COMMISSION OF THE EUROPEAN COMMUNITIES
DIRECTORATE-GENERAL FOR AGRICULTURE

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NITROGENOUS FERTILIZERS IN THE EUROPEAN COMMUNITIES

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FOREWARD

This report was written in a period of in-service training in the Division for reports, studies, statistical information and documentation of the Directorate-General for Agriculture.

I would like to thank everyone in the Division as well as all those who gave their valuable time and advice in the researching and drafting of this study.

K.J.McCarthy.

This report does not necessarily reflect the views of the Commission of the European Communities and in no way commits the Commission as to its future position in this field.

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INTRODUCTION

This report is mainly concerned with the role of nitrogenous fertilizers in the Community's agriculture; however, farmyard wastes are also looked at briefly. Nitrogenous fertilizers are important in agriculture for one main reason - they can supply one of the most vital nutrients needed for plant growth and they can be purchased and applied fairly easily. Without such nutrients on a large scale, the Community would have to import large supplies. Indeed because of fertilizers, together with other modern farming methods, including high yielding crop seeds, the Community sees large surpluses each year in many products.

However, the negative effects of nitrogenous (N) fertilizers are becoming more and more apparent both in combination with and without the impact released from manure. A farmer can of course apply fertilizers without due regard for his crop and burn it - even a weekend gardener taking care of his lawn needs to be careful in applying necessary nutrients. This type of damage is however easily seen, but there are other side effects too, that have resulted from the use of N fertilizers since the 1950's and that are going to continue .

One possible side effect is that of methaemoglobinaemia, the 'blue - baby syndrome'. This happens when nitrate is leached into aquifers used for drinking water, and when the drinking water is mixed with powdered milk, the nitrate passes into the bloodstream of infants; up to one year old the result may be fatal. Many doctors in fact recommend that only mineral water should be given to babies, and some advise that pregnant mothers should do the same. Some member states have had no such cases for many years now - the U.K. for example, - but countries have had and continue to do so, West Germany for one, and apparently a prospective member to the Community, Spain. Hungary has also problems.

The nitrate generally comes from inorganic chemical fertilizers and farmyard manure which find their way in the form of nitrate into water courses, whether surface or ground, which are then tapped in order to supply drinking water. It is however very difficult to obtain a clear picture of who is causing the pollution and where it takes place. More research and development is needed to understand what actually takes place in the soil and to investigate the complex leaching processes involved,and how the farmer can take advantage of the available nitrogen in the soil.

It is also possible that nitrate may be linked to cancer in adults, but as yet there is no agreement on nitrate's role, and more research is needed to investigate precisely what this role is. Here drinking water and diet, especially vegetables, would provide the means by which the nitrate could enter the body.

Meanwhile most countries in Europe had agreed to the WHO limit for nitrates in drinking water. The WHO recommendations changed recently - in 1984 - , but the European Communities had already laid down their own standards for drinking water five years ago, including nitrates, and this Directive has just come into effect. Many water sources in the Community - a majority of which originate from groundwater - are over the prescribed limits of the Directive.

Compliance with the limit will entail investment in water treatment plants This will be a very costly exercise for the water supply authorities involved, for example in East Anglia, England.

The nitrate contamination did not take place over night, but in fact over the last three and a half decades as intensive agriculture began to take-off and develop. The farmer is encouraged by the CAP to produce as much as possible, thus tending to apply more nitrogenous fertilizers so that he can increase his income. The farmer is only recently realising that he is causing pollution but also that he could apply his N input more efficiently, thus saving costs and pollution at the same time.

Thus any progress made today will help reduce pollution in the future and result in a healthier agriculture and population. Member state governments could propose guidelines for an environmentally sensitive CAP and recognise the problems nitrates cause by specifically drawing up a code for nitrogen use in agriculture. The Commission itself is already reviewing the CAP and hopefully will adapt it so that the environment is given proper consideration and in particular that the nitrogen input is regulated, where problems are identified and remedies suggested. Under the CAP's structural policy special incentives could be given to turn farmers away from intensive farming practices. Meanwhile the Commission is already working on a directive to protect groundwater against nitrate pollution. One day there may be a fully fledged " CEP " - a Common Environmental Policy -, in which agricultural practices are bound to, indeed have, to play important roles.

Part I "Nitrogen and Agriculture" examines the nitrogen input generally, including an explanation of the various processes involved, while Part II "Fertilizers in Agriculture", looks at fertilizers in a broad sense of the term and then moves on to nitrogenous fertilizers and consumption, price, future trends, farm management and use on grass and arable land, including leaching and runoff factors.

In Part III "The consequences of nitrogenous fertilizer use for health, the environment and the farmer" the damage fertilizers do is examined, including the problems facing drinking water and the costs farmers incur. Part IV "Recommendations and policy options" looks at what can be done by the farmer himself and by agriculture generally, which, depending on the choice of policy - persuasive or economical and financial or mandatory measures -, can be put to work. Part V brings the report to a close.

PART I

NITROGEN AND AGRICULTURE

Nitrogen (N) is a gaseous element comprising about 78% of the earth's atmosphere. It occurs naturally in the soil, whereby it is converted into usable forms for plant use by bacteria and by other natural processes. N, together with phosphorus (P) and potassium (K) are essential nutrients for plant growth. N is the most important component of the amino acids which provide the basis for the synthesis of cell protein. Amino acids combine and form these proteins in enzymes, in pigments such as chlorophyll and haemoglobin, and in vitamins of the B group. Nitrogen compounds are taken directly by plants, and by animals and man when they eat the plants. Thus N is essential for life, since through food production man can live and produce. It is estimated that daily in the U.K., each of the 56 million inhabitants takes in approximately 16g N in food (1). However, since N in its natural form cannot adequately meet the demand for increased food production, advanced countries, particularly the U.S.A. and Western Europe, produce synthetic ammonia in various chemical plants as the basic material for N fertilizers.

A farmer will use a N fertilizer because the nitrogen in the soil is not sufficient to meet the needs of crops grown (2). Nitrogen in the soil is in an organic form and not immediately available to plants, and since the amount of inorganic nitrogen released annually from the organic form - becoming (3), available to plants in the form of nitrates - is only a small amount, extra nitrogen is required, which is then produced synthetically by man.

The process of transformation from ammonia to nitrate is called nitrification, see figure 1., allowing plants to take up the necessary nutrients, which are then harvested for man and animal. Nitrogen fertiliser then, is given to plants increasingly in a readily absorbable form, while nitrogen in natural organic fertilizers, in the form of liquid and solid manure and treated human waste, has first to be broken down by soil micro-organisms into the nitrate form consumable by plants (4). A small part of the inorganic nitrogen may be temporarily immobilised by assimilation into micro-organisms when they are very active; these eventually decay and return to the soil organic nitrogen pool (5).

The application of N fertiliser to land is one of man's contributions to the overall nitrogen picture. Other contributions include urban waste, emissions of fossil fuels, leaks from septic tanks and building work. The nitrogen cycle involves the N gases of the air, the N In the soil, and the N in rivers, lakes and seas - man affecting all three. The main components of the N cycle itself are:-

(1) Biological N fixation
(2) Ammonification
(3) Nitrification, and
(4) Denitrification.

See figure 2.

Biological N Fixation

This is the major process whereby N is converted symbiotically from the air to vegetable matter various N_2-fixing forms, especially those of the bacterial genus Rhizobium, found in the roots of leguminous plants (see tables 1 & 2). However the enzyme complex nitrogenase which coverts N_2 from the air to ammonia, is rapidly inactivated by exposure to O_2 and is sensitive to ammonia; the latter prevents its synthesis in most organisms and inhibits its activity in some. Thus when there is a presence of N fertilizer, the soil organisms' ability to fix N_2 decline and may even stop. See figure 2. In the U.K. there is apparently a decline in the contribution of biologically fixed N to the Nitrogen cycle (6).

This fixed N is initially immobile, whereas N from rainfall or from inorganic fertilizer tends to be mobile. However the method of farming can also influence the immobile soil organic content. Grain legumes and forage crops such as lucerne and clover, which are important in grasslands, are the major contributors of fixed N. Thus when arable land is turned over to grass organic N accumulates, which is relatively immobile. Conversely, as old grassland is ploughed up, organic N declines since the soil organic N now becomes more mobile. When nitrogenous fertilizers is applied to grazed grassland the organic N reserves do increase, (7), while at the same time N_2 fixed symbiotically can be suppressed (8).

Ammonification

This is the breakdown of plant and animal organic nitrogen mainly by microbial action when conditions of soil moisture and temperature permit, to release ammonia. This process is also called mineralization. The organic nitrogen is also initially, immobile. The amounts mineralized depend on many factors including the farming of the area, for instance with grass, then the age, botanical composition and its previous management will be important. See figures 2 and 4.

Nitrification

This is the oxidation of ammonia to nitrite and then to nitrate, mainly brought about by chemoautrophic bacteria, a non-symbiotic process, allowing plants to take up the necessary nutrients. See figures 2. and 4.

Denitrification

This is the biological conversion of nitrate to gaseous products of nitrogen, N_2 N_2O and possibly NO. Thus while in a mobile form, nitrogen is returned to the atmosphere. This loss of nitrogen can also occur in canals, rivers, streams, lakes, coastal waters and seas. See figures 2 and 3.

Nitrogen Inputs

Inputs of the nitrogen cycle include precipitation, N fixation by lightning discharges, biological N fixation, the decay of organic matter, chemical fertilizers, animal sewage and industrial wastes, seeds, feedstuffs, straw and emissions from the combustion of fossil fuels. See figure 3.

Within the soil plant system itself, see figure 3, nitrogen is conditioned by nitrification, plant uptake, immobilisation by micro-organisms, the decay of organic material, denitrification, volatilisation and the size of the soil organic nitrogen pool and of the soil inorganic nitrogen pool.

Nitrogen Losses

Nitrogen, in various forms, for example nitrate, is lost from the soil plant system by losses to water : leaching to groundwaters, surface runoff to rivers and streams, and erosion to watercourses; and losses to the atmosphere : denitrification, ammonia volatilisation and the burning of straw. See figure (5). Plant uptake can also be considered a "loss", but not in the same light as leaching for example, since nitrogen can be recovered via a plant for consumption, but not so with leaching.

Nitrogen Sources

The most important sources of nitrogen for crops are biological N fixation, nitrogen from rainfall, recycled animal and human wastes in the form of farmyard manure, slurry and sewage sludge, decaying organic matter and nitrogen from inorganic chemical fertilizers where the nitrogen is "fixed" by chemical processes. These sources will be looked at more closely later on. Fixation by lightning, and nitrogen from seeds, straw, feedstuffs and emissions from the combustion of fossil fuels are considered less important sources of nitrogen. Septic tanks and building works may also be minor sources of nitrate, but their impact is small relative to agricultural land. See figure 4.

The most important outputs of nitrogen are :- plant uptake; losses to water : leaching and surface runoff; and losses to the atmosphere : volatilisation and denitrification. See figure 5. These will be looked at briefly below. Erosion to watercourses and the burning of straw are also outputs of nitrogen, but of less importance in comparision to those mentioned above. See figure 6 for the most important inputs and outputs of nitrogen for agriculture. For an overall view of the nitrogen cycle see figure 7.

Plant Uptake

Crops and other plants take up nitrates, oxidized nitrogen, in an inorganic form and incorporate it into their own cells. The major part of the nitrogen taken up by most crops is removed in the harvest, the rest remaining in the soil in the form of stems and roots, which then die and decay, releasing nitrogen to the soil organic nitrogen pool. Factors such as soil type, precipitation, evaporation, the choice of crop, and the amounts of nitrogen fertilizer and animal and human wastes will influence the amount recovered by the crop. Grass for example has a greater capacity to absorb nitrogen, but the process is very much dependant on soil temperature (9). An important factor is the rate at which nutrients are being released for the crop to take up. More often than not release takes place at a too fast a rate compatible with the seasonal growth requirements of the plant (10). Thus the risk of nutrient loss via leaching and denitrification may be considerable (11).

Losses to Water

Leaching

This is the movement down the soil profile of water containing dissolved material, transported through the soil to the groundwater, which is stored in water-bearing formations or strata called aquifers, which are principal sources of drinking water for man. See figures 8 and 9. Nitrates are highly soluble in water, and since water draining from the soil will reflect the nitrate content of the soil, influenced amongst other things by nitrogenous fertilizers, concern has been expressed at the rising use of fertilizers - 19.18 kg/ha of plant nutrient in 1955 to 91.92 kg/ha in 1982 (12) for arable & grassland for the Ten - in connection with various health hazards attributed to nitrates. These are mathaemoglobinaemia in babies, (13) fetal haemoglobin in new born babys (14) and possible cancer in adults (15). Meanwhile the level of nitrates in drinking water is rising and in some cases above the 50 mg of nitrate per litre (NO_3/1) mandatory limit laid down by the European Communities (16).

Surface Runoff

This is where water movement takes place across the soil surface into water channels, draining into rivers, lakes, possibly canals and eventually the sea. See figure 10. This water has had less contact with nitrates in the soil than that which drains the soil, and thus may have lower nitrate concentration. The extent of this concentration will be important for those water authorities obtaining their supplies from rivers. Another impact of nitrate is that where there are still waters, - namely where there is no current to wash the shore, such as in canals, reservoirs, lakes and coastal areas, there could be eutrophication which can have adverse effects on recreation and amenity, cause blockages in reservoirs, and in exceptional circumstances can result in fish suffocating, (17) as took place in Denmark.

Losses to the Atmosphere

Denitrification

This is the biological conversion of nitrate to gaseous products of nitrogen : - N_2, N_2O and possibly NO see figure 11. The rate of denitrification in the topsoil is strongly influenced by the nitrate concentration, the carbon supply, moisture levels in the soil, the content of ferrous material in the soil and the temperature. There are also indications that NO_3 reduction also takes place in underground layers with clayey soils. However this natural protection of the groundwater may be suppressed by water percolating through with a high content of dissolved NO_3 (18). The CWPU notes that if "very long transit times in the unsaturated zone" exist, "the possibility of significance denitrification cannot be ruled out" (19).

Denitrification may also take place in saturated aquifer (20). Concern has been expressed about the possible role of N oxides in reducing the ozone layer which protects the Earth's surface from harmful ultraviolet rays. A report from the U.S. National Research Council (1978) says that the ozone layer could be damaged by the continuing use of N fertilizers. However the report concluded that given the benefits of fertilizers in helping produce food, and given that the ozone delpetion is such a long term possibility that "no immediate corrective action is required", thus there should be "no drastic moves at the present to restrict the use of these fertilizers" (21). While the Royal Society report on the Nitrogen cycle in the UK notes that the effects of oxides of N on the ozone layer may be less than was earlier supposed, they say that the sources of the oxides in the atmosphere are uncertain and that the "extent to which oxides of nitrogen are produced from agricultural land and how this relates to changing farming practices, such as direct drilling and the application of larger amounts of N fertilizer are scarcely known ..." (22). A positive element of denitrification is the role it plays in areas with still waters:- canals, lakes and coastal areas. The conversion of nitrate to free nitrogen and N oxides which then escape to the atmosphere is a beneficial process removing excess nitrate from the water, thus reducing also the possibility of eutrophication (23).

Volatilisation of Ammonia

Ammonia may be volatilised from soils, plants, fertilizers, animal wastes and urban sources. See figure 11. If it is the case that the pH value of the soil is above 8, namely in an alkaline condition, volatilisation results in the conversion of ammonium ions to ammonia gas. Within the soil system itself, much of the loss may be rapidly re-absorbed by the soil or vegetation to constitute a "closed" micro-cycle of ammonia (24). However in acid conditions, ie where the pH value of the soil is less than 7, then nitrification may take place, resulting in nitrate which may be open to leaching. While recycling may take place, how it happens is uncertain, and investigation in detail on a quantitative basis has been recommended by the Royal Society Report (25).

On the soil surface volatilisation will release ammonia direct into the atmosphere, for instance from organic manure, treated sewage sludge, spread on the land or anhydrous ammonia fertilizer which has not been ploughed in. Some of this ammonia may of course be recycled by the vegetation. It is likely that the ammonia lost will return to the soil via rainfall, as part of the nitrogen cycle.

Ammonia in the atmosphere however may help to neutralize rainfall acidity through the formation of ammonium sulphate and ammonium nitrate (26), under certain conditions when the sun shines on evaporated ammonia, increasing ammonia evaporation may contribute to the acidification of the rain (27).

Thus while ammonia is a weak base, namely an alkaline, it is potentially a weak acid if exposed to solar radiation. Soil acidity can increase nitrification, leading to nitrate, which can be leached. In addition if rainfall acidity is neutralized through ammonium sulphate and ammonium nitrate, there is always the possibility of increased nitrate leaching since the ammonium in the rainfall will be subject to nitrification in the soil, leading to nitrate, and the nitrate in the rainfall may be directly leached.

References Part I

(1) Royal Society Report p.34.
(2) Only sufficient to meet 25-50%. Well-rooted crops in deep soils can take up N to a depth of at least one meter below the soil surface. That depth of arable soil in the UK contains some 10 N/ha, or about 50 times that needed for a good crop, but the N is not immediately available to the crop. Royal Society Report p.53.
(3) OECD Report 1983 p.18.
(4) OECD Report 1983 p.19; Royal Society Report p.46.
(5) OECD Report 1983 p.19.
(6) Royal Society Report p.39, ref.15.
(7) Ibid p.55.
(8) Ibid p.38; Paras.2.20-2.33, pp.66-75.
(9) Marie Sherwood p.233.
(10) N.Scott et al p.233.
(11) G.Rogers & J.Ashworth p.1219.
(12) K.McCarthy DG VI A2.
(13) Royal Commission Report p.87.
(14) Actualité Environnement p.II; G.Craun p.21.
(15) D.Forman et al p.620.
(16) European Council Directive 80/778/EEC of 15.07.80.
(17) H.Schroder p.9.
(18) K.Rasmussen p.79.
(19) C.W.P.U. p.17.
(20) Ibid p.19.
(21) New Scientist 28.09.78.
(22) Royal Society Report pp.32-33.
(23) Royal Commission Report p.121.
(24) Royal Society Report p.45.
(25) Ibid p.32.
(26) Ibid p.206.
(27) J.Forslund (DK) WRC paper p.4.

PART II

FERTILIZERS IN AGRICULTURE

In this section, fertilizer in general will be looked at briefly, and then nitrogenous fertilizers will be examined more closely. This examination will include nitrogen fertilizer consumption in the Community including a statistical analysis of application rates and predictions to the year 2000, costs of N fertilizers and impact on use, the difficulities in achieving optimal application rates, farm management in relation to fertilizer use on arable and grassland, and future trends in N fertilizer use in the Community.

Fertilizers

A fertilizer is any organic or inorganic material added to soil or water to provide plant nutrients and to increase the growth, yield, quantity or nutritive value of the plants grown therein (1). Thus a farmer wishing to increase his yields will apply fertilizers, organic or inorganic, the latter as straight P,K or N fertilizers, or compound fertilizers which may include any two or all three. The addition of nutrients to the soil will increase the available supply of those essential elements necessary for plant growth, but the determination of a crop's nutrient needs is an necessary aspect of fertilizer technology. This can be achieved by a detailed examination of plants and soil conditions in the fields, followed by simple fertilizer tests, quick tests of plant tissues and analysis of soils and plants. Once deficiencies have been identified, steps can be taken to remedy the situation. Such tests cost time and money, and not every area may have soil-testing laboratories to provide the farmer with the necessary information. Soil testing for nitrogen however is rare, thus not allowing the farmer to take full advantage of the nitrogen in the soil.

The farmer may have a choice of fertilizers, such as farmyard manures either in liquid form or dry matter, chemical fertilizers (nitrogen, phosphate and potassium), and others such as compost, treated sewage sludge in a solid form, green manuring, liming, and interpreting the meaning liberally one also finds peat and peat moss, seaweed, packing house wastes, pot ale, cottonseed meal, guano, bones, hoof and horn (2). Usually manure is interpreted as animal wastes, while fertilizer usually refers to chemical sources (3).

Manure

Farm manure, used correctly, has become more and more important as a source of plant nutrients. It may be in the form of dry manure, where the excreta has been collected on straw or other bedding material; or it may be in the form of slurry, liquid manure collected from channels running beneath slots in a piggery or a cow house. As animal production has grown, as the design of animal housing has improved and as a method of spreading it on land has developed, slurry has become more and more important as a cheap, natural source of nutrients. Most farmers with a decent supply of slurry from their farm will most likely invest in the equipment necessary to pump out, transport and then spread the slurry on his land, usually more on grassland rather than arable land.

However, farmyard wastes are potentialy just as contaminating and polluting as inorganic nitrogen fertilizers. Various Commission publications already exist in some detail concerning manure fertilization, especially the spreading of animal excrement on utilized agricultural areas (4).

In the case of slurry there are various problems apart from handling and application. Such problems include offensive smells given off in storage and spreading (5); the leaching of the nutrients, especially nitrogen to water courses and groundwater (6) with a negative impact on the environment due to the increasing eutrophication status of water bodies (7) and the pollution of water generally including drinking water (8); the possible spread of pathogens (9), which are dangerous to humans and animals; potential damage to the vegetation (10) and soil fertility including trace elements in the soil and vegetation (11); reduced yields and damaged soil properties (12); damage to the soil by the big wheels of heavy slurry tankers (13); and the economic costs of storing, transporting and spreading slurry, and any damage done to the soil, crop and water supplies.

However farmyard wastes should not be looked at in isolation, given that chemical fertilizers, while sharing many of the same problems, are more attractive to farmers. Any increased use of manure and slurry in order to obtain the best nutrient value, need to be applied more carefully and efficiently so that the risk of pollution is reduced and that farmers can see the benefits both on crop production and in their pockets.

