282	20	551
200	209		

3.2.3. Discussion

The experiments on trace elements using the Neubauer method have shown net response of barley seedlings to treatments with iron, zinc, manganese and boron. The quantities of elements added were relatively high in order to observe at which level toxicity phenomena would appear.

The experiments have demonstrated that while uptake is generally the most relevant factor to be considered, toxicity as manifested by growth reduction may in some cases be found without a corresponding abnormal increase in plant content. In the case of iron, the relatively high level of treatments failed to show perceptible differences in uptake. In the case of manganese, despite the absence of a perceptible growth reduction, highly significant differences in uptake could be obtained. With respect to zinc and boron, growth reduction brought about corresponding significant differences in uptake. Significant increases in plant tissue contents and uptake of these two elements were also observed with application rates far below the toxicity level. The results also show clearly in interaction effect between Fe and Mn, as well as between Zn and Al.

Generally, the lowest treatments already showed sufficiently discernible differences in uptake in comparison with the controls. Therefore, it seems that the response of cereal seedlings, in this case barley, is sufficiently sensitive to reveal the existence of different soil status with respect to manganese, zinc and boron to which this study refers. The uptake of iron on the other hand showed no significant relation with the corresponding treatments.

3.3 Pot experiments with contaminated soils

3.3.1. Soil contaminated with Zn, Cu and Pb.

A soil originating from an industrial area and showing high contents of Zn, Cu and Pb was used in a pot experiment with Perennial Ryegrass (R.v.P.)

- At a soil pH-H_2O of 6.45 the contents of these elements in the harvested plants were: 770 ppm Zn, 25.9 ppm Cu and 18.2 ppm Pb.

- Liming to $pH-H_2O$ 7.15 increased the yields but the tissue contents remained still at a very high level.
- Addition of the chelating agent E.D.T.A. to the soil caused invariably a considerable increase of the same trace element contents.
- The normal trace element situation of herbage plants is in the range of 100 ppm Zn, 10 ppm Cu and 5 ppm Pb.

3.3.2. Soil contaminated with Zn

Another series of experiments was undertaken with Zn-contaminated in comparison to normal soils. An extraction with 0.5 N HNO_3 (soil-solution ratio of 1/5) showed the following Zn contents:

Soil A (highly contaminated)	:	1330	ppm Zn
Soil B (contaminated)	:	270	ppm Zn
Soil C (reference soil)	:	27	ppm Zn

Table 15 shows the results of leaf analysis of plants grown on these soils.

Table 15: Trace element contents of plants grown in soils with different Zn contamination (in ppm).

	Barley leaves from Neubauer pot experiment				Oat leaves from normal pot experiment			
	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu
Soil A	1551	62	83	12	1923	66	36	3.7
Soil B	203	63	99	15	425	61	97	3.7
Soil C	74	64	375	12	65	64	189	3.7

Treating the contaminated soils with D.T.P.A. and with peat did not consequently alter this situation, but liming with relatively high rates of $Ca(OH)_2$ caused a substantial reduction of Zn-uptake and yield increase. However the Zn content in plants grown on the contaminated soil remained still very high.

4. General remarks

Our observations indicate that intensive use of solid fertilizer may result in a certain accumulation of nutrient elements in the soil and an enrichment of soil water with these elements. Further comparative studies with liquid and solid fertilizers are actually carried out. As far as our experience reaches, this type of contamination however is less important than soil and plant pollution with external sources of trace elements, which can lead to toxic accumulations in plants and actual yield depressions. An accurate idehtification of such situation is possible using simple pot experiment techniques. It is our experience that the most effective way for immobilizing an excess of unwanted trace elements in light textured soils, is a consistant increase of soil pH by liming.

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TWO STATEMENTS ON THE PANEL DISCUSSION

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Statement on Fertilizer Nutrient Recovery

Meaning of the term: $$\text{Recovery} = \frac{\text{Nutrient in the Yield}}{\text{Nutrient in the applied amount of fertilizer}} \times 100$$

The recovery value will be often misunderstood and the difference to 100% is explained as real loss.
The main factors influencing the recovery - value are:

1) According to the law of biochemical equilibrium no plant is able to utilize a soluble nutrient up to 100%.
The maximum value depends on the kind of nutrient and the kind of plant.
For nitrogen this maximum (theoretical) value for the most efficient plants (grasses) is about 90%.