Compost

Compost is basically a mixture of rotting organic matter made from waste-plant organic residues, such as peat, farmyard wastes, discarded plant material and soil. It is placed in a pit, moistened and allowed to decompose - it also recommended that ammonia be injected during its composition, and sometimes lime is added too. When properly prepared it is free of obnoxious odours (14). Nitrogen is released slowly and lasts the whole growing season. Composts are essentially fertilisers with low nutrient contents - thus large amounts have to be applied and maximum benefits usually come after several years of use. Of course cheap commerical fertilizers and expensive labour costs may regulate compost to the bottom of a farmer's options. There may be room here however for research into the viability of compost as one possible logical alternative to expensive synthetic fertilizers. In Kent;England, cereal growers have already been offered a novel way of getting rid of their straw and in return receiving a compost made with sewage sludge combined straw, provided by the local water authority. The latter is confident that where heavy metals are not a problem the technique could be taken up nationwide, perhaps with a possible role for the Commission here in the Community generally (15). At present there is no data available on the amount of compost and its nitrogen value used in the Community each year.

Sewage Sludge

Sewage sludge is an organic material, which remains after the treatment of sewage, and its value for soil improvement depends on the method used for treating the sewage. However comparatively small amounts are used in farming (16) and there are already a number of publications on sewage and its relationship to agriculture, sponsored by the Commission (17).

In one case after only one year, a sludge spreading operation in South Wales became so popular that there was a 2-4 week waiting list. There are said to be very few problems of smell with the sludge which is injected into a 75mm slit in the soil, covered and then rolled. The Welsh water authority carries out the work, all free of charge, including a land survey, soil sampling, analysis of the sludge and then the spreading (18). This scheme may possibly be an area for future activity where the agronomic value of sewage sludges can be realised. However due to the possibility of sewage sludge being contaminated - heavy metals, salmonella or other pathogens and so on - its use as a source of fertilizer should be monitored very carefully. A proposal for a Council Directive (EEC) on the use of sewage sludge in agriculture has been amended and perhaps may be adopted by the Community in the near future (19). There is some data available on sewage sludge use in agriculture. For example in the UK, the amount of N in the sewage applied on agricultural land in 1978 was 26 kt, about 1% of the estimated inputs of N (20). See Table 3. In France domestic sewage accounted for nearly 2.5%, some 225Kt. See Table 4. Further data is not available.

Green Manuring

Green manuring is ploughing in the plant and root system of a crop for its beneficial effects, although during growth it may be grazed. These green crops, such as clover or legumes, including beans and peas, have roots bearing module bacteria capable of fixing atmospheric nitrogen symbiotically, namely the bacteria of the genus Rhizobium. See page 2. The advantages of such crops include the addition of nitrogen to the soil, the increase in the general fertility level, a reduction of erosion, improvements of the.physical condition and a reduction of nutrient loss from leaching. However it is necessary to grow a winter cereal in order to obtain this reduction of nutrient loss (21).

Biological N2 Fixation

Fixation by leguminous crops may even reach 500 kg N/ha per year, although it is generally much lower (22). In marginal farming areas, for example rough grazing, N_2 fixation is important for animal production. In the U.K. biological N_2 fixation added around 0.15 m tonnes of N to the soils in 1978, 5.6% of the total compared to 1.15 m tonnes - 43% - added as N fertilizer,see Table 3. In France N_2 fixation accounted for 14%, 1.3m tonnes, and in Denmark 4.6%, 30 K tonnes. See Tables 4 and 5.

The contribution however by nitrogen fixation has decreased over the last 40 years, as N fertilizer use and arable land has risen. A reason for this is that N fertilizers can inhibit N_2 fixation, see page 2. The Royal Society noted that a combined fertilizer applied at the rate of 450 kg N/ha inhibited N_2 fixation by almost 80%, compared with control plants which received no fertilizer (23). In grasslands, grass-clover swards without added N fertilizer may fix 150-200 kg N/ha annually (24).

In France farmers in Brittany have cut out all N fertilizer on a trial to use rye grass leys with a high percentage of white clover. This has meant reducing nitrogen by, on average, 300 kg a hectare (25). This has resulted in large savings in fertilizer costs with no reduction in milk yield or stocking rate. Bloat - severe distension of the abdomen by gas, usually in ruminant animals - can be a problem with clover, but in the trial, out of 4 cows which died, only 2 deaths were related to bloat (26).

Further research is being carried out on the improvement of the N-fixing efficiency of legumes, and, "the biggest prize of all", transferring N fixation ability to other plants (27). If eventually success does come and perhaps this may not even be this century, as the the New Scientist commented in 1978: "drastic social and political changes will have to be made in order to implement the Ultra-green revolution on a world wide scale" (28). Meanwhile the F.M.A. writes that legumes "could not, and cannot, provide sufficient N to support the high yield levels obtainable and needed to feed our population" (29), while the Royal Society recommended that research on biological N_2 fixation receive increased support in order to develop more effective and in the longer term, possibly new N_2 fixing systems (30).

Other Sources

The remaining sources of fertilizer are of less importance here, but deserve some comment. Liming is important in order to maintain the lime status of the soil to an optimum level, based usually on a pH value of about 6.5, and keeping soil acidity within an optimum fertility band. Liming is important in those areas where rainfall leaches calcium and magnesium from the soil, thus creating acid conditions. This effect is enhanced if the rain itself is acid rain, and combined with the occurence of ammonia volatilisation which may increase rainfall acidity (31), the application of lime will have to be increased. In Scotland use is being made of pot ale, a waste product from malt whisky, to improve agricultural land. Chemical analysis shows however that the high concentration of copper, the acid nature of the ale and the high biological oxygen demand can pose threats to man and the environment (32).

A farmer may then have a choice of fertilizer as far as nitrogen is concerned, but in practice his choice has centred on animal wastes and synthetic fertilizers. As the F.M.A. states "the only source essential to maintain soil fertility and agricultural production and available on the scale required, is and will continue to be manufactured fertilizer". However the "Farmers Weekly" magazine writes that the future for nitrogen and agriculture and the environment lies in good management, including applying N only when crops need it and can use it, making economic senses for both farmers and environmentalists (33).

Nitrogenous Fertilizers

Nitrogenous fertilizers are the results of chemical plant processes which produce synthetic ammonia. One such process is the Haber-Bosch process, originally discovered through the researches of Fritz Huber in Germany just before the First World War. There was a close relationship between the use of nitrogen for fertilizers and its use for explosives, the latter motivating the development of an indigenous source of nitrogen for Germany's need for explosives.

Ammonia can be applied as fertilizer in various ways : either directly, or indirectly after processing, to ammonium nitrate, urea or ammonium phosphate. Application of the fertilizer may be in a gas, water solution or salt pellet form. Liquid spread under pressure becomes a nitrogenous gas when freed from the pressure as it enters the soil; this form and water solution forms need to be injected into the soil or otherwise heavy losses via volatilisation would take place. While ammonia and various compounds need to be ploughed in, nitrate fertilizers can be used for top dressing (34) since they are spread in a solid granular pellet form from a hopper on the back of a tractor. This method is of course more attractive to a farmer since it is cleaner and not obnoxious and easier to handle due to mechanisation. A farmer is more likely to invest in pellet fertilizer spreaders rather than in equipment to spread liquid fertilizers. This is particularly the case with anhydrous ammonia, the equipment for which is very expensive and specialised, and while also highly corrosive and inflammable, the form of fertilizer is rather dangerous if not handled properly. It is likely that a farmer would ask a contracter to carry out the job, but more precise information on crop nitrogen requirements may apparently give liquid fertilizers a new lease of life far beyond their present 10% Market share in the U.K., according to "Farming News" (35).

Nitrate and ammonia fertilizers are inorganic and thus react faster than synthetic urea, which is organic, and hence slower. Urea in its natural form is also the chief compound of nitrogen in the urine of mammals, which is generally used as a fertilizer, directly, or indirectly, for instance through collection in a cow house or piggery for example. However nitrates are predominent in plant growth since they can be rapidly assimilated by vegetation.

Consumption

Since the end of the Second World War there has been a large increase in the use of fertilizers, especially nitrogenous fertilizers. This has been due to a number of factors which have allowed crop yields to continue to respond to increased fertilizer application. Such factors include the development of pesticides, of crop varieties with a higher yield potential, of hormones to prevent lodging of cereals at high fertilisation rates, and improved weed control and better irrigation. In the case of certain crops, such as wheat, market prices compared to N fertilizer prices have encouraged high applications.

Consumption of N fertilizer for the Ten has risen enormously, from 1,557,741 metric tonnes in 1953 to 7,937,867 tonnes in 1982. Table 6 shows the consumption figures for N fertilizers for the Ten and the Twelve from 1953 to 1982, while figure 17 shows the rise in kg/ha of average application rates in the Community. Figures 12 to 16 show how N fertilizer has risen in comparision to P and K fertilizers in the Great Britain, West Germany, the Netherlands, Belgium and France.

There is little doubt that N fertilizer has been a major factor in the remarkable increases in cereal and other crop yields throughout Europe and indeed throughout the world. In the case of cereals, the harvested production for the Nine in 1955 was 62,873,270 metric tonnes, and by 1984 145,460,937 tonnes, an increase of 131% *, an average per yearly increase of 2.94% (36). An illustration of one development influencing yield and thus increasing N fertilizer use, is the development of various crop varieties. In recent trials carried out by a major fertilizer manufacturer in the U.K., a yield of more than 11 tonnes per hectare were achieved with the Longbow variety of winter wheat with a N top dressing of 251 kg/ha. This compares with an European average of 2.611 tonnes a hectare in 1960 and 5.13 tonnes in 1982 for soft wheat. In the U.K.soft wheat production per hectare in 1955 was 3.35 tonnes and in 1984 7.63 tonnes (37).

The desire to obtain greater increases in crop production, has meant an increase in N fertilizer applications. Since the 1950's these rates have increased dramatically; for Denmark an increase of 348% per ha from 1955 to 1982; for the Netherlands and France increases of 165% and 411.8% respectively in the same period (38). Such figures have been calculated on the basis of average N fertilizer application per ha for arable and grassland excluding rough grazing (39). Table 7 shows in kg/ha of plant material the average application for the Ten and the Twelve from 1955 to 1982, while figure 17 shows this on a graph from 1960 to 1982, and Table 8 shows the index of kg/ha application from 1955 to 1982.

This data was employed in a time trend computer programme (40) to carry out a statistical analysis of the application of N fertilizers per hectare from 1955 to 1982 in a TSP ** package. The rates per hectare were calculated on total N fertilizer consumed divided by an arable and grassland figure excluding rough grazing. Further analysis was not possible, i.e. for arable and grassland individually, due to the lack of necessary data. However the results have proved the increasing use of N fertilizer, with calculated figures being very close to available data. For most Community countries, including Euro-10 and Euro-12, the correlation was almost one, showing a linear response in application. For Greece, Italy and Ireland the result was curval linear, indicating increasing applications. On the basis of these correlations the programme was extended to include predictions of N fertilizer applications up

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* 1955=100

** Time Series Processor

to the year 2000. The results are very interesting. France's rate in 1982 was c.83 kg N/ha (41) and by 2000, 132 kg N/ha; for Italy the rates were 78 kg N/ha (42) and 244 respectively, perhaps too high given the climate in Italy; and for the Ten 92 kg N/ha (43) and 144 kg ha respectively. Table 9 shows the estimated values of N fertilizer rates calculated by the programme.

These values are of course only calculated against one variable : time. Other variables such as energy prices, N fertilizer costs and prices, higher yields of new crop varieties, future investment in livestock, improved farm management, the future of the CAP, alarm over nitrate concentration levels in water and environmental measures generally, will be important in influencing future N fertilizer rate in the Community. The predicted average rate in the year 2000 for Ireland is 657.63 kg/ha, from an application of 74.50 kg/ha (44) in 1982 is an unrealistic rate, given that the highest rate for maximum yields from grassland is 450 kg/ha (45), but it indicates an increasing trend up to the year 2000. The Dutch figure may also be unrealistic given that there are severe water contamination problems in the Netherlands and that the real values of N fertilizer rates were dropping in 1981 and 1982 (46). Denmark's figure is also too high since some action has already been taken fertilizers (47).

The figure for the U.K. seems about correct. The Royal Society Report gave a figure of an extra 0.6 million tonnes per annum to be consumed by the year 2000 (48). This gives a total of 1.56 million tonnes of N fertilizers to be consumed in 2000, which divided by available arable and grassland excluding rough grazing, gives an average application rate of 173.50 kg/ha (49); the predicted computer programme figure for the year 2000 is 171.77 kg/ha. Thus the predicted values for N fertilizer application rates in a majority of cases, can be useful indicators of high and potentially very dangerous N fertilizer application levels.

An increase of N fertilization is more than likely to take place in grassland other than on arable land. But it is possible that increases may also take place on arable land. See page 18 for arable land. According to sources * in the U.K., application rates are close to an optimum level for arable crops and the rate of growth of N fertilizers will affect grassland since current usage appears to be below the optimum (50). This optimum is probably more in line with the interests of the manufacturers and not necessarily in the interests of the farmers, and decidedly not in the interests of the environment. However, such variables as those mentioned above will play important roles in affecting N application rates for arable and grassland, not least those initiatives taken by the Community.

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* F.M.A. &. N.F.U.

Nitrogenous Fertilizer : Costs and Prices

One variable affecting N fertilizer application in the near future may be N fertilizer prices. The rising cost of N fertilizers may persuade farmers to buy less and use their input more efficiently or turn to an alternative method. While OECD forecasts, the Royal Society, the Royal Commission and the fertilizer manufacturers themselves believe that further increases are likely in N fertilizer use, there has been a move in the opposite direction in Northern France. Dairy farmers in Brittany have been persuaded to switch from N fertilizers to white clover as a source of N, in order to reduce costs. In an 1983 experiment liveweight gains were similar on the clover mix on which 50 kg/ha was spread to get the crop going, compared with ryegrass swards where up to 350 Kg/ha had been used (51). Experience during the last three years has proved that cutting out N and putting more clover in the seed mix does work, however it also means taking greater care with grassland management. Even with the risk of bloat Mr. Gaonach, a dairy herd farmer, decided to go ahead and to use clover since nitrogen was becoming very expensive and the local advisers' enthusiasm had impressed him. He was now saving about 81.42 to 87.24 ecus a hectare. Mr. Coten used to apply 400 Kg N/ha each year, but now no nitrogen is put on (52).

The fertilizer industry is a cut throat business as manufacturers try to increase their market share. The farmer has seen rising fertilizer prices - from 1975 to 1983 absolute prices of nitrogenous fertilizers rose by 89% in the Nine * - but in real terms prices have remained fairly constant while application rates have risen enormously (53).According to Hood (1982), applying N fertilizer to a wheat crop in 1982 was just as profitable in cash terms as it was 25 years ago, with an increase of approximately fourfold for the use of N fertilizer in the UK over the same period (54).

In 1982 Europe's farmers paid out over 5504.56 million ecus for N fertilizers, representing a sizable stake in the agricultural sector by the chemical industry in one product alone (56). According to the UK National Union of Farmers' commercial services committee, British farmers were in no position to face the latest round of fertilizer price increases following the 1985 May agreement on EEC farm prices. UK farmers paid around 544.7 million ecus for fertilizers in 1984 and expect a bill of around 592.1 million ecus in 1984 (57). Irish farmers spend around 145.8 million ecus each year on fertilizer, approximately 87.5 million ecus on nitrogenous fertilizers (58). Increased input prices are likely to bring protests but there should be no excuse then for not changing N input management as a response to such price increases.

The aim of the farmer is of course to use his fertilizer input in such a way that the most profitable rate is employed. Farmers realise that the cost of nutrients must be looked at the value of his crops, or even balanced against an alternative, namely investment in soil conservation and other improvements needed on his farm.

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* 1975=100.

Most farmers then seek to maximise their profits by increasing their nitrogen fertilizer applications to the point where the price received for the marginal yield from the last kg of fertilizer, is just more than the cost of the fertilizer. Further applications would lead to lower profits since beyond a point on the yield curve the marginal return on the input, nitrogen, decreases. If the price of the crop(s) - the reward for the farmer - is much higher than the cost of the fertilizer, which is one cost amongst others, it will be financially worthwhile for the farmer to apply fertilizer beyond the point where marginal yield declines. This is the case with farmers in the Community, whose reward is determined by the Council reflecting a political price not a free market one. Thus at the present farmers are encouraged to produce as much as possible and a large increase in the real price of fertilizers will be needed in order to affect farmers' responsiveness to fertilizer prices.

Figure 18 shows the relationship between deflated N fertilizer prices and the average N fertilizer application rate for arable and grassland from 1973 to 1983 in the Euro-Ten. In the periods 1973/74 and 1979/81, the application rate did fall as real prices rose. However the impact of a 9.99 ecu price rise in the first period led only to a reduction of 2.31 kg N/ha; and in the second a price rise of 5.26 ecus resulted only in a reduction of 1.84 kg N/Ha. From 1974 and 1982 respectively, the application rate continued to rise. Thus over a period of ten years, N fertilizer prices have had little or no impact on farmers' decisions to apply them. Any tax on N fertilizer would have to be very substantial in order to substantially influence farmers' responsiveness to price.

Farm prices set by the Twelve in the future will of course have an impact on farm profits and thus indirectly on N fertilizer use. In addition factors such as inflation, energy and transport costs and competition from chemical manufacturers will also influence farmers, like those farmers in Northern France, and those farmers on the marginal side of the supply curve, to change their tactics.

Ironically the Community's milk quotas have led to increased fertilizers sales, at least in the UK, an increase of 9% from June 1983 to May 1984 (59) This took place after a switch by dairy farmers in order to make more silage and use less costly bought-in feed. This resulted in a 9% increase of N usage on grassland (60) and compensation for manufacturers which sold less feed. Any leaching affect will depend on the way the grassland is managed, and any effect on groundwater will not be felt for some time.

Energy Costs

Concern has also been expressed over the amount of energy needed to produce N fertilizers. However given the rising food production and intensive modern farming practices of today, many would say that to maintain the supply and reserves of food for such a large population like the Community's - 250 million plus - the cost of energy in producing fertilizers is a small price to pay. If people were given the choice between less food and reduced energy costs, and indeed reduced pollution and health hazards, and secure supplies of food but at a higher cost, the latter would be chosen.

The Royal Society Report (1983) gives 1% as the UK's figure of total national energy consumption for the production of N fertilizer; total agricultural uses to the farm gate add another 3%, giving 4% (61). In 1978 both direct and indirect energy use in the UK was 4%, in France 6.4%, in Germany 3.2% and in Denmark 14.2% (62). Chemcial production of N fertilizer requires on average an energy input equivalent to that provided by two tonnes of oil; improvements are being made all the time, with ICI being able to reduce the energy used in the production of ammonia fertilizer close to the theoretical minimum, which is seen as a considerable breakthrough (63).

Agriculture should aim to reduce the amounts of energy spent on making N fertilizer especially as existing methods of supplying nitrogen to intensive agriculture cannot continue indefinitely, taking into account that there are other sources of power available to fix nitrogen. Whether the answer lies in a more appropriate N fertilizer for crops and environmental considerations, or in widespread biological N_2 fixation, or in better management of reduced amounts of fertilizer to maintain yields taken for granted by many, especially by the farming community, some action needs to be taken.

Cheaper Supplies

Cheap imports to the Community is also a factor to be taken account of. The market is upset and farmers are then encouraged to perhaps apply more fertilizerbut to the detriment of the environment and not necessarily to the pocket of the farmer. In 1976 the French chemical fertilizer business nearly collapsed after an influx of cheap nitrate fertilizers from elsewhere in Europe (64), In the U.K. this summer fertilizer prices fell due to an import threat of up to 500,00 tonnes, roughly a third of the amount consumed in 1982, thus allowing farmers to reduce their costs and possibly even apply more (65). If restrictions are to be considered for nitrogen fertilizers in the Twelve, then foreign imports will also have to be considered.

Optimal Application Rates

One way to cut costs and reduce N fertilizer applications, is to determine the optimal application rate. The optimal rate of N fertilizer application is difficult to achieve since there are various complex factors to be taken into account. These include the weather conditions, the degree of nutrients needed by the crops, the type of soil, the extent of the soil nitrogen content, the previous crop and the danger of leaching. It is also generally cheaper to give one large application rather than a number of small dressings, tempting the farmer to over-fertilize and thus increase the possibility of losses to water and the atmosphere. Farmers therefore face considerable problems in evaluating the amount of N fertilizer to apply. In extreme weather conditions for example, financial losses below the normal optional rate may be greater than those above, and farmers may tend to aim for above rather than below the normal optimal rate (66).

In some countries the farmer will usually be able to get advice from government agencies, which provide annual recommended rates for crops under a range of soil and climate conditions, aiming at maximising the farmers' returns. See Table 10 for an example. However most of the guidelines are relatively simple and not all agenices provide detailed guidance through the year (67). In addition a farmer may be influenced by fertilizer salesmen, who may advise over-fertilisation as insurance in aiming for maximum returns, in spite of possible unfavourable weather conditions. The fertilizer industry is of course motivated by other considerations, one of those being maximising sales.

At the beginning of a curve reflecting nitrogen input and yield increase, there is a linear response to increased fertilizer application, but application rates and yields will differ for grassland on one hand, and various crops - including different varieties - on the other. Grassland normally shows a linear response for a certain application is well above the maximum yield application for cereals (68). Some crops may show a decrease in yield as the N fertilizer is applied in high doses. If there has been a drought, crop uptake will be affected by water availability, while heavy rainfall can leach much of the nutrients out of the soil up to an equivalent of 50% of the fertilizer applied on arable land (69), especially if the soil is of a light sandy type (70).

While farmers may damage their crops by applying too much N fertilizer, leading to the lodging of crops and turning a healthy plant into a sick one, an aware farmer can maximise the availability of the nitrogen content in the soil by sowing a winter cereal to take advantage of the N retained by a previous legume crop, so that less N fertilizer is needed to be applied in order to obtain satisfactory yields, releasing capital intended for fertilizer.

Farm Management

The availability of N in the soil and so the potential use of the nitrogen present, can also be influenced unintentionally by the farmer through other general farming practices, such as ploughing up grassland, not using a winter crop, burning straw, and in drainage and irrigation management.

Ploughing and Crop Residues

Ploughing up grassland stimulates mineralisation and nitrification, thus deep ploughing techniques and temporary grassland with a high turnover rate will encourage the formation of nitrate, and as a result increase the N available for leaching (71). Ploughing in grassland or a crop both adds plant material to the soil, for example clover, and promotes its eventual conversion to inorganic nitrogen. It is possible that ploughing grassland can stimulate nitrate release for 3 or 4 years subsequently and together with N fertilizers, result in a long-term impact on aquifers. Often crops cannot take up the N being released since it is happening too fast. After the Second World War in the U.K., a great deal of grassland was ploughed, and this has significantly contributed to the present burden of certain aquifers (72). This will be looked at later. Residue from a crop can also result in excess nitrate in the soil once ploughed in, and it is likely to be leached before it can be used in spring, unless a crop is sown to take advantage of the nitrate.

Drainage and Irrigation

An important effect of drainage is that it diverts into rivers most of the nitrate, which otherwise would have ended up in aquifers. However incomplete drainage can allow the same nitrate to seep down into an aquifer. Drainage may also increase the formation of nitrate, since in heavy soils it may increase mineralisation (73). Tests carried out showed that N losses into drainage water and in surface runoff were increased by the drainage of land and by raising the N application rate, but losses were decreased by re-seeding (74). It is contended however that good drainage improves crop response to fertilizer, reducing the application rate needed as well as reducing the need for chemical sprays, thus yielding a net conservation benefit (75). Irrigation may also lead to increased nitrate leaching, while efficient irrigation will allow plant growth with less nitrate for leaching. Burning straw or accelerating its decomposition can also increase nitrate leaching and result also in losses to the atmosphere.

Thus in addition to calculating N application rates, the farmer may distort his sources of analysis through his farm management.

Grassland

Nitrogen fertilizer is seen as one of the major inputs to grass whereby the potential of grassland for producing milk and meat can be tapped. N grows grass, grass yields herbage for feed and can also take stock to graze. However, nitrogen fertilizer has not been the only factor at work in the pasture, since feed grain, lime and non-N fertilizers have also played their role, not forgetting factors like management practice:- the purpose of the ley, the cutting and grazing frequency, soil type and the weather, especially the rain.

The type of ley will be important since leguminous plants, such as peas, beans, lucerne and clover, can supply N via atmospheric fixation, and around 100 to 200 kg N/ha may be fixed annually (76). A pure clover stand without N fertilizer may fix up to 500 kg N/ha and a good grass-clover ley up to 200 kg N/ha annually (77). There is evidence that mixed swards can produce herbage yields equal to those of rye-grass swards receiving as much as 300 kg of nitrogen per hectare.

However natural N_2 fixation declines markedly with increasing amounts of N fertilizer applied, see figure 19. Thus a potential natural supply of N declines while the synthetic supply increases. The F.M.A. does say that in its opinion legumes cannot provide sufficient N to support high yield levels (78), but in trials at Grange in the Republic of Ireland, swards with high clover contents and low N application had higher margins over fertilizers, than those with low clover content and high N application (79). In northern France a switch to more clover in seed mixes for ryegrass leys has resulted in large savings in fertilizer costs with no reduction in milk yield or stocking rate (80). It is essential however after a legume crop, to grow a winter cereal to take advantage of the N fixed and thus minimise nitrate leaching (81).

Animal faeces and urine voided directly on to grazed grass are also sources of N, but the value is limited since it is rather unevenly distibuted - some grass gets too much and some gets too little. Some will be volatilised, and what is not taken up by the soil or crop, is likely to be leached and will also increase the leaching losses since the urine speeds the passage of nitrate (82), especially from synthetic sources, through the soil and into watercourses.

However grassland can and does absorb large amounts of nitrate from N fertilizers and other sources through a well distributed fibrous root system and because perennial grasses can absorb nitrates and water throughout the year if temperature and soil-water content of the soil are appropriate. But the relationship between the amount of nitrate mineralized from the organic N in the soil, along with the influence of N fertilizers, is a complex one. For instance, N accumulates faster under grazing than cutting, especially so when large amounts of N fertilizer are applied to the soil (83). When the grass is not regularly cut and removed, the rate of accumulation is scarcely influenced by added N fertilizer. But when grasslands are ploughed there will be a loss of the nitrogen-nitrate levels that have built up, these start to break down and can be worked out of the rooting zone into the soil water (84). Meanwhile denitrification can account for a large part of the N being lost - 5 to 10% of the added N fertilizer may be lost from loam and clay soils under grass (85). Due to these losses, extra N fertilizer may be necessary in order to obtain satisfactory yields of grass.

Depending on the purpose of the grass, N fertilizer applications can range from zero to 247 kg N/ha, depending whether it is rough grazing or paddock grazed, see Table 10, or as recommended, 300 kg N/ha, or even 450 kg N/ha (86). However practise in the U.K. has shown that around 40% of permanent grass receives no nitrogen at all, for short-term leys it is an average of 150 kg/ha and about 70 kg N/ha on a permanent pasture. These figures are slightly out of date, since the milk quotas would have raised these figures, and are of course different from the average rate per hectare calculated by K. McCarthy. In order that the farmer may be aware of the N in his soil and apply the optimal rate of N fertilizer,and prevent losses through leaching, a better understanding of the mineralization-immobilisation relationships of N in grassland soils, the extent of denitrification losses and the role of N_2 fixation in grassland management is required.

Arable Land

As with grassland after the Second World War, there was a marked increase in crop land as European countries began to expand production to meet the demand for agricultural produce. However uptake of nitrate by cereals and other crops is less efficient than with grassland, and often there is no crop grown in the autumn and winter periods to take advantage of nitrate released by the previous crop. In addition N fertilizer applied to arable land will leach at a higher rate than compared to grassland (87), and arable with light sandy soil will leach more than land with heavier clayey soil (88).

Crop uptake is of course important for the farmer, and there has been lots of progress made concerning various crop varieties and their response to higher levels of nutrient supply (89). Maximium yield systems have been found for potato crops and work is being carried out on new types of cereals (90). This is also likely to increase N fertilizer use and thus lead to increases in nitrate levels in water supplies. Sources in the UK have tentatively suggested that N usage on cereals - 75% of the arable crop - in twenty years times might be about 1.5 times that at present, implying an additional 0.15 million tonnes per year by the year 2000 (91).

In general N recoveries from optimum fertilizer applications in trials in the U.K. ranged from 30 to 70% and on average were about 50% (92). Under optimal experimental conditions Jenkinson (1982) has figures of 96 kg N fertilizer/ha with a 92% recovery of N fertilizer for winter wheat, and spring barley at 78 kg N/ha with 58% recovery. However higher application rates for winter wheat - 144 kg - and spring barley - 95.7 kg, resulted in lower recovery rates of 86% and 51% respectively (93). These rates are however above the average, and it is generally accepted that for many arable crops cultivated under present practices, roughly 50% of applied nitrogen is recovered in the harvested crop (94).

Thus while the graph of D.Greenwood - see figure 20 - showing the average yield of wheat in various countries in Western Europe relating linearly to the amount of fertilizer applied up to 220 kg N/ha, it is very likely that only around 50% of the fertilizer applied was responsible for the yield, apart from the influence of other factors. These factors include animal manure spread, the amount of nitrogen in the soil and the nitrate in the rainfall that could have influenced growth. Around 50% then is open to loss if a crop is not sown to take advantage of what it can of the nitrate left in the soil. If there is heavier leaching than normal then the farmer may be just pouring his money down the drains every time he applies N fertilizer to his crops.

In order that the farmer does not pour his money down a drain and not pollute the environment, and instead make the most efficient use of his inputs, there needs to be a far better understanding of important soil processes, such immobilisation, mineralisation, root penetration and the uptake of inorganic N by the plant, in order to achieve better crop response and growth to correct amounts of nutrients. An ideal answer would be to find a way to graft a biological N_2 capability onto plants in order that they can supply themselves with their own nitrogen. Any progress in the above areas would go some way in minimising the loss of N fertilizer which is a valuable commodity to the farmer but a hazard to the environment and most likely to man too.

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PART III

The Consequences of Nitrogenous Fertilizer Use for Health, the Environment and the Farmer

Here the impact of nitrates in diets and drinking water will be looked at, followed by the costs to the environment, in the drinking water and surface waters, and to the community. Finally a look at the way the farmer is affected by nitrate losses, his input costs and any reduction in his income level, and how the CAP will affect N fertilizer use as decisions, directly, or indirectly, to reduce future food production are put into force.

Health

The health risks posed by nitrates in water supplies are methaemoglobinaemia in bottle fed infants - known also as the blue baby phenomenon, which can be fatal, and a possible increased cancer risk from an increase in nitrate exposure through the production of N-nitroso compounds from drinking water and diet. The question has also been raised concerning the possible relationship of high nitrate/nitrite ingestion and that of miscarriage rate in humans, as well as the impact on infant development (1).

Methaemoglobinaemia

Nitrate in drinking water was first associated with methaemoglobinaemia * in 1945, and up to 1981 approximately 2.000 cases had been reported in North America and Europe, mainly in the period up to 1960. Approximately 8% - 160 - of these cases resulted in death (2). In West Germany there have been various cases, and the nitrate contamination of drinking water is proving to be a real problem for the Hungarians (3).

In the U.K. only 10 cases have been recorded in the last 30 years, one of them fatal. Methaemoglobinaemia is very rare in the U.K., but if the guide level of 25 mg NO_3/l laid down by the Community is seen to be exceeded, then bottled water must be provided for infants (4). In April 1982 in West Germany, the Lower Rhein (Niederrhein) village of Wachtendonk experienced water rationing because the nitrate content of the tap water was at a dangerous level, more than 100 mg N/l (5). Two weeks later the levels dropped but concern was still expressed over the amount of N fertilizers being used on the fields. In February 1984 the decision was taken to provide free bottled water for infants in Bad Schussenried, Swaben, West Germany (6), because tap water contained 100 mg NO_3/l. But in April 1984 a 12 month old baby girl suffered brain damages resulting in spastic paralysis due to a water source contaminated by an area of heavily fertilized arable land (7).

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* Methaemoglobinaemia affects the blood in such a way as to reduce its oxygen-carrying capacity; in Appendix 1 there is a detailed description of methaemoglobinaemia.

It is apparently difficult to obtain data on the levels of drinking water, since the water analyses carried out where there were indeed cases of methaemoglobinaemia in the U.K. did not take place for weeks or months after the disease was diagnosed, during which time the nitrate levels may have dropped considerably; the role of bacteria contamination in the water was however not looked at, nor were dietory sources (8). There is also some concern based on certain animal experiments, over the possible chronic effects (just under the methaemoglobinaemia threshold) of the absorption of nitrate/nitrite on the health and normal development of infants (9).

The Cancer Factor

A risk which cannot be discounted is that nitrate may be active in causing some forms of human cancer *, especially gastric cancer, through the formation of chemical compounds of the classes known as N-nitrosamines and nitrosamides. There is no reason to doubt that N-nitroso compounds are as carcinogenic to human tissues as they are to those of other animals (10). Whether the compounds are formed from components of the diet in sufficient amounts to present a cancer risk, is not yet clear. However, it is likely that any risk will be heightened by exposure to excess nitrate. High nitrate concentration in drinking water may be an important factor, but the effect of such concentrations will be complicated by other complex factors. These include, other sources of nitrate in the diet, especially vegetables: including the direct intake of nitrate and nitrosamine from preserved foods; other dietory and non-dietory carcinogenic factors; and long latency periods for cancers.

Diet

Dietary sources are important since foodstuffs can have nitrate or nitrite added as a preservative in cured meat, and vegetables can take up nitrate from the soil or have it added in the form of N fertilizer or farmyard manure. Many vegetables that receive high fertilizer applications can accumulate high concentrations of nitrate in their leaves and roots (11). Experiments carried out by W. Schuphan (12) showed 76mg Nitrate-N/100g fresh weight in 1966 for a harvest of spinach receiving 320 kg/ha of N fertilizer. The danger may be increased if the spinach is then cooked in water containing nitrate. On the other hand Dutch lettuce eaten uncooked, was found to contain an average of 244mg/100g fresh weight by Swedish scientists; on the 1.02.1972 Schuphan found 186mg nitrate in 100g of Dutch lettuce, thus almost the entire content of nitrate is consumed by adults.

One might expect that areas of high-nitrate diets, including drinking water with a high nitrate level, would indicate regions where there was a high stomach cancer rate. This appears not to be the case in the U.K., where a team of epidemiologists discovered that the high cancer-risk areas had little nitrate and the low cancer-risk areas a lot of it (13). Thus if another as yet identified factor is important in reacting with nitrate to cause or not to cause stomach cancer, this factor has not yet been identified. Further research into the cause of stomach cancer and the nitrate agent is needed, until some conclusion is reached, without a doubt, over the problem of nitrates.

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* See Appendix 1 for a further explanation.

WHO Limits

The WHO appear to see lower levels of nitrate in drinking water as important since they tightened up their recommended guideline in 1984, reduced the 100mg * level to 44.25mg Nitrate/l ** (14), below the Community's mandatory level of 50mg Nitrate/l, and thus indirectly lending support to the EEC level. The latter also has a guide level of 25 mg Nitrate/l and it appears that most drinking water sources in the Community are over this level and many are over the mandatory level of 50mg Nitrate/l (15). The drinking water problem will be dealt with below.

The Royal Commission believes that there is no basis to the cancer risk from nitrates in man since a positive relationship between nitrate levels in drinking water or in food and the incidence of cancer cannot be proven (16). It is of course advisable to prudently reduce the intake of nitrate and nitrite in drinking water and diet, but more attention and monitoring has to be paid to other sources of nitrate in order to identify further those persons at risk, due to age, health, sex, heredity and various other factors. As long as the question remains open as to risks of nitrate in man, decisions must be taken to maximise safety and on the principle of preventive measures given the inadequacy of present knowledge. But on the whole, one of the major reasons why nitrate levels have risen in diet and drinking water, has definitely been due to the increased use of N fertilizers (17).

The Environment

Agricultural development over the last 50 years has led to various changes in the means of production and the management of the farm, and these changes have had serious impacts on the environment. The demand for better and more profitable yields has not always produced the best results for both agriculture and the environment. Agricultural practices can lead to an increase in yields on one hand but can also lead to an increase in crop disease and infestation by pests and pollution of the environment, and in order to market the produce at its best, further treatment of the crops are required, for example with pesticides which can lead to river contamination with risk to man and animal. But in order to produce more, the farmer applies nitrogen fertilizers and farm manure, with the risk of runoff and leaching thus poisoning the environment. W.Schuphan (18) outlines in three figures which show the dangers of intensive agriculture; the results of too much and too little N fertilizer since too little nitrogen can reduce the quality of the crop; and the possible damage due to improper use of nitrogen as fertilizer. See figures 21, 22 and 23.

As early as 1972 H.Henkins noted that in many publications it was being asserted that agriculture was making a significant contribution to the eutrophication of surface waters (19). In the same period a list of quotations referring to agriculture's pollutive role was included in the publication. That situation has not changed - fertilizers are still polluting the environment. Various remarks on agriculture and the environment are reproduced in Appendix 2.

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* 22.6mg Nitrate-N/l.

** 10mg Nitrate-N/l.

Much criticism has been levelled at the use of N fertilisers for resulting in the pollution of streams rivers and groundwater sources and causing eutrophication (20). Various reports state that the increase of nitrate in waters can be attributed mainly to changes in agricultural practices, including increased fertilizer usage (21). In western Europe water extracted for drinking water from boreholes is already contaminated above the mandatory limit of 50mg N/l for the European Communities.

Nitrates are slowly moving down towards aquifers, in some cases taking 30 to 40 years, leading to what is called a "time bomb" effect (22), and at present no directive or limit is aimed at protecting groundwater from nitrate pollution, although the Commission is currently working on a proposal. Water resources may be contaminated above the 50mg N/l limit laid down in the Ten, as long as drinking water at the tap remains inside the limit. As a result water is being treated if contaminated above the 50mg N/l limit, in order to reduce the nitrate levels.

Surface Runoff

Much N fertilizer contamination of streams and rivers is caused by surface runoff, and much later by the nitrate in water discharged from groundwater. Slurry is also a major pollutor, especially if farm land is flooded after slurry has been spread on the land. It has been the case that authorities have deliberately flooded land in order to prevent a town being flooded. It happened in the case of Preston in Northern England (23), and as a result a pig farm was flooded and the waste washed into the river. Here at least the respective authorities have taken responsibility for such pollution. Thus in two ways, streams, canals, rivers and coastal areas can get contaminated.

Streams and rivers carry the nitrate to lakes and coastal areas, and in some countries to canals, as in the Netherlands (24). Here nitrate concentrations have a strong positive relationship with runoff rates, and the peaks tend to occur from late autumn to early spring (25); here of course rainfall is a very important factor.

The concentrations of nitrate in waters are however increasing. In Denmark the annual transport rate of nitrate-N increased two-fold over a period of slightly less than 20 years (26). In the U.K. there has been a steep increase registered after 1960 and increases have occured at all sampling sites, roughly a doubling of concentrations over the last 20 years (27). In addition the eventual discharge of an aquifer to a river means that river concentrations are influenced by (a) a rapid loss of nitrate from the soil zone caused by runoff and (b) a slow loss of nitrate from the soil zone caused by groundwater. For those countries/regions taking their water supply from rivers, pollution is a very important consideration. Farmers may even subject their cattle and land to excess nitrate if they take water from local contaminated streams or rivers or canals, or if they use such water to irrigate their land.

Drainage and Irrigation

Drainage is also an important factor in influencing runoff. The expansion of cropland and the intensification of crop production has been accompanied by improved under-draining of the land. Whether or not drainage encourages nitrate leaching - as stated in the OECD report (28) - efficient drainage is likely to divert nitrate from the groundwater to surface waters, while bad drainage is likely to increase leaching. In the U.K. around 50% of land is drained (29), and a major part lies over the area of contaminated groundwater. Test in the U.K. show that there were serious losses of N applied to grassland, and these were increased by raising the N application rate, but decreased by re-seeding (30).

This however is not to say that drainage increases or is the cause of nitrate leaching, but bad drainage might well be. Opinion has been expressed on the contrary that drainage can yield a net conservation benefit, reducing the fertilizer rate needed and improving crop response (31). Also, experiments carried out have indicated that a change in land use, i.e. from grass to arable, may be more significant in relation to the quantity of nitrate leached than drainage itself (32).

Irrigation in the Community has also increased enormously in order that output can be increased, but over irrigation can seriously increase nitrate leaching, and irrigation has generally been correlated with higher fertilisation rates. As a result higher leaching has often been the case (33).

Leaching to Groundwater

Nitrate loss from the soils take place through direct leaching, thus contaminating aquifers holding the groundwater from which drinking water is supplied. Groundwater has several advantages over surface water as a source for drinking water. These include :

(1) It is relatively free of pathogenic organisms and purification for domestic or industrial use is not normally necessary;

(2) the temperature is nearly constant, which is advantageous if the water is used for heat exchanges;

(3) it is generally free of turbidity and colour, and its chemical composition is usually constant;

(4) groundwaters are not seriously affected by short droughts;

(5) most groundwaters have not been affected by radiochemical and biological contamination;

and

(6) groundwater is available in many areas that do not have dependable surface water supplies, since the groundwater has been stored by nature through many years of recharge.

See Figure 8.

Now it appears that these groundwater sources are in danger of pollution due to nitrate, to a level where expensive water treatment is necessary or new sources have to be discovered. There is still a lot of controversy over the source(s) of pollution, since complex factors influence the amount of nitrate that is available to leach. It appears however that as nitrogen fertilizer use has increased, so too has the nitrate content of groundwaters. There is evidence to show that there is a very close relationship between intensive farming practices and high rates of nitrate losses to groundwater. Concentration in excess of 100mg N/l were widely encountered in unsaturated zone pore-waters in the U.K. beneath arable fields, suggesting leaching loss in excess of 50 kg N/ha per annum (34). While much lower nitrate concentrations are characteristic of unsaturated zone profiles beneath permanent grassland, initially up to 200 kg N/ha per annum of nitrate may be released from chalk soils following the ploughing up of pastureland (35).

Ever since 1968 when concern was expressed about fertilizers being serious pollutants of the environment (36), various scientists have tackled the problem of N loss from the soil with special regard for N fertilizers, since improved soil fertility by the latter means increased soil N levels and a greater potential for nitrate to escape and to eventually trickle down to the aquifer and pollute the groundwater held in the aquifer. It must be said that while N fertilizers are likely to be the main culprits in contaminating groundwater supplies, the complex relationship between the soil organic N pool and the soil inorganic N pool is not yet fully understood, nor are the various interacting relationships between N fertilizers, nitrate from rainfall and the effect of farmyard manure especially slurry, the soil N itself and farm management generally, and where one can apportion blame. Rainfall carries nitrate and also provides the recharge of the aquifer, and the natural transformation of nitrogen to nitrate adds to the available nitrate for leaching, while animal wastes too, spread on the land, contribute to the nitrate available for leaching.

Denitrification and Ammonia Volatilisation

It is possible that one might have seen a rising trend - but of a much lesser degree - in the nitrate content of ground- and surface waters any way, if no N fertilisers had been applied. On the other hand, denitrification and ammonia volatilisation may have been able to reduce the nitrate available for leaching in the soil, in the unsaturated and saturated zones of aquifers, in streams, in lakes, in canals, in rivers and coastal waters to result in hardly any increase at all for nitrate levels and eutrophication.

Not enough is known also about the reduction processes that affect nitrate, both in the soil and on its way to the aquifer and in the groundwater and other waters generally. Ammonia volatilisation may in fact add considerably to the N content of the soil (37), and not enough is known about the role of denitrification in the soil and vis-à-vis aquifers. Much of Denmark's groundwater nitrate concentrations have remained low (up to now) in spite of high nitrate inputs at the surface and relatively short transport times to the aquifer, and the reason may be due to the damp clayey soils, chemically and microbiologically (38). However for other soils and other aquifers and conditions, denitrification may negligible, and it may be the case that this natural protection of groundwater may not hold if percolation by water with a high content of NO_3 takes place, thus suppressing any beneficial effects of denitrification in underground layers (39).

Nevertheless N fertilizers have been applied in increasing amounts and at at the same time nitrate levels in ground- and surface waters have been rising, especially in intensive agricultural areas, where up to 50% of N applied to arable land is not recovered (40).