2) Lower values as the theoretical one are caused by:
   - (a) the amount of applied fertilizers in the non-harvested parts of the plant (roots and other residues);
   - (b) the reached production level on the yield curve. Decreasing values, if the declining part of the curve is considerable (upper part);
   - (c) the saturation rate of the sorption or fixing capacity of the inorganic and organic constituents of the soil (clay minerals and humus);
   - (d) real loss by leaching or volatilization, and on slopes additionally by run-off and erosion.

Losses from the use of commercial fertilizers are negligible, if

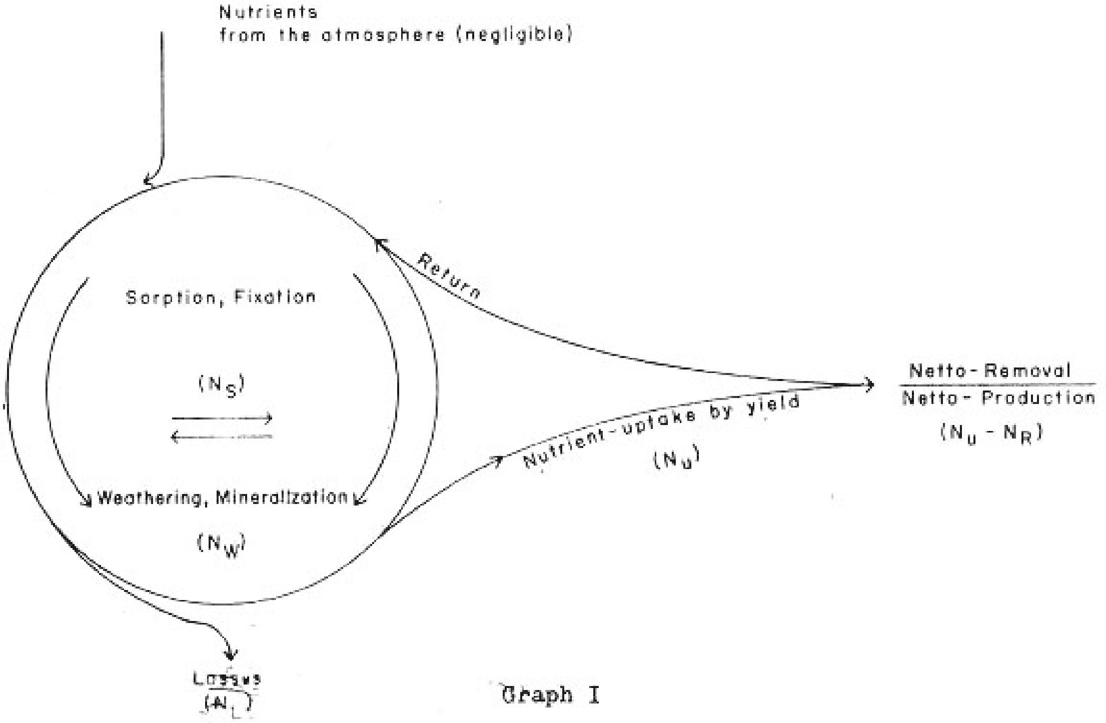
- the applied amount is in agreement wiht the plant's need;
- the released nutrients from the soil reserves are taken into account;
- timing and locating are accurate;
- the right fertilizer material is used.

Main conclusion from this statement:
The recovery value never permits any information about losses-

Statement on the Role and Importance of Commercial Fertilizers

Plant production in farm-systems without any use of commercial fertilizers is limited by the nutrient-flow (flux) of the soil based on weathering and mineralization.
The level of production is very low (normally $<$ 1000 kg cereals/ha) because it is a nearly closed system - with some uncontrolled inlets (nutrients from the atmosphere) and outlets (loss by leaching, volatilization, and on slopes run-off and erosion).

The model for this system in which legumes are not considered may be illustrated by Graph I.



Graph I

In the equilibrium state with respect to the production level (agricultural production climax)

$$N_W - (N_S + N_L) = (N_u - N_R)$$

where N_W is the decisive factor for the netto production. Its positive effect depends mainly on the climatic conditions (weathering intensity, microbiological activity, etc.)

This system offers no additional potential to increase the yield.