Nitrate Movement to Aquifers

Various experiments have been carried out to discover how and to what extent nitrates move from the soil profile down to the aquifer, but this in itself is no easy task. The passage of nitrates will be a function of several factors. These include:

(1) the type of farming activity practised in the area, - arable or grass, inefficient or efficient drainage, the previous crop grown;

(2) the applications of organic and inorganic fertilizers, especially the timing of such applications;

(3) the weather conditions in the area, especially rainfall which will affect the recharge of the aquifer;

(4) the texture of the soil profile, including temperature, humus content, acidity, whether light sandy or heavy clayey soils;

(5) the nature of the soil organic N pool and the soil inorganic N pool and the degree of denitrification and volatilisation;

(6) the depth of the water table;

and

(7) the nature of the aquifer itself - its geological and hydrological make-up, including its permeability and the denitrification factor.

The hydrological character of the aquifer will be quite important since its permeability will dictate the passage of the recharge and thus the nitrate passage See figure 9. If there is a predominantly fissure flow of recharge, ie where the water can enter via various fissures and cracks, the recharge process will be relatively fast, perhaps taking a year. If there is an intergranular displacement movement as the agent of recharge, i.e. where water moves and seeps around the rock structure, such example is that of water flowing around a cluster of snooker balls, then the recharge process will be relatively slow, perhaps up to 50 years. In sandstone aquifers travel times can be less than one year from the soil zone to the saturated zone of the aquifer, even where the water table is relatively deep. But for chalk aquifers the average rate of travel is much slower, around one metre a year (41).

Time Bomb Effect

A time delay of decades before some aquifers are affected by nitrate release from the surface, means that banning N fertilizers and taking action on manure now, will not prevent the damage presented by the nitrates that are slowly trickling down. The nitrates released from ploughing up land during and after the Second World War in the U.K. are only just reaching the aquifers (42), causing nitrate levels to rise in some parts of the country. Since more N fertilizers are being applied, and in the eyes of the Royal Commission in the U.K. no plateau is in sight (43), future water supplies are likely to be heavily contaminated by those fertilizers applied since the Second World War, and will have to be treated for human consumption or shut down by the water authorities responsible. The time-bomb effect seems unavoidable, but for future generations, influencing and managing the N input today, will affect the amount of nitrate available for leaching and thus reduce contamination levels tomorrow.

While it is very difficult indeed to do tests and experiments to establish leaching rates and discover soil properties, I.Burns and D.Greenwood write that it is quite impractical to carry out experiments to cover more than a minute proportion of soil, crop and weather conditions to obtain information about leaching, and that much uncertainty still exists about the importance of leaching on the nitrogen economy of soils both within and between regions of most countries (44). But the farmer will need to know how to manage his nitrogen input economically and safely in order to prevent leaching in the near and far future.

Remarks on Nitrogen Losses

Some general observations can be made about nitrate losses. For instance, heaviest losses generally occur during the late autumn, winter and early spring (45), especially when there are no crops to mop up the excess nitrate in the soil after a leguminous crop. Losses will be much larger for lighter sandy soils than for heavier clay soils (46). Underdrainage of the land can divert nitrates on their way to the groundwater to streams and rivers instead (47). Losses are smaller from grassland than from arable land, but heavily stocked grassland can increase leaching, while ploughed up grassland will also release nitrate which is then open to leaching.

Rainfall is also an important factor, very often unpredictable. It causes damage by washing away nutrients where exceptional conditions obtain (48), or causes 'nitrate peaking' after a very dry summer (1975) (49). Heavy rainfall or little rainfall can be an advantage, as in Ireland, Greece and southern Italy, where either high rainfall levels dilute nitrate levels to a safe degree, or where there is not enough rainfall to carry away the nutrients (50).

The Union of the Water Supply Associations from the countries of the European Communities carried out a survey on the problem of nitrates, and have summerized the situation in the Community (51). Belgium, Denmark, France, the Netherlands and the U.K. all have increases of nitrate levels in water sources which are to be found under areas of intensive agricultural activity. For example:-

(1) The nitrate content of the groundwater in the agricultural zones, south of Brussels is steadily increasing (52);

(2) opinions in Denmark have centred around the applications of fertilizer in agriculture, especially animal manure (53);

(3) in France waters having a high nitrate content are predominately in the north and the west of the country which is intensive farming country (54);

(4) in West Germany the increase in nitrate and supply systems affected by high concentrations were more frequently in rural units; concentration in groundwaters is a consequence of the increased application of fertilizer by means of mineral fertilizer (400% increase) and farm-produced fertilizers (150% increase since 1950) (55);

(5) in Luxembourg some wells situated in agricultural areas, the nitrate content is steadily increasing (56);

(6) in the Netherlands, pig slurry is considered the main cause of groundwater contamination, from which 66% of the drinking water is derived from groundwater (57);

(7) in the U.K. 30% of the water supply comes from groundwater, and the report indicates that only nitrate arising from agriculture is only due in part to the application of fertilizers, ploughing of grassland is also an important factor; rivers in the U.K. in Central and South East England have an upward trend in nitrate concentration, and this also applies to groundwater (58a).

Most of the nitrate leaching takes place in predominantly arable areas of the Community. Figure 24 shows on a map the concentrations of arable land in the Community, areas which correspond with available evidence of areas with high levels of nitrate concentrations. In addition, the authors in one Commission publication identify areas of possible surplus nitrogen from farm manure due to high stocking rates (58b). Many of the possible problem zones overlap with predominantly arable areas given in figure 24. Thus, according to the maps, utilised agricultural land receiving both animal excretment and nitrogen fertilizers would certainly result in excessive nitrogen in the soil and for the plant, thus increasing the risk of leaching.

Sources

It is however very difficult to predict the loss of nitrate and other nutrients from the land as well as attempting to determine how much was lost from what source. In Belgium the main sources appear to be attributed to a geochemical origin and/or increased organic loading (59) - the average N fertilizer rate for Belgium and Luxembourg is 129.45 kg N/ha (60); in Denmark there were different sources but attention has focused on N fertilizer (61).

In France N fertilizers, present farming practices (62), in Germany, fertilizers and farm-produced fertilizers; farming activities generally in Luxembourg (63); in the Netherlands pig slurry is seen as the main cause - N fertilizer application in 1982 was 244 kg N/ha (64); and in the U.K., not only fertilizers are to blame but also ploughing of grassland (65).

Tests and Models

Meanwhile the existence of tests and of models to predict vertical flows, groundwater flows and catchment areas and so on (66), are very useful to show that N fertilizers indeed are or are not the main culpits and if not what is, and also in identifying water sources at risk so that appropriate action may be taken. At the moment the experimental basis for assumptions of mobile nitrogen (natural or artifical) are clearly somewhat limited, but the models established, however crude can be improved and developed to take into account the complex variables involved. These include the development of a soil leaching model on a monthly or weekly time scale in order to predict seasonal fluctuations in surface water nitrogen levels; the development of more realistic aquifer quality models (67); and models with regard to input from soil leaching, bacteriological denitrification, dispersion in the unsaturated zone and nitrate stratification in the saturated zone (68). But without adequate accurate data, sophisticated modells will be worthless.

Eutrophication

Surface runoff will result in nutrients - nitrate and phosphorus - being washed off the land to streams and rivers, with a percentage coming to rest in sluggish or still waters, such as in slow-flowing rivers, man-made reservoirs, lakes, canals and some coastal waters. This may also take place due to nitrate contaminated groundwater discharges. These nutrients are taken up by algae and aquatic plants which then grow to an excessive degree; this process - the enrichment of the water by nutrients, is called eutrophication. The growth of algae and other plants cut off the light from aquatic vegetation which then dies. The dead vegetation removes the oxygen from the water and together with the elimination of food sources, and this can lead to a decline and a possible disappearance of fish and other living creatures. The body of water then becomes lifeless and stinks. However it must be noted that in freshwater it is usually phosphorus not nitrogen that limits eutrophication, but in seawater it is usually nitrogen (69). Much more research is needed though on nutrient limitation to tackle this major scientific problem of great sociological and ecological relevance.

Under exceptional circumstances large quantities of fish can suffocate from the lack of oxygen. This was the case in 1981 in Danish coastal waters, from Skagen to Flensbergen on the West German coastline. Apparently meteorological conditions had triggered off the events, but the real cause was to be found in the rising pollution of the sea with nutrients, primarily nitrogen compounds (70), and such nitrogen domestic losses play a dominating role in the eutrophication problem, according to H. Schroder (71). In 1981 there were massive mortalities of fish and benthic organisms on Sweden's west coast, in Laholms bay. The cause suggested was one of runoff of agricultural wastes into a partly enclosed bay (72).

Phosphorus

Phosphorus is also important in influencing the growth of algae, not just nitrogen. Phosphorus is not transported to groundwater since it is rarely leached through the soil but instead is washed from the surface (73). The Italien Adriatic coastline has been experiencing eutrophication, due not so much to agricultural runoff, but to the increased phosphorus discharge by households into rivers discharging into the Adriatic (74). However in the Swedish case, nitrogen was suggested on the main culpit, and in addition it was claimed that Swedish farmers use such large amounts of nitrate and phosphorus fertilizers that even if they stopped using them, there is a sufficient amount left in the soil to last two seasons. This presumably applies to other countries as well (75). There is now a tax on fertilizers in Sweden, partly due to environmental reasons (76).

Cross-Frontier Pollution

An added difficulty in the Swedish case was that the pollution source was found to be a cross-frontier source not only from Sweden but other countries in the northern and central part of Europe; the extent of the sources have not yet been determined. It may also be the case that the pollution of groundwater may come from agricultural sources outside the country in question. This may take place as aquifers polluted in one country transport nitrate contamined water across border zones - this may of course take decades - where it may be then used as a water source. This feature of cross-frontier pollution is likely to be very difficult to substantiate, but it is possible since groundwater flow may be identified. More investigation is needed on this topic.

Effects on Tourism and Recreation

Eutrophication can not only have adverse effects on fish and aquatic life generally, but can also affect recreation and amenity, as in the Norfolk Broads in the U.K., in Lake Maggiore in Italy, Lake Mjosu in Norway and in the canals and polders of the Netherlands. In the Norfolk Broads, addition factors such as the impact of the heavy exploitation for tourism and recreation, and phosphorus levels in the water due to the large amounts of sewage effluent entering the Broads (77), were important besides the impact of intensive farming practices. In Lake Mjosu, the lake was in danger of becoming completely dead and a large campaign was organised to reduce discharges not only from agriculture but also from households and industry; within a period of three years the Mjosu returned to its unpolluted state (78). Holland has problems with excessive eutrophication in its urban canals, which act as a significant sink for many pollutants, including those from agriculture. Urban pollution plays a more dominant role, but whatever the extent of the source is, the canals function for recreation - fishing, boating, swimming and a habitat for aquatic life, is upset (79).

Water Treatment

According to the mandatory Council Directive 80/778/EEC, drinking water may not contain more than a maximum of 50mg N/l. Derogations may be applied for under the directive which are not given automatically; permission may be granted if there is no public health hazard, however, member states have had five years notice of this directive in order to comply with the new levels. Action taken by the water authorities include several alternatives. However any alternative will mean an extra burden for the consumer and water rate payer, whether it consists of increased co-operation between regional water authorities and between national authorities on an international level, or building plants to treat contaminated water and/or supply bottled to infants in dangered areas. Strategies will also depend on adequate information on existing nitrate concentrations and on comprehensive monitoring, modelling and forecasting of concentrations for all water sources.

Water Management Measures

A usual practice for water authorities is to blend high nitrate waters with low nitrate water reserves or, since reserves may only be replenished once a year, promote the search for new sources of water, by sinking new wells in low-nitrate groundwater areas, or deeper wells in existing high-nitrate areas. This goes hand in hand with optimising the use of existing sources. Blending however may result in the distribution of nitrate contaminated water just below the maximum permissible level all the year round - which in practice is frequently the case (82). It may also result in discouraging longer-term measures aimed at replacing the lower quality sources. Bottled water for infants may avert the risk of methaemoglobinaemia but it appears unfeasible to supply large sections of the population with such a service. The Royal Commission report noted that it would be virtually impossible to undertake a supply of bottled water low in nitrate to all bottle-fed infants in London (estimated 50,000 infants) with a high degree of certainty (83).

Conventional drinking water treatment processes remove practically no nitrate and such processes that exist have not really reached full scale operational level. The more sophisticated technological measures include physical or chemical treatment processes:-

(a) reverse osmosis
(b) ion-charge process
(c) electro-dialysis

and biological processes:-

(1) autotrophic denitrification
(2) heterotrophic denitrification
(3) assimilation by higher plant species. (84).

See Table 12 for non-agricultural practices for nitrate pollution control.

One system replaces nitrate with bicarbonate ions, which are the main constitutent of sparkling mineral waters, like Perrier*. The end product is drinking water not only suitable for babies but with the slightest of fizzes, with no waste to dispose of, as there is replacing the nitrate ions with chloride ions (85). Costs are however high, up to 5,8623 ecus (86) for an apparatus to purify 75 m^3 an hour. The Dutch are likely to have to treat 100 million m^3 groundwater a year, and while the cost of drinking water will go up, it is cheaper than finding alternative supplies to drink (87). In Britain the ultimate cost could be 10 times the Dutch.

It is estimated that if all water sources in the UK exceeding 50 mg N/l were treated by the use of an ion-exchange process, the total capital cost would be around 72.4 million ecus ** and the annual running costs around 24 million ecus **. If there was an occasional treatment of sources, the capital cost would double to around 144.8 million ecus ** and running costs would increase to around 32.2 million ecus ** per year (88). In Germany initial investment costs would range from 489,156 ecus per 100 m^3 if the necessary equipment could be fitted into an already existing water treatment plant; up to 2.4 million ecus per 100m^3 if an entire installation has to be built with average variable costs around 0.147 to 0.269 ecus/m^3 for a reduction from 100 mg N/l to 50 mg N/l over a depreciation period of 20 years (89). Further research is needed though to establish the real costs and benefits of priorities concerning water treatment control outside the agricultural domain, and then to compare these costs and benefits with the impact of any agricultural measures.

Such costs are substantial; the Fertilizer Manufacturers Association say that there is a lack of evidence justifying the new limits set by the Community (90), even though the limit is now Community law which has to be upheld, while the recommended limit of the WHO is below the Community one. Meanwhile steps should also be taken to reduce the impact of agricultural practices, particularly the use of nitrogenous fertilizers, on nitrate levels in water. Although opinion is in favour of more efficient applications of N fertilizers, the Royal Commission in the U.K. feels that it would be more cost-effective for water authorities to install plant for nitrate removed than to impose restrictions on fertilizer use (91). It is likely however that such investment will be needed, but as regards future nitrate levels in water sources, something has to be done about agricultural practices and especially N fertilizers. This problem will be looked at more closely in part IV.

Nitrate and the Farmer

Farmers apply N fertilizers to supply nutrients to the plants with the aim of increasing total biological production per hectare of land. However the uptake of nitrogen fertilizer is not efficient since the farmer on arable land may lose up to 50% (92) of the nitrate applied due to leaching, surface runoff, immobilisation in the soil, denitrification and ammonia volatilisation.

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* For comparision, the nitrate content of sparkling mineral water is 1.9mg/l for Spa Reine and for Evian 3.8mg nitrates/l.

** 1976 Values.

The Percentage of Fertilizer lost

There is still a lot of controversy though over how much of the N applied as fertilizer is leached from the soil to the water supplies, and how much is lost due to other factors. The F.M.A. quote the Royal Commission Report * as saying that around 5% to 10% of fertilizer applied could be lost by leaching into water supplies (93), around 30% of the total nitrate leached from the land. In the light of other sources, this figure is likely to be higher. One Danish report (94) gives an average leaching value for the country as around 35% from an average application of 53 kg N/ha which has been modelled from actual figures; while an earlier report, the Danish NPO report gave fertilizer as constituting 59% of the input per hectare, with 24% of the output being leached, with around 68% no longer available to the farmer (95).

A French report gives N fertilizers as accounting for nearly 40% of the input per hectare, with 22% of the total input lost to drainage, while a Belgian paper gave Dutch figures which showed that for a 100kg of nitrogen applied, 20kg was lost to drainage water and 20kg leached out (96). In the U.K., the Farmers' Weekly gave rape as an example, where 275 kg N fertilizer/ha was applied, and 64% was not recovered in the crop (97); the Royal Society Report gives N fertilizers as 43% of the input to agricultural land in 1978, with leaching as 12% of the output, and livestock excreta accounting for 38% of the input and 20% of the output, through volatilisation (98). The WPC journal gives an approximate figure of 33% of N fertilizers that is lost on average by leaching (99).

What ever the dispute about the leaching percentage of N fertilizers, agriculture generally has been using the available N input inefficiently. In 1950 the total N input for Danish agriculture was 102 kg N/ha, with a loss to the environment of 83 kg N/ha; in 1980, the total input was 217 kg N/ha and a loss of N to the environment of 187 kg N/ha, a loss of 81% and 86% respectively (100). See Figure 26 for Denmark in 1950 and in 1980. In 1978, total N input to U.K. agricultural land was 2668 Kt, but a loss of 1301 Kt not to recovered by the farmer, around 49% (101). In France input totalled 7.45 mt, while losses amounted to 4.93 mt, around a loss of 66% (102). In all case, N fertilizers were a major input, along with farmyard manure. The farmer has a vested interest in using or affecting what ever inputs there are to his best advantage, aided by agricultural services, governments, the Community and the fertilizer manufacturers.

Costs for the Farmer

Farmers in Ireland spend around 87.5 million ecus each year on N fertilizers, and a loss of 10% would be around 8.75 million ecus, while the NPO figure of 24% would cost 21 million ecus (103). If a figure of 10% loss for the Ten is taken in 1982, then 7937.787 Kt out of a total of 7937787 Mt consumed would not have been available for crop uptake, a cost of over 550.4 million ecus (104). In the U.K., during the 1970's, in the arable land of the aquifer outcrops of Eastern England alone, 80 kg N/ha, worth over 9 million ecus could have been lost annually by leaching (105).

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* About 5% if the best conditions for efficient uptake exist, p.107.

As far as cereals are concerned, careful overall fertilizer management may not be enough to compensate for reduced N fertilizer use. The use of annual crops with a short vegetative period e.g. barley, will often lead to substantial leaching of nitrate especially on light sandy soils. Farmers are likely then to see reduced profits from their cereal crops rather then on the milk and meat production side if incomes are not supplemented from other sources. De Haen in his article (106) includes a rough comparative static estimate to give an idea of income losses involved for barley and maize on light sand or moderately light silty soils, which leach the most nitrate.

He also provides calculations for the amount of NO_3-leaching, where a N fertilizer application rate of 50 kg/ha would result in 45 mg NO_3-/l, which with a persistence rate of 50% results in nitrate contamination of 22.5 mg NO_3-/l in groundwater; or with an application rate of 150 kg N/ha, a leaching of 100mg and a contamination rate of 50%, results in a contamination level of 50 mg NO_3-/l in groundwater, the mandatory limit bid down by the Community.

Using German fertilizer response functions for barley and maize under average crop rotations (107), yield and income reductions were derived. For barley there was a 3.3% yield reduction and the costs of realizing this reduction, defined as reduced profit was 81.93 ecus/ha; for maize the reductions were 20% and 130.36 ecus/ha (108) respectively. J.Agapitidis in his report (109), has plotted the yield and anticipated leachate based on N fertilizer application rates advised by member states, in order that the limits laid down by the directive would be complied with. For grains like wheat and barley, no or small reductions would be required - given the same growth conditions - , but taking cereals together, adjustments and losses may well amount to a considerable share of total gross margins, as in the case of maize.

This is the type of range of income losses if the 50 mg/l standard were to be met under certain circumstances and if no other action was taken by the farmer to improve the N content of his soil. The above calculations have to be interpreted as examples, but they are important since they underline the need to take into account farm income effects when policies affecting N fertilizer are considered.

If N fertilizer management could be improved to the point where minimum loss is suffered, then it is likely that a farmer's income can remain the same. If however cuts in application rates are imposed without any extra measures taken by the farmer, then his income will decline. Without a doubt, productivity would be greatly reduced if N fertilizer use were to be drastically reduced. An average yield for wheat in the U.K. of 1.9 tonnes per hectare, without N fertilizer - organic farming -, compares with 6.31 tonnes per hectare with an average dressing of 183kg N/ha, with perhaps some manure dressing (110). Of this 183kg, up to 50% and perhaps even more is open to loss, leaving around 90kg to be taken up by the plant. Experiments at Rothamsted in England have shown that a plot with no manure of fertilizer produces a yield each year of about 2.2 tonnes per hectare, indicating the soil's ability to keep on supplying a certain level of nutrients almost indefinetely (111).

With or Without Fertilizer

There have been other changes which have of course have allowed greater productivity, but it can be said that a farmer is dependant on the supply of nutrients to grow crops and thus an essential element influencing his income level. A farmer will, for example, not only apply N fertilizer to increase yields on suitable agricultural land, but also on land that is poor in nutrients and otherwise outside his grasp.

A farmer today is likely to make losses if he does not use N fertilizers. Once costs have been covered, applications thereafter up to the point where extra fertilizer costs are not matched by increases in revenue, will make the whole operation worthwhile. However the impact of the CAP is to allow the farmer to produce at a guaranteed market price, thus CAP subsidies and interventions have induced farmers to increase food production beyond the point of need where large surpluses mount up.

Thus reducing crop yields via less N fertilizer use would result in less surpluses than previously, less nitrate available for leaching, reduced costs of water treatment for future generations, and a reduction in entrophication where N is the limiting factor. On the other hand less N fertilizer used means a reduced income level for farmers, unless they are able to maintain yields via other methods; big farmers are likely to have an advantage over small farmers here, as they transform their N fertilizer management.

Moving to an extreme position, if no N fertilizers were applied and no other measures were taken, in general food prices would rise and/or food manufacturers would provide fewer extras/alternatives on supermarket shelves. In this case, the farmer may be compensated to some extent by the increase in prices, and possibly through other mechanisms, such as direct payments. The latter obviously depends on the political decision-making regarding the place of agriculture and food production in a government list of priorities. C.Taylor and K.Frohberg estimated that in a situation of high price flexibility for the U.S. cornbelt, farmers' incomes might even rise as a consequence of N restrictions (112).

The CAP and Nitrogen

Clearly the impact on both farmer and consumer will depend on the kind of instruments chosen to carry out nitrogen control policies and the market situation. In the case of the Community, political decisions determine the market situation and agricultural policy, and any steps at reducing surpluses, not only through N fertilizer policies will stumble over the farm household income problem. The CAP is not only an agricultural policy but also a regional and social policy, encouraging farmers to sell all they produce at a profitable price. This profitable price may be eroded by reductions in food production, entailing reductions in the use of N fertilizers, and vice versa, if no other compensatory mechanism is agreed to politically by the Community.

Any movement of farm prices to international levels by a reform of the CAP should lead to an increase in resource allocation. This together with the cost of nitrogen fertilizers, may then lead to a greater efficiency in N fertilizer management, thus helping to reduce nitrate losses. However at the moment, given the limited responsiveness of N fertilizer use to price changes (113), the reduction in N fertilizer use may not be large, but nevertheless it would be a step in the right direction.

The price mechanism cannot really be depended upon to produce desired results; other policies would have to encourage farmers to reduce N fertilizer use, if this is the desired aim, and different policies again would be needed to reduce food production, since a farmer may employ different methods to achieve similar yields such as careful timing of fertilizers, sowing legume crops, using fertilizers compatible with the crop and careful handling of manures and slurries. The success of alternative methods has already been witnessed in Brittany, where milk farmers have cut out N fertilizers and have put more clover in their seed mixes with large savings in fertilizer costs with no reduction in milk yield or stocking rate (114). If milk and meat farmers can be persuaded to switch to alternative methods, while there may be slight drops in yields, they may be more than compensately by savings in fertilizer use.

However the Community's milk quotas have ironically resulted in farmers buying more N fertilizers to improve their output by better grass management in order to save on expensive compound feeds. Farmers need to be very careful with their timing of fertilizer on grassland since this is essential for reducing leaching losses. See Part II p.15.

As nitrogen fertilization has increased, nitrate levels in water sources have also risen. The complex passage of nitrate in the soil to the ground water is not fully understood and more research and anaylsis is needed in order that the farmer with can be adequately advised on the management of his nitrogen input. Special account needs to be taken of the nitrogen content of the soil itself, so that the farmer can tap this source rather than apply excess inorganic chemical fertilizer or organic manure. No matter what disagreement there is over nitrogen losses and application and the damage involved, the farmer is seeing a large part of his valuable input not being realised in his crop, which directly or indirectly constitutes his income.

The real factor influencing nitrogen use as far as agriculture is concerned, is the CAP policy itself. A changing CAP, including questions such as the regeneration of rural communities; fair income levels for the farmer; the role of the real market in determining prices; greatly reduced surpluses but at the same time guaranteed supplies; less intensive agricultural practices; released agricultural land for recreation, wildlife preservation, energy crops and tree crops for timber, as well as developing environmental aspects within the CAP, will all influence the nitrogen input. A fertilizer policy of some kind, whether of a "softly-softly" nature or of a mandatory nature, is needed, for both inorganic and organic inputs, but such a policy needs to be developed in tandem with other aspects of the CAP, and on its own will not solve the problems of surpluses or farmers' incomes in the Community today.

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Part IV

Recommendations and Policy Options

The future of the Common Agricultural Policy is likely to determine any adopted nitrogen fertilizer policy; on the other hand fertilizers themselves cannot be looked at in isolation from other factors. Manure, slurry, compost, new varieties of crops, energy crops, farm management and new technology, will also play their various roles in shaping the agriculture to come. It is important however that some form of policy must be adopted to tackle the problems of over-fertilization, but in the meantime there are several recommendations that could be usefully employed by the farming community with increased savings rather than costs. They would result in a more efficient agriculture, a more environmentally sensitive agriculture and less contamination for the future. These recommendations, both for agriculture on the farm and off the farm, will be looked at first, and afterwards various policy options will be examined.

Recommendations for Agriculture on the Farm

The farmer can take immediate steps to change his farming practice in order to match nitrogen to his crops and to take into account water supplies and the surrounding environment. A farmer can not prevent some leaching but he can prevent a lot. He can do this through his fertilizer management, both organic and inorganic, and through his farm management generally.

Dressing and Application Methods

Farmers using split dressings of N fertilizer help tailor the supply of nitrogen to meet the requirements of crops without creating an unnecessary surplus which then may end up in the ground- and surface waters. A little at a time and not all at one go, perhaps three four times, especially on those soils which are most susceptible to nitrate leaching, will allow crops the chance to take up the nitrates and reduce the chances of losses. Methods of application are important: for example injected liquid/gaseous N fertilizers prevent erosion of the fertilizer from the surface and it may also prevent leaching by increasing N availability in the root zone and thus encouraging early uptake. In Denmark 70% of N fertilizer used is applied as anhydrous ammonia under pressure directly into the soil before sowing (1).

The Weather Factor

Another important factor will be the weather; applying N fertilizer when heavy rainfall is expected or when the ground is very wet, frozen or covered with snow, will increase the chances of nitrate loss via surface runoff and leaching to groundwater. In drought conditions N fertilizer on grassland can lie on the surface and not be washed in until it is too late in the season for the grass to absorb it. Then there is a high risk of nitrate being washed out in autumn rains. Thus a farmer needs as accurate weather forecasts as possible in order to apply nitrogen with a reasonable safety factor. A farmer can also reduce the loss of nitrogen via ammonia volatilisation by avoiding the use of ammonium salts on calcareous (lime) soils (2)).

Recommended Dressings

The farmer can also influence nitrate losses by following and not exceeding recommended crop dressings from various advisory services; more fertilizer is not better for the crop, the environment, for our health and certainly not for the farmers' pocket. These crop recommendations can be up-dated to take into account various factors such as the permeability of various soils and stages of fertilizer timing and so on.

Using the Nitrogen in the Soil

Another option open to the farmer is to incorporate the nitrogen availabile in the soil into his fertilizer management. Crops release nitrogen in the soil, varying of course from crop to crop, for example lucerne and old arable land, thus dressings should be adapted to changing soil conditions. For instance wheat grown after ploughing a good grazed ley may need no N fertilizer, while cereals following cereals on old arable land will need a supply of nutrients. For autumn sown crops the N already available in the soil and released by mineralisation, is usually enough for the autumn and the winter - when leaching occurs - , and thus no dressing will be needed at the time of sowing. Indeed advisory services in the U.K. think that more N is applied in cereal seed beds than economically justified (3). Then, as facilities are made available to farmers, for instance through test kits to assess the nutrient requirements of the land, including nitrogen, or through various local agricultural stations enabling analysis of soil and plant samples, the timing and amounts of N fertilizer could be improved more and more.

Using Manure

Farmyard manures are useful sources of nitrogen for the farmer if handled properly and carefully, since they release nitrates slowly and can prevent excess in the soil. This of course poses problems of storage, handling, transportation and application in accordance with crop requirements. Perhaps slurry could be produced in a more concentrated form, by improving the catchment area in the pig house and cow house, and dilution prevented by storage away from the rain and runoff water. This would improve the value of slurry for the farmer and a pellet form could make transport and storage very easy.

Manure storage facilities with impermeable material underneath and protected as much as possible to prevent ammonia volatilisation, will also prevent losses. A farmer can also change the nutrient values of slurry, by adapting animal feed composition to reduce phosphorus content as took place in the Netherlands (4). This could also reduce eutrophication in areas where waterbodies are filling with algae, since phosphorus is the limiting factor in fresh water. Odour is often a nuisance but studies have already been carried out on this problem (5).

Most of the advice concerning the application of nitrogen fertilizers apply to manure and slurry, except that whenever possible they should be ploughed into the soil as soon as they are spread ; this helps to prevent ammonia volatilisation and odour emission (6a), but there are be other drawbacks such as too much concentrated slurry in one place and the very large degree of traction power needed in the operation. Of course the farmer may find himself having to limit the size of his livestock enterprise according to the law, based on criteria such as the size of his holdings, as is the case in Denmark.

If a farmer with a large supply of manure and slurry finds that all of it is too much for soil and crop needs, perhaps he may be able to deposit it at special manure and slurry " banks " in his local area, so that other farmers can use it. This means of course investment in such facilities, but the manure bank idea is already in action in the Netherlands (7). Further more drastic measures could mean the limiting of cattle per hectare, as is the case in Denmark, and strict rules on the spreading of manures and slurry (8).

Farm Management and Nitrogen

A farmer can also influence the N content of his soil by his farm management generally, namely through green manuring, using clover in more grass leys, ploughing, catch crops, drainage and irrigation. A green manure grown through the winter, taking advantage of the nitrogen in the soil, can be ploughed in in the spring. This is also the idea of catch crops - such as grass, turnips, rapeseed; even winter wheat - sown after harvest to make use of mineralised nitrate from the previous crop. Fallow land will result in increased leaching, and catch crops can mean a cheap crop for the farmer because he needs less N fertilizer. Catch crops may not be easy to incorporate in some rotations and depend on local soil, climate and crop cycles.

By avoiding burying legumes through ploughing, the farmer can prevent excessive amounts of nitrate being leached out (9). Care needs to be taken with the ploughing in of any crop such as wheat stubble, since deep ploughing will speed up mineralisation of organic nitrogen from crop residues or from permanent or temporary grassland (10). Denitrification can be prevented by avoiding ploughing organic materials into wet soil that may become anaerobic, and careful cultivation to avoid compression of the soil in order to prevent it becoming anaerobic. Temporary grassland could be given longer periods in crop rotations, so that ploughing would be less frequent. Indeed, Mr. Archer a regional soil scientist of ADAS (U.K.), sees the three year arable and three year grass ley system as a "potential disaster", and in his view the monoculture approach offers better protection against the risk of water pollution (11). Such a move will mean a drastic change for traditional farm management.

Minimum cultivation techniques for crop sowing minimize sudden nitrate release and associated autumn and winter nitrate leaching. However these techniques brought on by the movement from energy intensive practices, such as direct drilling of seed into the stubble of the previous crop, can only be beneficial in terms of nitrate leaching if the fertilizer application is not increased; but in practice fertilizer application rates rise.

Drainage and Irrigation

High rates of water moving through the soil can increase leaching of available nitrate, and most farmers try to improve the drainage of their soils, especially heavy soils. Thus nitrate is directed away from groundwaters to surface waters; here investments in storage tanks for contaminated water could allow natural or perhaps chemically induced denitrification to take place over a period of time (6 months). This could be then discharged into a stream or river or be used as irrigation water.

Irrigation itself needs to be controlled in order to prevent too much water around the crop root zone and not allow a downward water movement. "Drip irrigation" systems have been already designed for horticultural crops which minimize wastage of water and leaching of fertilizer (12), and perhaps other systems could be developed.

Recommendations for Agriculture off the Farm

Fertilizer R & D

Researching and developing new fertilizers by the chemical industry, can help solve the problem of fertilizers releasing nutrients too fast for crops to use. Slow release fertilizers do exist, such as ammonia- treated vermiculite, which has performed well under trials (13). Synthetic urea is a potential slow release fertilizer if various inhibitors can be built into the product, and if the cost and efficiency can be improved. It may be also be possible to use slow release techniques in producing ammonium-containing fertilizers, so that plant needs can be matched more easily. Another possibility is to use nitrification inhibitors to improve recovery of mineralised organic N, where the nitrogen is held in the soil until crop uptake can make use of it. According to experiments carried out they could be of use in preventing losses of nitrate, particulary in situations where large amounts of N may be mineralised during autumn and would be liable to loss prior to crop uptake (14).

What is needed is a less soluble N fertilizer that can release nitrogen in amounts which can be taken up by the crops, and which is in balance with the N content of the soil and does not pollute the environment. However such R & D has not been carried out by the chemical industry as yet. However recent research by manufacturers has resulted in better fertilizer spreading equipment so that patchy crops, wasted fertilizer and financial losses (up to 14.21 ecus a hectare in the U.K.) can be avoided. An electronic device called the Amatron ensures that metering units in the spreader boom compensate for variations in the speed of the tractor; an application accuracy of 1% is claimed but at a cost of 852.25 ecus (15). This is an example of the type of research that can lead to a more efficient application of fertilizers.

Government and Community Action

Governments are in the position to take action on checking levels of nitrates in drinking water and in foodstuffs, especially vegetables, possibily introducing penalities where levels are considered too high. Also proposals could be introduced to stop tap water being supplied to infants up to a year old in endangered regions, and perhaps where feasible, supply bottled water. The Community could take more vigorous "environmental friendly" action on the structural side of the CAP, and as was mentioned in the Commission's 'Green Paper'. It could also encourage change in today's traditional nitrogen fertilizer and manure practices as new policy guidelines are drawn up.

New Technology

Biogas-technology could applied to the problem of the excessive supplies of manure and slurry through government and Community projects. Bio-gas is not in itself an answer to the problem of nitrates, since the waste after treatment, whether from farmyard manure or sewage sludge, still contains roughly the pre-treatment levels of nitrate. However the possibility of such energy processes on a viable scale, could encourage the building of manure banks at local levels, to ensure careful processing of manure and slurry containing nitrate. After use for energy processes, it could then be treated for agricultural use, once the high levels of nitrate have been reduced. Here the Community has a role to play in sponsoring new technology in agriculture, whether it be bio-gas or crops grown for energy.

R & D

Research projects could be set up to carry out research on technical issues and areas with a lack of precise information, sponsored both by the Community, member governments and the chemical industry. Such projects could include a better understanding and quantification of the N cycle; nitrate movement in soil and water; the leaching in the root zone, subsoil and the saturated and unsaturated parts of aquifers; the denitrification mechanisms; slow release fertilizers; biological N_2 fixation in crops; horticultural methods and plant varieties to produce vegetables of low nitrate content and a better evaluation of health risks, including any possible nitrate link with cancer. A list of possible areas for research is given in appendix 3.

For an overal view Table 13 shows the type of practices agriculture can engage itself in. Any of these measures and others could be incorporated into some form of policy statement, either as recommendations or mandatory rules, directly, once a decision has been taken politically by the member states to do something about environmental pollution by agriculture, or indirectly as decisions are taken about the future of the CAP. Various policy options are examined below.

Policy Options

Here various types of measures will be examined, such as persuasive steps, economic and financial measures and manadatory measures. The questions of compensation for the loss of income farmers may have to suffer and the principle of the Polluter Pays and its relationship with agriculture will looked at.

Persuasive Measures

A policy of persuasion and education, appealing to a farmer's pocket as well as his conscience, would take the first steps to control N pollution. A farming community aware that it is in its own interests and to the betterment of the environment to manage its nitrogen input more efficiently, thus limiting pollution effects on water quality and food quality, would be more ready to adapt than if it was faced with mandatory government or Community action. Such a policy would need to communicate effectively with the farmer on the best cultivation and husbandry practices, and be backed up with quantitative information and recommendations from advisory services.

These services could include the evaluation of the nutrient content of land, manures and so on, so that the farmer may progressively take steps to minimize nitrate pollution. Codes of Good Practice to prevent nitrate losses could be drawn up and effected through agricultural training and extension services to provide credibility and incentive in the eyes of the farmer. Here, a role by the manufacturers will be important as N fertilizers have to adapt to changing circumstances. Such codes will mean close co-operation between various experts, such as hydrologists, soil experts and environmental health experts. Such a policy can also be orientated towards endangered areas where environmental effects could then be given priority. Opposition will come from the manufacturing lobby as they see sales dwindling, and from the farming lobby as they see reduced incomes and perhaps lost livelihoods, even though farm efficiency and thus income may be improved through a change of fertilizer management and cropping pattern.

While such a policy cannot avoid a major discussion and likely disagreement between the main parties involved, and even though such a discussion is necessary, a "softly-softly" approach has a better chance of acceptance than an outright conflict from a policy laying down mandatory regulations and fines. Once the problem of nitrate pollution by agriculture is accepted by governments, a guideline policy can begin to lay the basis for further developments once discussed and agreed on by the participants. However the role played by the CAP will influence factors enormously.

Economic and Financial Measures

A policy aiming for a more direct impact on the origin of nitrate contamination is one composed of financial and market instruments. Charges and subsidies, the stick and the carrot, can change the market value of N fertilizer. Direct subsidies can be used to change N fertilizer management in areas with serious environmental problems. The main problem would be to find those enterprises causing the most serious problems, and to control the level, frequency and timing of nitrogen is likely to be very difficult if not impossible, but subsidies to encourage the use of green crops such as legumes may be successful. Costs would incur on the administrative side as well as on the general budget side, and thus subsidies are likely to be more attractive accompanying other policies, such as a tax on fertilizer and so on.

Tradable fertilizer rights (16), influencing the market for fertilizers may also be an option. Rights traded within a certain district could ensure an average per hectare level of nitrogen, hopefully, not exceeded by a large amount. Administrative costs would again occur, and an inter-regional trade in fertilizer rights might result in a concentration in those intensive farming areas where pollution is already a problem. On the other hand, fertilizer could be directed towards production processes with efficient N use.

A fiscal policy to levy a tax on fertilizers would affect farmers everywhere, even those who manage their N input efficiently. However the tax burden could be shifted slightly away from the farmers by taxing distribution outlets for selling too much N fertilizer, and even back to the manufacturer by setting levies on amounts over agreed production quotas, and reducing or taking away any tax relief on manufacturing components, even on the finished product. While quotas could be fixed, such interference in the free market may be very unattractive to some member states.

Taxation

In order to affect a farmer's responsiveness to fertilizers, given the low price of fertilizer vis-à-vis the price of the output, cereals for example, a tax on fertilizers would have to be rather high, thus penalising those farmers using fertilizers prudently as well low income farmers. Governments could perhaps agree to certain price levels for fertilizer in local markets where consumption is seen to be excessive, ensuring more expensive products rather than making the manufactures agree to lower prices as a way of subsidizing the farmers, which is what happens in Belgium at the moment (17). Recent estimates of elasticities of demand for N fertilizer price changes, based on the assumption of optimal adjustment, are as low as -0.1 to -0.16, depending on the kind of crop and the type of location (18).

V.Johansson produced results in Sweden showing that it would be necessary to raise the price of nitrogen by about 100% in order to reduce utilisation by about 30%, giving a tax of over 16.7 billion ecus; in order to reach the level of 50%, it would be necessary to raise the price on nitrogen by 400%, giving a tax corresponding to over 32.1 billion ecus. He notes that it would be possible to adjust the use of nitrogen with regard to environmental considerations without causing any serious problem concerning the supply of agricultural products. It was assumed that the revenue collected would be redistributed to farmers, for food subsidies and for financing exports of grain and other agricultural commodities (19). However the administrative problem of running such a system would hardly be possible to operate in Sweden, let alone in the European Communities. Sweden recently introduced a tax on fertilizers, but there is no available information at the present time on how such a tax is organised nor as regards the impact of such a policy.

Even if the farmer is aware of the polluting effect of nitrates, he will have little incentive to reduce its use, since the value of the extra crop produced is likely to exceed the cost of N fertilizers, which is a relatively modest factor in farming expenses compared with energy, manpower, equipment and so on. Such a policy is likely to result in bringing those in favour into direct conflict with those not in favour, principally: the chemical industry, those of the farming community, and those governments which for one reason or another, have decided against such a policy. Community action has already affected the agro-chemical industry, as farmers turn from expensive compound feeds to N fertilizers - ironically - in response to the fairly recent milk quotas. It is also likely that a considerable time lag will have passed before any policy is produced with the backing of the Community.

Compensation

While increasing the commercial price of N fertilizer, more efficient management and application of N fertilizer and a more economic use of available organic fertilizers may well take place, a crucial factor will be compensation for farmers who suffer a loss of income. Such farmers are likely to lose most on arable land, but on grassland, with careful management, there is likely to be savings for farmers in the majority of cases. Such a factor is likely to be a major stumbling block. If farmers are not to be compensated, since according to the "Polluter Pays principle" *, the farmers should indeed be the ones to pay, not the taxpayers as a whole - although the principle aim is the abatement of pollution, not the generation of revenue (20),- it brings in the whole future of the CAP. Will restrictions on N fertilizers be possible in order to reduce surpluses, while similar or somewhat lower price levels of the CAP are maintained, and a compensatory mechanism used to compensate farmers indirectly from loss of income ?; or will restrictions on N fertilizers be used as part of a new CAP policy, with more realistic market prices, very close or equal to international prices, while there is selective indirect support for certain groups of low income farmers and the majority of producers left to the forces of the open market ?

This is not a question that can be an answered here, but certainly any policy formulated on N fertilizers will play an important role in the overall policy of the CAP. Lower output prices will indeed encourage efficient resource allocation and result in a lower budget burden, but a price decline on its own would have to be fairly large to result in a sizable reduction in N fertilizer use, which would lead to sizeable income losses. Such a policy is unlikely to be considered on its own as an answer to nitrate pollution.

Mandatory Measures

A policy incorporating some or all of the above plus various other measures enforced by law, is likely to be the final alternative open to the Community once accepted politically by the member states. Measures could be incorporated in a Code of Good Practice introduced by the Community with mechanisms for checking and fining polluters and could include agricultural, water, health and environmental objectives and considerations. Such a code would require an enormous amount of input, since available information is not sufficient as to be acceptable to all parties, and such input would cost time as well as money, perhaps undesirable in view of present budgetary constraints and political difficulities. This policy could identify endangered areas and implement measures to prohibit highly-intensive N use, promote various soil management practices and cover crops to take up excess soil N in the winter, and set upper limits on the N fertilizer input per hectare in the light of the total N available.

A back-up policy would then be needed to resolve farm household income problems. Measures could be adopted in problem areas without penalizing the whole farming sector, but such a cost will be measured in the high degree of measurement and control. Such costs, due to monitoring water resources, possible endangered food stuffs and then fining those responsible will be

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* This will be looked at below.

difficult to relate to the origins of the pollution. Control may be feasible for surface waters but groundwaters are difficult to trace. On the whole however, farmers are likely to react and adjust their N fertilizer management accordingly, but reaction will depend on the number of check points, checking frequencies and the amount of the fine.

The Polluter Pays Principle

Once a policy decision has been taken to reduce N fertilizer use, there still would remain the question of compensating farmers for financial losses suffered. If farmers are to be compensated then the principle of the polluter must pay could not apply. Criticism may then come from industry where this principle is more rigidly applied, and perhaps from the Commission itself, since the Polluter Pays Principle is a part of its environmental policy. Protest may also be raised from that part of the chemical industry producing N fertilizers as they argue on the basis of lost production, higher costs and unavoidable job losses.