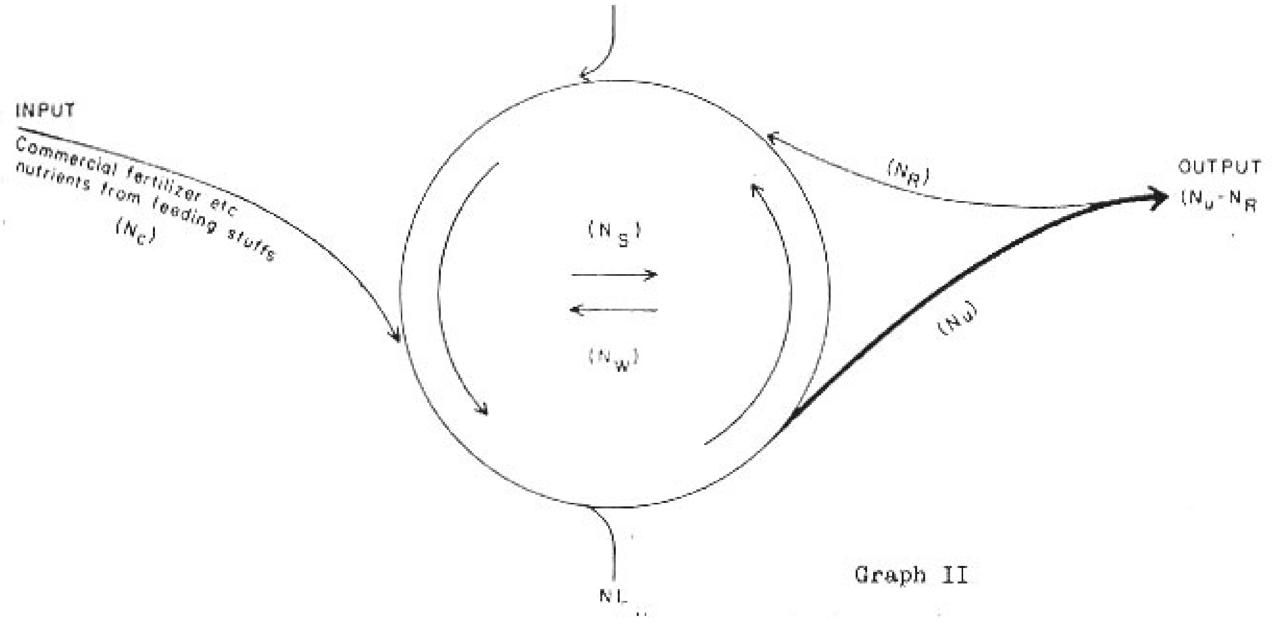
This system is still in use in many developing countries with a high population density.

The most effective way to make more of this system and to increase the yield is to introduce nutrients from outside into this system, that means to use commercial fertilizers or other nutrient importing material (N-Fixation of legumes included).

By this the system will be opened, getting into the function of an input-output system, a model of this may be illustrated by Graph II.

In the equilibrium state:

$$N_W - (N_L + N_S) + \boxed{N_c} = (N_u - N_R)$$



Graph II

With increasing amounts of commercial fertilizers N_c becomes more and more important and in a high developped agriculture with a high production level:

$$N_c > N_W$$

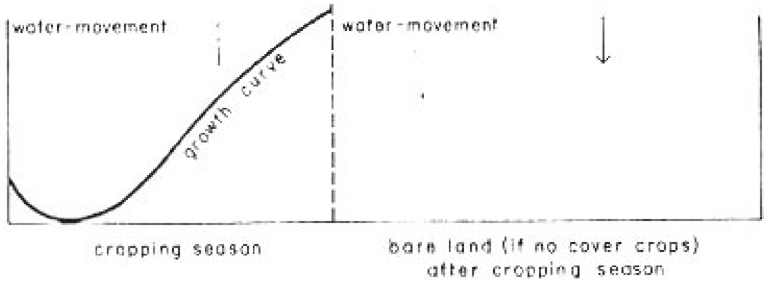
The role of the soil has changed from a nutrient releasing natural body to a turn-over system with the main function to transform the input material (commercial fertilizer) into plant-food with a high degree of efficiency.

The nearly closed system of model I necessarily included a fallow period as a regenerating phase.

Comparing both systems (model I with model II) losses of nutrients by leaching, run-off and erosion are higher in the first than in the input-output = system, as already mentioned by other speakers during this meeting.

Commercial fertilizer use and the role of timing with respect to eutrophication.

The following graph may characterize normal conditions on arable land in many european countries.



Application period for soluble commercial fertilizer	Application period for F.Y.M. and other animal wastes
Effect Negligible nutrient losses, only by run-off and erosion at the beginning	Effect More or less nutrient losses by run-off, erosion and leaching especially during the mineralization phase.

Conclusion

In this and similar cropping systems eutrophication is mainly caused by organic manure and animal excreta in connection with mineralization processes in the organic matter of the soil.