The environment is part of our heritage, but there is no market cost for its use; as production takes place waste disposal may sometimes pollute the environment at no cost to the producer, but costs are incurred by other users of the environment in terms of reduced amenities, degradation of natural resources, health risks and so on, as well as by taxpayers generally as governments pass measures to clean up the environment. This means that there is an inefficient allocation of resources, resulting in a market price which does not reflect the real cost of goods, to society's overall detriment.

If environmental costs were reflected in the price mechanism of a free market economy, then producers would be required to pay a charge close or equal to the environmental costs that result from production and are then likely to adjust their activities in order to reduce their costs, thus production, price and consumption levels will reflect the value of the food produced compared with the value society places on environmental resources, and this is the essence of the Polluter Pays Principle, one of the fundamentals of the Community's environmental policy.

The principle that the polluter has to pay has not yet been applied to agriculture in all cases, and such a move was voiced recently - at a workshop on the protection of groundwater from nitates sponsored by Commission at the beginning of July this year - that farmers should pay (21), and it was heard remarked that by compensating farmers for loss of income due to less intensive agriculture, is like paying a murderer not to kill you. Certain measures do exist in various member states and further measures are likely to be taken in the near future.

For example, in Lower Saxony, West Germany, inputs of manure per hectare of farmland are already restricted by local regulations (22); in Denmark rules have been laid down to govern the relationship between livestock and land at not more than two 'big' cattle per hectare, while other regulations govern the use of manure and slurry (23). The Dutch authorities are drafting legislation as regarding manure use in agriculture (24); and measures exist in the U.K.

where it is an offence to allow polluting material to enter water, for instance, the application of slurry on land near to a borehole or overlaying a shallow aquifer (25). In East Anglia, with 15% of the drinking water over the Community limit for nitrate content a study has been commissioned by the Department of the Environment which may lead to controls on nitrogen application (26).

It is virtually impossible to measure nitrate pollution per farm, and only real control can be exercised through fertilizing, organic and inorganic, and through farming practices generally. On the other hand a farmer will not always be able to control efficiently his nitrate losses; there is always going to be some degree of leaching and surface runoff, and thus the risk of unfair charges will remain. Once charged a farmer may try to pass the cost onto the the consumer by raising food prices. In the Community this is unlikely to happen since prices are determined politically. However there is a forced reduction in N fertilizer use, leading to then to reduced incomes in the farming community, the farming lobby as a group will exert considerable pressure in order to achieve some form of compensation.

Meanwhile measures need to be adopted so that initiative is provided for the farmer to diminish the pollution effect of his actions rather than to ignore the consequences of them. Also how governments decide to use any revenue from various fines and levies, will be important for the credibility of a combined agriculture-water-environment policy. Plans and guidelines will need to be drawn up in order to tackle the nitrate problem effectively.

While member states will of course implement such a policy, the Community itself can perhaps exercise an overall view so that Community objectives are upheld. It is not usual for the Community to involve itself in farm management, but some type of involvement will expand the Community's role in member states, possibly under the Guidance section of the CAP.

Whatever policy is adopted it is clear that something should be done by the main polluters as soon as possible in order to ensure minimum or at least reduced pollution for the future. The farmer, together with the advice and support of government and advisory agencies and the manufacturers, can limit N leaching considerable by changing his N fertilizer and manure management on arable and grassland. Indeed advisory agencies are already outlining the danger to farmers, as at the Irish Johnstown Cattle Research Centre in May this year on their open day. Hints on spreading were given as well as indicating the costs that could be saved and how pollution of water would otherwise be the result (27).

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(2) See Part II p.5.
(3) U.K. Government Response Paper, p.17.
(4) OECD Report 1983 p.64
(5) OECD Report 1983 p.65; also see ref.13 of Part II.
(6a) Farmers Weekly 16.08.85; OECD Report 1983 p.65.
(6b) E.Rordam Varesa Workshop paper; Danish Parliament Resolutions 31.05.85.
(7) P.Worthington WRC paper; A.Jongebreur p.329 in J.H.Voorburg.
(8) E.Rordam(DK) idem.
(9) C.Gude, EP Working Document I.
(10) C.Gude,C.Bourguignon, EP Working Document I.
(11) Farmers Weekly 5.04.85.
(12) OECD Report 1983 p.63.
(13) N.Scott et al p.253.
(14) G.Rodgers & J.Ashworth p.253.
(15) New Scientist 27.06.85., Sterling = 0.568166 ecus on 27.06.85.
(16) De Haen p.461.
(17) P.Worthington DG XI.
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(19) V.Johnsson; for Swedish tax proposal see Riksdag 1983/84 Vol.176; Swedish Krona = 6,70494 ecus on 14.09.83.
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(23) E.Rordam idem
(24) P.Worthington WRC paper.
(25) Ibid.
(26) Big Farming Weekly 9.05.85
(27) Farm & Food Research (IRL), June 1985 p.84.

Part V

Conclusions

The use of nitrogen fertilizers, let alone farmyard wastes, has various implications associated with the health of the population, in particular infants; for the state of the Community's drinking water resources, both now and in the future; for various foodstuffs, especially vegetables; and last but not least, for the efficiency, performance and reputation of agriculture generally. The enormous technical and productive progress that agriculture has made in Western Europe since the Second World War, has brought many results, both substantive and positive. It is also likely that the future will bring further changes in agriculture due to accelerating technical and economic factors. The role of energy crops and bio-technology will also have "profound implications for the production and utilisation of agriculture products in the Community and in the world at large".*

Agriculture's progress, both in the past and for the future, has had and will continue to have an impact on the surrounding environment and on the health of its customers. At the same time the Common Agricultural Policy has seen the accumulation of surpluses which remains a burden for the Community's taxpayers and a price support system which favours large farmers not small farmers.

The cost of the CAP for the Community can be measured mainly by the surpluses that have to be bought and then disposed, and the high food prices consumers face. There is however another cost, which is the hidden cost and damage that intensive agricultural practices do to water supplies, foodstuffs and the environment generally. The cause of the nitrate pollution, whether in groundwater or in lettuces, has been blamed time and time again on inorganic nitrate fertilizers and farmyard wastes.

The use of nitrogen for producing food is essential and most of this valuable commodity has been provided synthetically since the Second World War. Farmers under the CAP have used artifical fertilizers to grow as much as they can and are likely to continue to do so. The dangers of over-fertilization, either from chemical fertilizers or farmyard wastes, have not been recognised by all member states in the Community, nor by all farmers or their organisations. Some of the measures taken to date by a few countries go some way in tackling the problems of pollution. What is needed however is proper guidance at a Community level, given the importance of the agricultural sector and its relationships with other areas such as public health and the environment, and given that the Community has responsiblity for organising agricultural policy in twelve countries with a total population of over 300 million.

The Community has already managed to bring the question of some kind of nitrogen fertilizer policy into the limelight as the result of its Drinking Water Directive, in force since August of this year. Special treatment processes are needed to supply drinking water to consumers if the sources have

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* Green Paper "Perspectives for the CAP" July 1985.

levels over the 50mg N/l laid down by the Directive, unless derogations are applied for and given. The levels of nitrate in the Community's resources will increase in the future making some kind action necessary. At the moment the Commission is working on a proposal to include nitrate in a Council Directive - 80/68/EEC - on the protection of groundwater against certain dangerous substances, and here a response is called for from inside the CAP, since nitrogen fertilizers and farmyard manures are the main culprits.

It is the role of the Community to investigate areas where nitrogen, as a vital agricultural input, can be regulated in order to ensure a healthier agriculture and to safeguard foodstuffs and water resources. The Community needs to investigate the problem especially on the agricultural side to see what can and cannot be accomplished. The Community needs to promote awareness of this problem at various levels, not least the farmers', and to produce some proposals, after consultation with appropriate groups, so that the agricultural factor in the pollution equation is reduced. Questions of finance and penalities and implementation can be tackled once member states officially recognise the problems caused by intensive agriculture.

Expensive water treatment plants will be needed in the near future in order to comply with the Directive, but this is not to say that the continued use of massive inputs of nitrogen should go on because the polluted water will be treated any how, and when various alternative methods could be employed. On the other hand it should not mean an an about-turn for modern farming, but rather a more sensitive environmentally and efficiently based agriculture than before.

Organic Farming

Organic farming is nothing new, the Chinese discovered the secrets of organic farming by experience alone, and practised it for four millenia, maintaining an enormous population. This was done on land no better than elsewhere, without, until the last century, the use of artificial fertilizer or chemical biocides, and without having spoiled their land. This is not to say that modern agriculture should surrender all its facilities and capabilities, but that both previous and modern farming methods should be integrated, to produce an agriculture sensitive to the land as well as the grown crops. Organic farming on its own cannot supply society with the food needed, but if more research and ideas were put into the problem, supported and sponsored by governments, industry and Community, productivity could improved enormously.

Thus there should still be a place for organic farming in the Community's agriculture which should be encouraged rather than discouraged. Any movement in this direction should also be accompanied by the development of new ideas in order to put bio-technology to work, for example, using the available nitrogen in the soil to grow energy crops, or to give grants to those enterprises willing to change over from intensive farming methods to organic practices.

Farmers need to be aware of the problems nitrate causes, and environmental, water authority, agricultural and chemical manufacturer experts need to get together to provide advice and concrete action for the farmer on how best to change long established farming practices and habits, and how to handle his nitrogen input. If the political will can be found to help change present farming methods and to promote good farming practices for everyone, in the face of opposition, even if only reducing the use of N fertilizer or limiting livestock per hectare, then the first step will have been taken.

If nitrogen fertilizers are restricted in some way under the present CAP, then cereal farmers are likely to see reduced incomes even with careful nitrogen management, but dairy and cattle farmers, by utilising their nitrogen to the full, present income levels are likely to be maintained generally speaking. On the other hand, any loss of income on by farmers will always be contested by the interested parties and pressure will also come from the chemical industry, which will argue on the grounds of lost jobs, lost revenue and lost investment in the Community. Any decision taken will reflect the various pressure groups' interests, let alone those of the two new members. Thus the Community should be prepared to remedy these problems in the light of all the factors involved and not just a few. Any measures taken also need to be farsighted: if only half-hearted measures are adopted and implemented with no further ones being foreseen, then farmers may toughen their position even more as they see themselves being regulated in an uneven fashion.

The entry of two new member states will make progress slow, but a policy must start sometime and now is as good a time as any, especially as the Commission itself is reviewing the CAP, and its own Drinking Water Directive is having an impact on the problem. The Community has a duty and a right to act on the problems of over-fertilization which has effects both inside and outside agriculture. This means close co-operation between the Directorate Generals responsible in order to produce a policy. The policy should tackle all problems and pressure groups in order that agriculture in the Community may be a viable and <u>healthy</u> sector in the 21st century.

A nitrogen fertilizer policy on its own will not solve the problems of the surpluses nor income, and a tax by itself is unlikely to work especially when the tax needs to be at least 100%. However a tax may be politically more preferable since it is visible proof of government and/or Community action.

In respect of nitrogen fertilizers themselves, the first step should be one outlining the losses to the farming community resulting from their application, losses not only affecting the environment but also the <u>farmer's pocket</u>. A second step would identify those areas liable to result in losses - in descending order of loss - when over-fertilization takes place. The third step would then suggest to those farming areas various remedies and practices in order to reduce those losses.

A rationalized fertilizer input policy needs to be drawn up which will deal with <u>all</u> nutrient supply sources, water resources, health and the environment in one interlocking package. Society has after all only one " environment " which can supply man's needs; once man has taken a hand then it is liable to be abused, thus resulting in problems for future generations.

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APPENDIX I

METHAEMOGLOBINAEMIA

Oxygen is required by all human tissues, to enable them to combust the food materials brought to them by the blood and other body fluids. The oxygen is carried from the lungs by combining with haemoglobin in the red blood corpuscles to form oxyhaemoglobin: oxygen is released from this carrier in the tissues, & the desoxyhaemoglobin left behind is returned to the lungs for re-oxygenation. For the haemoglobin to be able to act as a carrier, the iron atom within the molecule has to be in the reduced (Fe II) state: if the iron atom becomes oxidised (Fe III), the pigment is converted into methaemoglobin, which cannot participate in oxygen transport. If sufficient methaemoglobin is present in the blood it produces clinical symptoms of oxygen starvation, the main characteristic being cyanosis, sometimes seen as a bluish discolouration of the lips. The condition is known as methaemoglobinaemia and, for the reasons we describe below, it is largely confined to infants in the first few months of life. Given recognition of the symptoms and appropriate treatment, recovery is rapid and complete.

Since haemoglobin is constantly exposed to oxidative stresses, small amounts of methaemoglobin are formed all the time. In the normal adult, these are efficiently reduced again in a reaction catalysed by an enzyme termed methaemoglobin reductase; however, this enzyme develops only gradually after birth. Any condition that favours the formation of methaemoglobin is thus likely to pose a threat to infants up to about 6 months old. An additional factor that exacerbates this hazard to infants is that about 80 per cent of the blood pigment of the new-born is in a form (foetal haemoglobin) peculiarly susceptible to oxidation; this form is only gradually replaced by the more oxidation-restistant adult variety.

Nitrate in itself is relatively non-toxic but, when ingested in food or water, it is partly reduced to nitrite by bacteria in the mouth and in the gut: nitrite is a powerful oxidising agent which is able to convert haemoglobin in the blood to methaemoglobin. The reduction of nitrate to nitrite may also occur to a relatively greater extent in infants than in healthy adults as infants tend to have less acid in their gastric juice; this allows nitrate-reducing bacteria to grow in the upper gastro-intestinal tract from which nitrite is absorbed. The effect is enhanced if the infant has an infection causing diarrhoea. Other factors that make infants more at risk are that they have a high fluid intake in relation to their body weight, and that the water used to make up proprietary baby foods may be decreased in volume by repeated boiling, so increasing nitrate concentrations *.

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*Source : The Royal Commission Report pp.87-88

NITRATE AND HUMAN CANCER

A potentially more worrying suggestion is that nitrate may be implicated in some forms of human cancer, especially gastric cancer, through the formation of chemical compounds of the classes known as N-nitrosamines and nitrosamides. These N-nitroso compounds, some of which are extremely powerful carcinogens in a variety of animal species, can arise from the interaction of nitrous acid with secondary and tertiary amines, amides, and certain other nitrogen-containing compounds. Nitrous acid is produced in the body from nitrites under acid conditions; amines and amides occur naturally in food. It is, therefore, important to establish whether material amounts of N-nitrosamines occur in food, or are produced under the conditions found in the body.

It has been reported that N-nitrosamines are widely distributed in the environment, though at extremely low levels. The development of sensitive analytical procedures, particularly the combined use of gas chromatography and mass spectrometry, has enabled these compounds to be detected also in many foddstuffs, particularly those rich in secondary amines (such as fish). The occurrence of N-nitroso compounds has been discussed at conferences sponsored by the International Agency for Research in Cancer (1).

In addition to the formation of nitrite from nitrate that occurs naturally in the body, nitrite is often added as such, as a preservative to bacon and to cheese, meat and fish products that are eaten without further cooking. Not only can this be aesthetically pleasing - the oxidation by nitrite of pigments in meats produces methaemoglobin, which imparts an attractive red colour to them - but it prevents the growth of bacteria that multiply in the absence of oxygen and release harmful toxins. In particular, nitrite inhibits the growth of Clostridium botulinus and the germination of its spores. This is important as the organism can cause botulism, a form of food poisoning that is often fatal.

Whatever the source of nitrite in the body, it will inevitably form nitrous acid under acid conditions such as exist in the stomach and that may arise in the urinary bladder if that is infected with bacteria. It is also possible that some biological process, the nature of which is not yet understood, may effect the interaction of nitrite with secondary amines under conditions of near neutrality. Indeed, there is evidence that traces of nitrosamines are excreted normally with the faeces; these are thought to be formed in the lower gastrointestinal tract (2).

The administration of N-nitroso compounds to experimental animals is known to result in the induction of cancers. There is also no doubt that N-nitrosomines can be detected in the stomachs of experimental animals that have been fed concurrently with certain amines and nitrite (3); furthermore, this feeding regime resulted in the induction of some tumours. However, the number of tumours dropped sharply as the doses of nitrite and amines were reduced and no tumours were induced when nitrate was used in place of nitrite. Nitrosamines have also been shown to be present in the urine of rats which had been fed the amine piperidine together with nitrate and in which bladder infections had been experimentally induced (4).

We may note here that some recent research in the USA (5) which involved the feeding to rats of large amounts of sodium nitrite in the absence of any added amines, has suggested that nitrite itself may be carcinogenic without the formation of nitrosamines. The report on this work emphasised that the data were only suggestive and that "the results do not permit assigning nitrite a proximate carcinogenic role".

There is no reason to doubt that N-nitroso compounds would be as carcinogenic to human tissues as they are to those of other animals. The question we have to ask is, therefore, whether the compounds are formed from components of the diet in sufficient amounts under conditions that obtain in normal life. That they can be produced in man was shown by examination of the blood before and after a meal that contained the appropriate constituents (6), and by examining the urine of patients with infected and uninfected bladders (7). In the first case, however, the amount was minute; while in the second, the relationship to bladder cancer depended on infestation with parasites that caused bilharzia, which introduces the additional factor of mechanial irritation. Neither of these studies can be regarded as establishing a causal link between nitrosamines and cancer in man *.

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*Source : The Royal Commission Report pp.90-91.

(1) (a) Bogovski P., Preussmann R; & Walker E. (Eds) 1972, N-nitroso compounds, analysis and formation, Proceedings of a Working Conference, Heidleburg 13-15 October 1971, International Agency for Research on Cancer (I.A.R.C.), Lyons.
    (b) Bogovski P. & Walker E. (Eds) 1974, N-nitroso compounds in the environment, Proceedings of a Working Conference, Lyons, 17-20 October 1973, I.A.R.C., Lyons.
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(2) Wang T. et al 1978, Volatile nitrosamines in human faeces, Nature 276, pp.280-281.
(3) Greenblatt M. & Mirvish S. 1973, Dose response studies with concurrent administration of piperazine and sodium nitrate to strain A mice, Journal of the National Cancer Institute 50, pp.119-124.
(4) Hawksworth G. & Hill M. 1974, The in-vivo formation of N-nitrosamines in rat bladder and their subsequent absorption, British Journal of Cancer, 28, pp.562-567.
(5) Newberne P. 1978, Final Report: Food and drugs Administration contract FDA 74-181, U.S. F.D.A., Washington; see also, idem 1979, Nitrite promotes lymphoma incidence in rats, Science 204, pp.1079-1081.
(6) Fine D. et al 1977, Formation in-vivo of volatile N-nitrosamines in man after ingestion of cooked bacon and spinach, Nature 265, pp.753-755.
(7) Hicks R. et al 1977, Demonstration of nitrosamines in human urine urine preliminary observations on a possible etiology for bladder cancer in association with urinary tract infections, Proceedings of the Royal Society of Medicine 70, pp.413-417.

APPENDIX II

QUOTATIONS ON AGRICULTURE AND THE ENVIRONMENT WITH REFERENCE TO FERTILIZERS

"The Rhine full of dead fish makes less impression on me than the fate of the little stream that rises here in this neighourhood: at first rapid-flowing and pure, then chocked with with algae that have outgrown their strength through fertilizers on the adjacent pastures".

NRC Handelsblad 5.01.71.

"To provide India with only half of the European nutritional level will need 50 times as much fertilizer, herbicide and insecticide as at present. Those who would like to practise this in the entire third world ought to consider that three-quarters of these substances eventually end up in the ocean, a deadly onslaught on the phytoplankton in the oceans, that performs photosynthesis there. Every attack on it is an attack on life in the sea, on the last extra food source that man has left".

Haagse Post, 25 November 1970.

"We must now admit that agriculture too has certain drawbacks from this point of view. The use of fertilizers, for instance, since a great deal - up to a half it has been asserted - finishes up with the ground water in ditch and pond, can lead to an excessively high salt content in the water. There may well in fact be something that can be done about it, for instance by producing less rapidly soluble nitrogen fertilizers".

19NU Vol.7 No.1.

"The despoliation of the environment shows particularly in water pollution: surface water, industrial effluent and water 'purified' by installations which still contains unfiltered salts".

"Nearly half of all fertilizers spread on earth misses the target and sooner or later ends up with the rain in the surface water".

Haagse Post, 10.06.70.

"...Another product which has made the world stand in awe at the wonders of (chemical) technology is fertilizer. In the meantime we know that fertilizers (mainly phosphates and nitrates) may well be doing more harm to the environment than is good for us. Half of all the fertilizer spread on earth misses the target and ends up in the water, giving rise to proliferation of algae and water plants. These die off and in decomposing use up all the available oxygen in the water, so as a result rivers, lakes, ponds and seas become unusable for drinking water, recreation or as biological purification catchments and dangerous on account of the disease germs which develop there".

"Fertilizers furthermore have an as yet not well known side-effect on the balance of nature that you can taste on our apples; they don't taste of anything any more. Vegetables, grass and fruit are, as it were, 'forced' with fertilizers (nitrogen, the farmer says) and because of this there is a risk that though the plants may look large and vigorous, yet through one-sided absorption of only one growth substance they lack all kinds of trace elements that may well be what gives the product its taste or food value. 'Our mountain of butter is growing on nitrogen': the faster the grass grows, the more the cows per hectare of grassland, the more litres of milk at so many cents per litre subsidy. In 1966 in some places in the Netherlands 163kg/ha of nitrogen was being spread, against a permitted maxmium of 75kg/ha. In this misbehaviour we Dutchmen once again stood at the top of the European list".

From: 'Mother Nature is no longer cleaning our dirty nappies',
Reprint from Elseviers Weekblad.

"The contribution of detergents to overall phosphate pollution may according to an estimate by Dr.Beek (Unilever) be put at 15-20% of the total phosphate pollution; about two-thirds is accounted for by agriculture".

From: 'Enzyme accidents still not a thing of the past',
Elseviers Techno, Vol.2 No.16, August 1971.

"To this is then added the drainage water from farmland which, particularly in the Netherlands, is very rich in inorganic salts. This eutrophication, too, is quantitatively of great significance. The use of fertilizers leads not only to the discharge of eutrophicating nitrogen and phosphorous compounds in drainage water, but also in the industrial preparation of these fertilizers more or less poisonous or otherwise damaging pollutants are emitted".

Landbouwkundig Tijdschrift 82-5, 1970.

"Although contamination and environmental pollution in the first place conjure up associations with towns, cities, built-up areas, traffic and industries, it cannot be denied that technified agriculture too has a share in it, and to an increasing extent at that. To agriculture's share belong not only such well-known things as pesticides and fertilizers, but also in addition the increasing quantities of pollutants from bio-industry which can be particularly detrimental to the equilibria in soil and water. The amounts of nitrates and phosphates, just like traces of certain metals or metal compounds, need to be regarded with just as much suspicion as excess pesticides".

Landbouwkundig Tijdschrift 85-5, 1970.

"A new factor (Salinization) also needs to be taken into account in this regard. If a Markerwaard of 60,000 ha comes about, farmers will come as well; all together they are going to use thousands of tons of salts and poisons on their lands. The water pollution this will cause is still not being taken into account".

' Markerwaard off the map?'
Economisch-Statistische Berichten 2811, 18.08.71.

"Agriculture is partly to blame in this (water pollution - Ed.), since in order to produce a large quantity of food, appreciable quantities of inorganic material like fertilizers are added to the soil This fertilizer needs to be soluble so that it can be taken up by the plant, but this results in it also being to some extent easily washed away by the rain. Large quantities then finish up in the surface water, in ditches and canals, then they get pumped up into the catchwater basin where they tend to cause pollution".

Man against Environment, 1970.

"But now man is interfering ...
An excess of fertilizers and deadly agricultural poisons wash off the fields into the ditches, drains squirt out human and domestic sewage, poisonous effluent from factories froths out and pollutes the healthy environment".

Uit zelbehoud, published by "In den Toren", Baarn 1969.

"This week in Britain the Royal Society in London published the results of a three year study of the nitrogen cycle in Britain... some of its conclusions are uncomfortable. For example, only one tenth of the nitrogen added to agricultural land ends up in food; much of the rest escapes into the environment. In some drinking water supplies nitrate levels already exceed those allowed by an EEC directive. One third of the acidity in rain is due to nitrates... Britain will have to spend 200 million to 1,600 million pounds over the next 20 years installing denitrifying and bottling plants. Water ratepayers may baulk at the idea of paying for farmers' profligacy with fertilizers."

The Economist 28.01.84.

"In much of western Europe drinking water from boreholes is already contaminated by nitrate, to a level that the EEC has decided is "unacceptable". This pollution will grow steadily worse. Farmers are drenching their land with nitrate fertilizers, which will percolate down into the water supply over the rest of this century."

The Economist 2.03.85.

"...Too little is known about the way the body metabolises nitrite to estimate how great a risk of cancer, if any, the additives (for preservatives in food) pose. Despite these uncertainties... reductions in the amount of nitrites allowed in meats 'might be considered', as the effect at issue is a serious and irreversible one of cancer".

US National Research Council Report.
New Scientist 28.09.78.

"Emphasis on fertilizer nitrogen as the key to pasture productivity diverts research and extension resources from the search for the real, and as yet unidentified, constraints on output. Worse it encourages the substitution of expensive, energy-intensive grazing systems based on heavily fertilised grass swards in place of clover-rich pasture which, skilfully managed, could be equally productive and far less costly in terms of both money and energy. Recent increases in the cost of nitrogenous fertilizers have done little to allay such doubts... In a grassland improvement strategy based on heavily fertilized pure grass swards, there is little room for clover. Livestock farmers traditionally included clover in their pasture seed mixtures. The legume has long been regarded as the major improver of soil nitrogen levels and herbage production. But a high-nitrogen economy will not tolerate the mixed grass/clover sward... (grasses) squeeze clover out of the sward... Clover offers the livestock in industry an opportunity to reduce costs and support energy dependence without greatly cutting back output. At a time of rising fertilizer costs and mounting EEC surpluses in animal products, the continued neglect of clover appears indefensible.

New Scientist 15.02.79.

"...That the interest of having a viable agriculture with good productivity and abundant cheap food is, of course, paramount - but not so paramount that you can totally disregard the environment."

Sir Hans Kornberg, Chairman of the
Royal Commission on Environmental Pollution.

The Report says "There is no doubt...that the increasing use of...(nitrogenous) fertilizers has led to rising levels of nitrate in water supplies.

Royal Commission Report on Agriculture and the Environment.

"Most of the nitrate in drinking water comes from fertilizer that is spread on the land. There has been a sharp increase in nitrate levels in recent years, as the use of fertilizers has increased. Some scientists believe that a further increase is inevitable, because of the time taken for fertilisers to reach drinking water".

New Scientist 20.09.84.

"...15% of the drinking water in East Anglia (is) over the new EEC safety limits for nitrate content... A nine month study...may lead to controls on nitrogen application... There is a nitrate problem and it is getting worse. According to a Ministry of Agriculture expert, nitrogen application would have to be halved to have any effect of water supplies".

Big Farm Weekly.

"Far more attention should be paid to late fertilizer on grassland to avoid leaching losses... Badly-timed late nitrogen can lead to very severe leaching, wasting money and adding to the water nitrate problem... (and) there's an urgent need for more work on the losses from late fertilizer to give farmers a tactical approach to show the optimum time for summer applications - a sort of late "T" sum".

Big Farm Weekly 25.05.85.

"An independent scientific review of the risks posed by nitrates in drinking water must be made before new EEC regulations cause needless public spending on pollution control. So says the director general of the Fertilizer Manufacturers Association, Mr John Mottram. Acceptable levels of nitrates in drinking water were still being governed by standards laid down in 1970 by the World Health Organization*. These were based on evidence which showed that, at these levels, risk to human health was almost nil. Yet the EEC was about to reduce the acceptable (old) levels by half said Mr.Mottram".**

* These levels were changed in 1984 by the WHO and lie below those of the Community.

** A transition period of 5 years was allowed by the EEC, which ended in August 1985.

"In many areas of the country (U.K.) there is now a struggle to meet water quality standards... Much of the problem is due to nitrates escaping from agricultural land... The future lies in good management. Applying nitrogen only when crops need it and can use it makes economic sense both farmers and environmentalists.

Farmers Weekly 5.05.85.

"A major report on fertilizer use in Ireland accuses farmers of adopting the attitude that if some fertilizer is good then more must be better... Many farmers...fail to take into account the fertility buiit up in the soils".

Farming News 10.05.85.

"It is important that the farmer should use nitrogen efficiently so that he gets good value for this costly investment. Inefficient use can lead to escape of nitrogen into surface and ground water, with detrimental effects on water quality".

Farm Food & Research (IRL) 1984.

"The future of Europe's natural environment is inextricably linked with the development of its farming sector... just as farming shapes the environment, so farming itself depends on sound environmental conditions. The maintenance of soil structure and avoidance of soil erosion, the purity of air and water and the general equilibrium of ecosystems are all essential to a prosperous agriculture. And public support for stronger environmental considerstion should not be underestimated..."

Speech by Commissioner Stanly Clinton Davis at the
European Parliament Environment Committee 16.09.85.

Chaque année, quelque deux millions de tonnes de nitrates pénètrent dans le sous-sol et se dirigent vers les nappes phréatiques: nous 'buvons' ainsi chaque jour 50 milligrammes de nitrates... La pollution des nappes phréatiques par les nitrates est un phénomène lent... Si nous les (mesures préventives) prenions aujourd'hui, peut-être éviterions-nous les ravages spectaculaires que ce phénomène nous promet dans une cinquantaine d'années?... Les principaux accusés: l'agriculture intensive, grande consommatrice de nitrates comme engrais at l'accumulation des déjections animales de l'élevage industriel".

La Recherche No.1106 Vol.16 September 1985.

"Putwater in Vlaanderen meestal niet drinkbaar... Volgens de normen van het KB van 27.04.84. wordt het water...'niet drinkbaar' beschouwd... Dat blijkt vooral uit de vrij algemene overschrijding van het stikstofgehalte: ammoniak, nitriet en nitraat liggen resp. 13, 14, en 52 t.h. boven de norm".

De Standaard April 1985.

"Klärschlämme taugen nicht zur Bodenverbesserung oder Düngung in Landwirtschaft und Gartenbau, sie sind 'zu giftig und in ihren langzeitwirkungen unberechenbar".

Opinion of a scientific team from Cornell University,
USA, Der Spiegel October 1981.

"Zwei wochen lang wähnten sich die Einwohner der niederrheinischen Ortschaft Wachtendonk wie im Krieg. Das Trinkwasser war rationiert, jedem Bürger standen täglich nur zwei Liter zu, mit dem Eimer abzuholen zwischen 16 und 19 uhr an eilends eingerichteten Abgabestellen... Das leitungswasser enthielt Nitratbeimengungen in bedenklicher Konzentration.
Das baden-württembergische Landwirtschaftsministerium etwa hat ein Faltblatt herausgebracht über 'Nitrat im Trinkwasser', in dem es heisst: 'Der Landwirt kann und muss Anstrengungen unternehmen, den nitratgehalt des Wassers, des wichtigsten Lebensmittels, zu verringen'. So sollen die Bauren, wenn irgend möglich, auf die Herbstdüngung verzichten und im Winter auch keine Jauche und Gülle ausbrengen.
'Vor allem', fordert der Wasserchemiker Quentin, 'sollten die Bauern nicht meer nach dem motto düngen: Viel hilft, und mehr hilft mehr' ". Abbau der Uberdüngung erscheint als der vernünftige Ausweg".

Der Spiegel June 1982.

"Die Arzte im unterfränkischen Marktbreit fertigen eine ungewöhnliche Rezeptur: Sie forderten die Mütter auf, zum Anrühren von Babynahrung nur noch Sprudel zu verwenden - das Trinkwasser der Kommune hatte, so ein Mediziner, einen 'dramatisch hohen Nitratanteil' und war nicht meer geniessbar... Im weiten Teilen der Bundesrepublik hat die - vor allem durch Stickstoffdüngung verursachte - Belastung des Grund- und Trinkwassers längst den von der EG empfohlenen, nach Möglichkeit anzustrebenden Richtwert von 25mg/l überschritten, oberhalb dessen Nitrat bei Säuglingen das Risiko der sogenannten Blausucht erhöht... Das Umwelt-Ubel ist durch jahrzehntelange ökologische Unachtsamkeit entstanden. Uberall, wo nach der Bauernregel 'Viel hilft viel' gedüngt wird, in Obst- und Weinbaugebieten wie auf Getreideflächen, ist der Nitratspiegel drastisch erhöht. Deutschlands Landwirte, deren Stickstoffverbrauch sich in den letzten zehn Jahren verdoppelt hat, kippen tonnenweise nitrathaltigen Chemiedünger oder Jauche und Gülle aus der Massentierhaltung in die Landschaft".

Der Spiegel 9.04.84.

"Jahrelang haben sich Bonns Politiker um den Schutz von Luft und Wasser bemüht, aber das dritte und sensibelste 'Umweltmedium', den Boden, übersehen... Die Erde ist unsere Mutter. Was die Erde befällt, befällt auch die Söhne der Erde... Uppige Düngung aber fügt dem Boden und dem Grundwasser nicht nur Schwermetalle zu, sondern auch eine andere Gruppe von Schadstoffen: die nicht minder gefährlichen Nitrate... Nitratanreicherung im Bodem und im Grundwasser is 'praktisch irreversible' ".

Der Spiegel 6.07.84.

"Baden-Württemburg will die Bauern des Landes mit einem 'Wasserpfennig' für Grundwasserreinhaltung honorieren...Eine 'Perversion des Verursacherprinzips'.. Das sieht so aus: Die intensive Bodenbearbeitung der Landwirtschaft hat vor allem durch hohe Nitratbelastung, ausgelöst wiederum durch reichliche Verwendung von künstlichen Düngemitteln und von Jache, zur Schädigung des Grundwassers geführt. Nachdem das Ubel erkannt war, wurden und werden in ländlichen Berichen immer mehr Wasserschutzgebiete ausgewiesen, auf denen Chemie-Einsatz und Gülle-Giessen verboten oder beschränkt ist. Die Bauern müssen dort ihre Bewirtschaftungsmethoden ändern, mitunter auch die Erzeungung drosseln oder die Nutzung umstellen. Reddeman (CDU Abgeordneter im baden-württemburgischen Landtag, Vorstandsmitglied des CDU-Bezirks Südbaden und Präsident des Badischen Landwirtschaftlichen Hauptverbandes) liegt zwar richtig, wenn er klagt: 'Vor fünfzehn Jahren hat man uns geraten, die Produktion durch mehr Düngung zu erhöhen, heute heisste es, dresselt die Produktion und düngt weniger, ihr verschmutzt das Grundwasser'.
Aber Reddemann stellt die Dinge auf den Kopf, wenn er die Bauernregel ausgibt: 'Der , der Wasser entnimmt, ist der Verursacher, also soll er auch zahlen'... Und wenn ein Bauer durch übermässige Düngun das Grundwasser verunreinigt habe, dann könne er nicht dafür belohnt werden, dass er die Schädigung reduziere: 'Es ist schon sehr eigenartig, dass das Wasser verschmutzt haben, jetzt auch noch Geld dafür haben wollen", Jurist Rommel.

Der Spiegel 24.04.85.

APPENDIX III

POSSIBLE AREAS FOR RESEARCH

1. Better understanding and quantification of the nitrogen cycle, nitrate migration and leaching mechanisms in the soil, subsoil and aquifers, and denitrification mechanisms.
2. Cold resistant crops and continous cropping cycles capable of providing soil cover all the year round.
3. Crop varieties which (a) take up and utilise the nutrients in the soil more efficiently,
   and (b) provide good yields with lower fertilizer application.
4. Horticultural methods and plant varieties to produce vegetables of low nitrate content, especially in intensive production and greenhouse cultivation.
5. Fertilizer application concepts and techniques to ease plant uptake and minimise losses; controlled-release nitrogen fertilizers and mixtures of fertilizers with different release rates.
6. Quick and inexpensive field techniques for sampling and analysing crops and soils in order to assess nutrient requirement and availability; similar techniques for assessing fertilizer value of manure and slurries.
7. Animal breeding techniques which give solid manures or concentrated slurries instead of diluted slurries. Improved storing, handling and spreading techniques which reduce odour and disamenity for the farm worker and ensure better assimilation by coil. Inexpense deodorising techniques.
8. Practicable systems for methane production, for different sized production units, which would also improve the characteristics of animal fertilizers for their final utilisation.
9. Research into and development of techniques to raise the productivity of organic farming.
10. Low cost nitrate removal techniques for drinking water, which would not lead to the introduction of other undesirable substances (methanol, chlorides, organochlorines etc.) in treated water.
11. Feasibility analyses and cost comparisons of agricultural measures versus water treatment, blending, dial networks etc., for the medium and long term demand.
12. Alternative techniques and products to replace nitrate/nitrite in cured meats and other food preparations.
13. Better evaluation of health risks (including cancer) of nitrate/nitrite/nitrosamines in the human diet; a more precise understanding of dose/effect relationship; possible chronic effects (below the threshold of methaemoglobinaemia) of the absorption of nitrate/nitrite on health and development of infants as well as on pregnant mothers.
14. Improved hydrological survey of nitrate contamination of aquifers and surface waters. Methods for forecasting the evolution of nitrate concentration in aquifers. Dynamics of nitrate diffusion in unsaturated zones and aquifers. Isotopic methods for identifying the origin of nitrate in waters. Nitrate balance in river/aquifer interchange.
15. Development of feasible policies to pursue objectives which reduce the nitrate problem.

(a) Transformation of Nitrogen Fertilizer to Nitrate in the Soil.

$$NH_3 \xrightarrow{(H^+)^{(1)}} NH_4^+ \xrightarrow{\text{NITRIFICATION}} NO_2^- \longrightarrow NO_3^-$$

Ammonia Used directly as Fertilizer | **Ammonium ion** | **Nitrite** | **Nitrate**

$$\xrightarrow{\hspace{6cm}}$$

Rapid Transformation (Oxidation)

(1) H^+ supplied from 3 possible sources:

a) Water (H_2O) OH + H^+
b) Various organisms in the soil - Coo (H^+)
c) Minerals in the soil, oxides - H^+

(Source: A. Moreale DG VI A2)

(b) Transformation of Ammonium Nitrate Fertilizer to Nitrate in the Soil.

$$\begin{tikzcd}
NO_3^-NH_4^+ & NH_4^+ \arrow[r, leftrightarrow] & NO_2^- \arrow[r, leftrightarrow] & NO_3^- \\
\text{Fertilizer splits into:} \arrow[ur] \arrow[dr] & & & \text{Nitrate} \\
& NO_3^- & & \\
& \text{Nitrate} & &
\end{tikzcd}$$

(c) Transformation of Urea Fertilizer(Organic) to Nitrate in the Soil.

$$\begin{array}{lllllll}
 & & & \text{Ammonia} & & & \text{Nitrate} \\
 & NH_2 \longrightarrow & H \longrightarrow & NH_3 \longrightarrow & NH_4^+ \longrightarrow & NO_2^- \longrightarrow & NO_3^- \\
CO(NH_2)_2 & CO \longrightarrow & O \longrightarrow & CO_2 & & & \\
 & NH_2 \longrightarrow & H \longrightarrow & NH_3 \longrightarrow & NH_4^+ \longrightarrow & NO_2^- \longrightarrow & NO_3^-
\end{array}$$

Urea Fertilizer. Divides when meets water. The result is 2 sets of Ammonia, which are then transformed to nitrate.

K.J. McCARTHY DG VI A2.

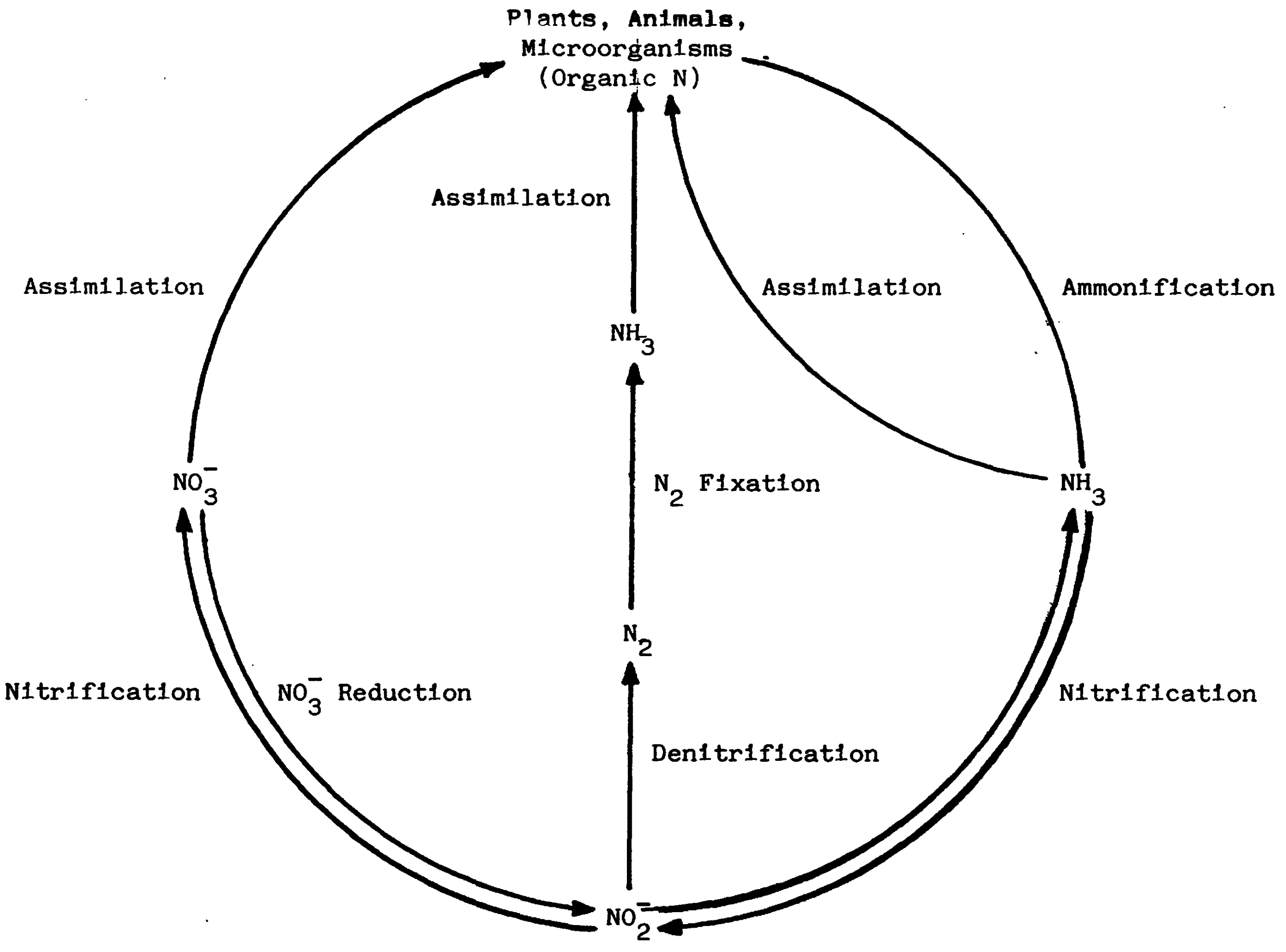
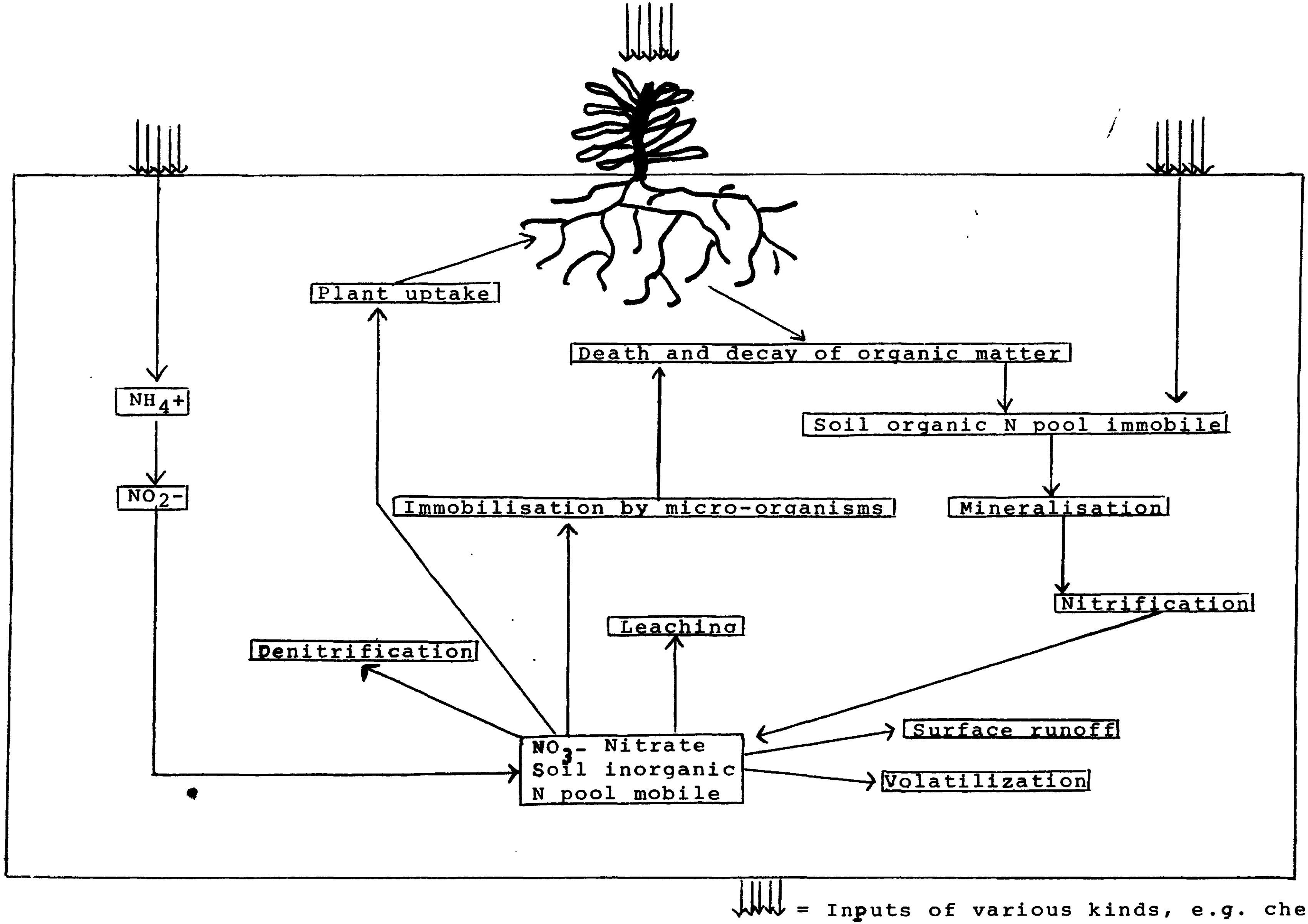


Figure 2. A generalised Nitrogen cycle, showing the major processes involved.

From : "The Nitrogen Cycle of the United Kingdom", The Royal Society 1983. p.34.



= Inputs of various kinds, e.g. chemical fertilizers

Figure 3: Nitrogen within the Soil Plant System.

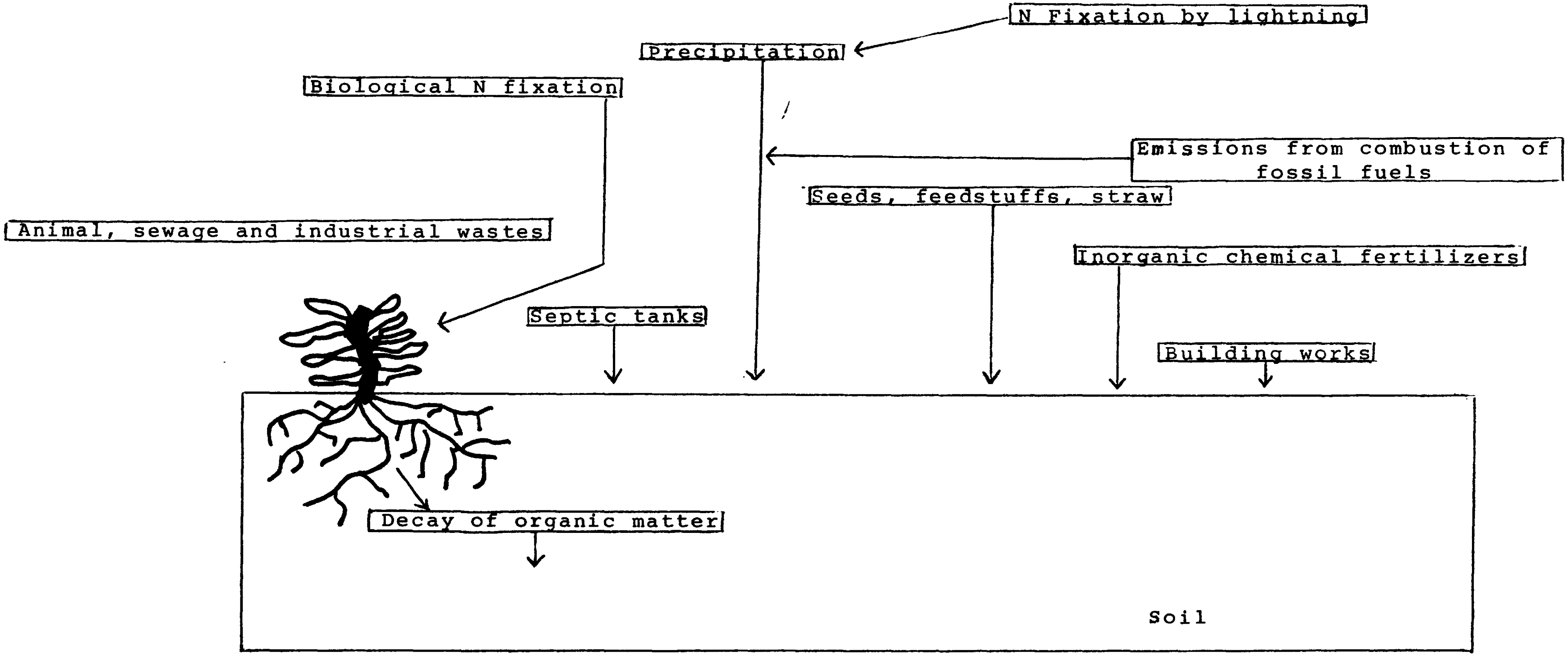


Figure 4: Inputs to the Nitrogen Cycle.

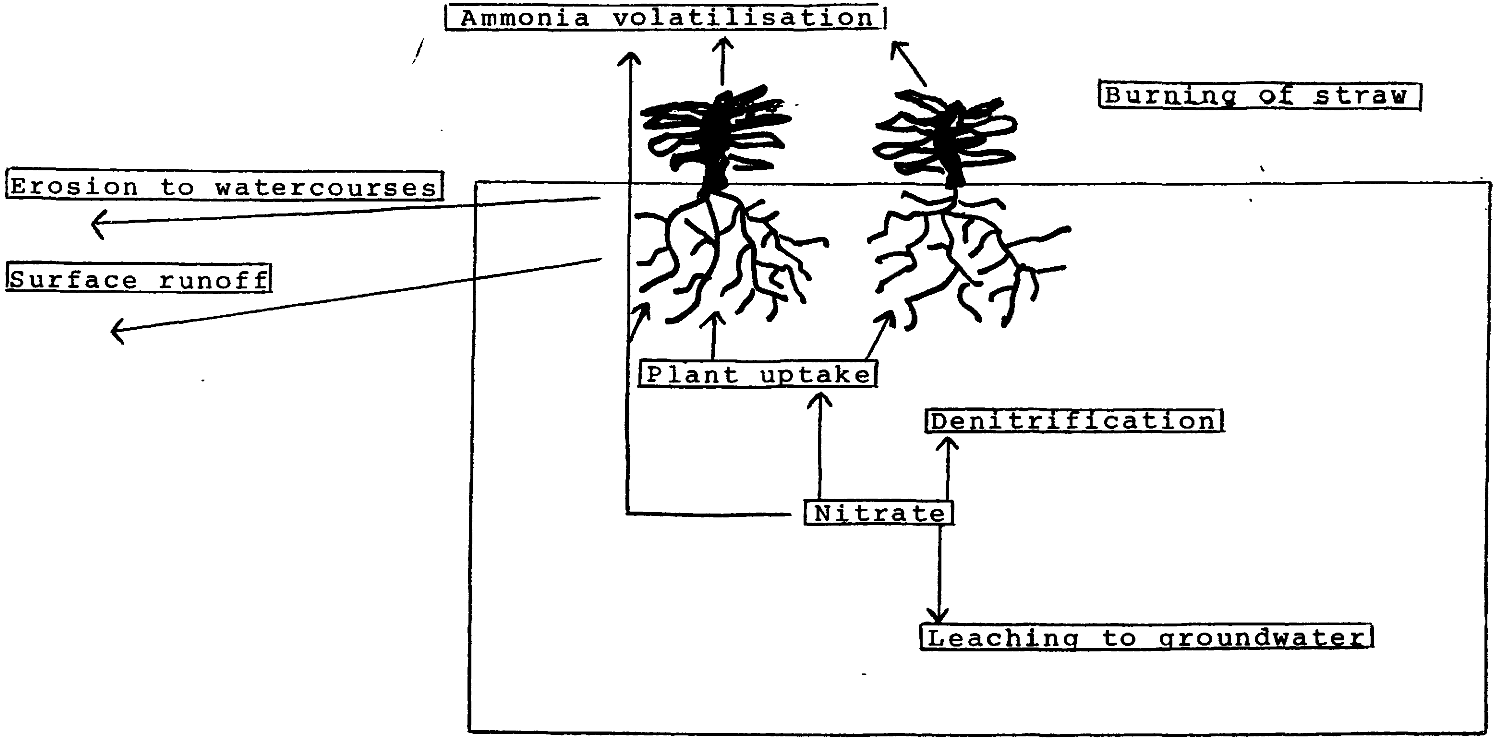


Figure 5: The Sources of Nitrogen Losses.

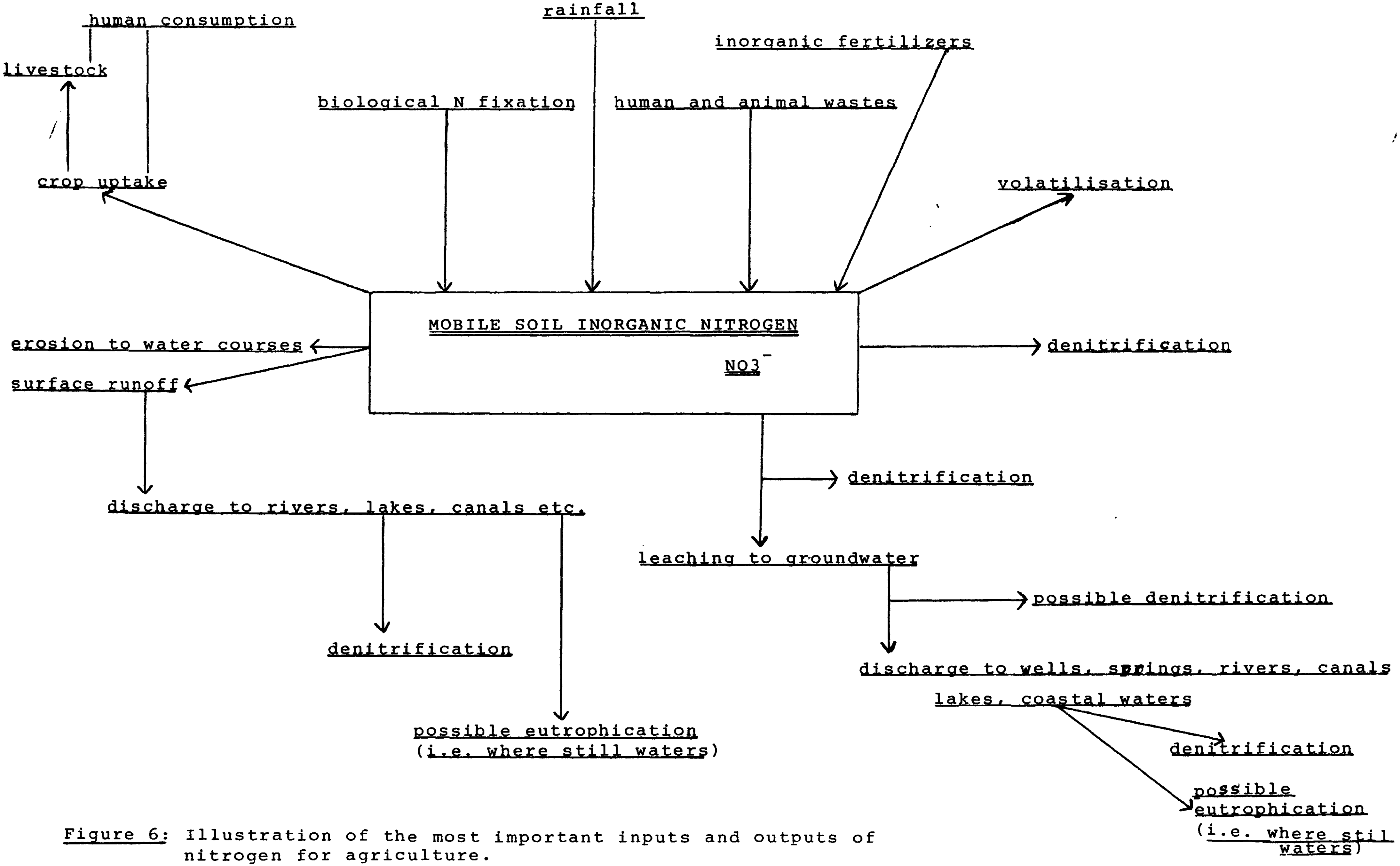


Figure 6: Illustration of the most important inputs and outputs of nitrogen for agriculture.

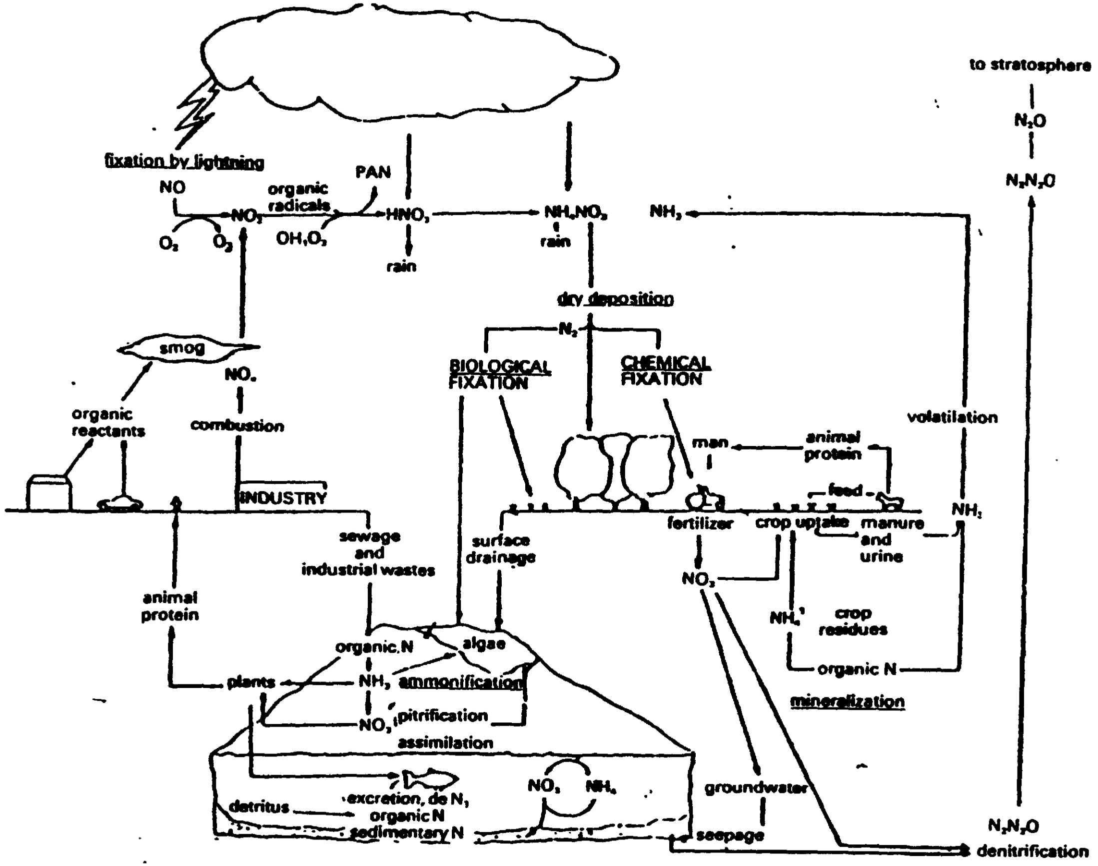
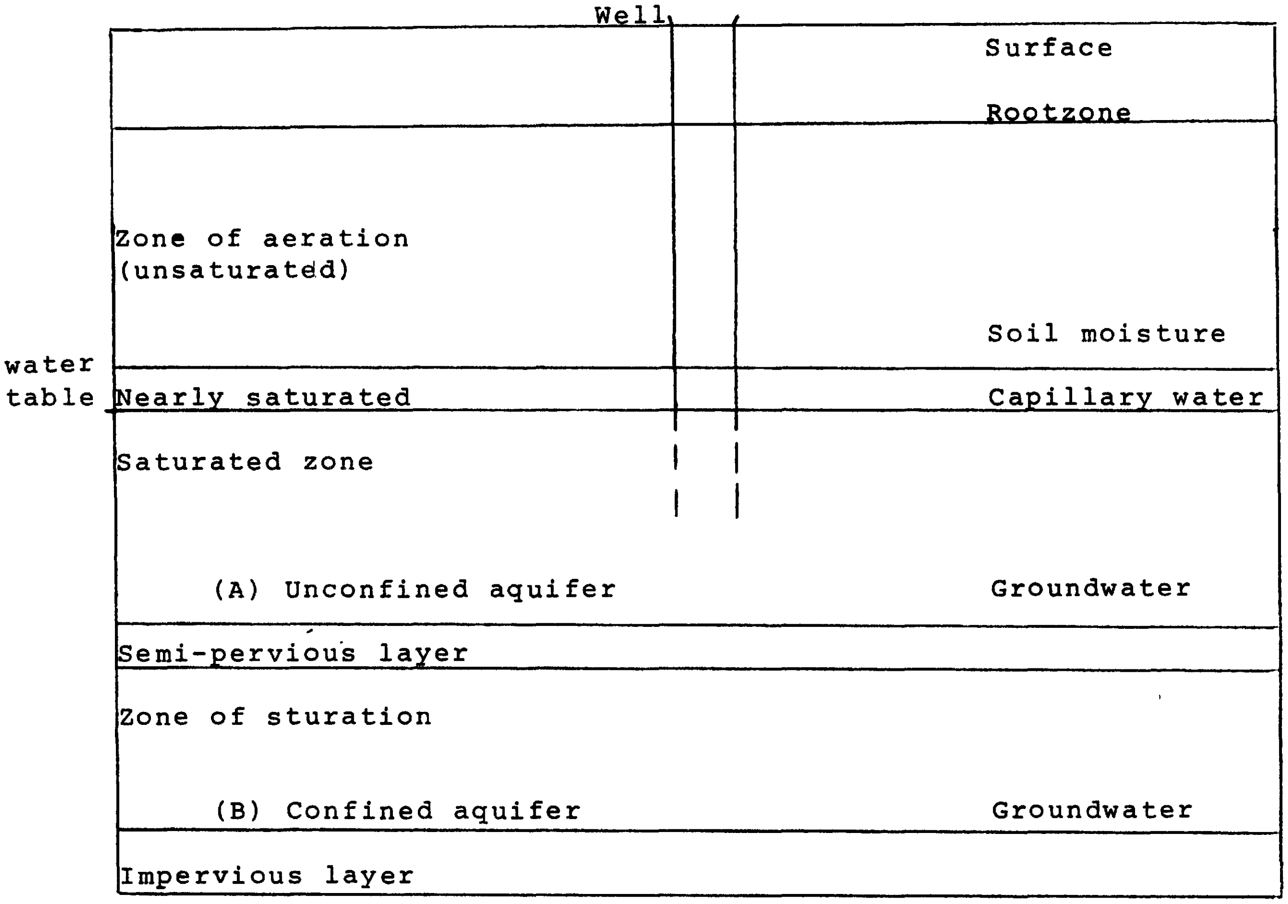


Figure 7: The Nitrogen Cycle.
(Source: The Royal Society Report 1983, p.36)



Groundwater is the water of the zone of saturation which is generally beneath the depth of penetration of plant roots; water from this zone feeds springs, streams and wells, and eventually discharges into lakes and/or rivers. Movement of groundwater however will be dictated by the geological and hydrological conditions of the ground layers.

The best type of aquifer are those composed of gravel, sand, limestone, sandstone or basalt, such as the chalk, Permo-Triassic sandstone and Jurassic limestone found in Western Europe. An unconfined aquifer (A) is one with its upper surface (the water table) open to the atmosphere through permeable material. A confined aquifer (B) has an impervious layer to separate it from the atmosphere. However, although confined aquifers do not readily transmit water, tests have shown that over a period of time, it will contribute large quantities of water by slow leakage to supplement production from the principal aquifer.

The drinking water supplies in the Community are based to a large extent on groundwater: -
B 76%; DE 73%; DK 99%; F 68%; UK 32%;
IT 88%; L 73%; NL 67%; IRL 20%.

Figure 8: Position of groundwater in relation to the surface.

(Source: J. WINBURNE and *the Encyclopaedia Britannica Ready Reference and Index*, Vol. I, p.465)

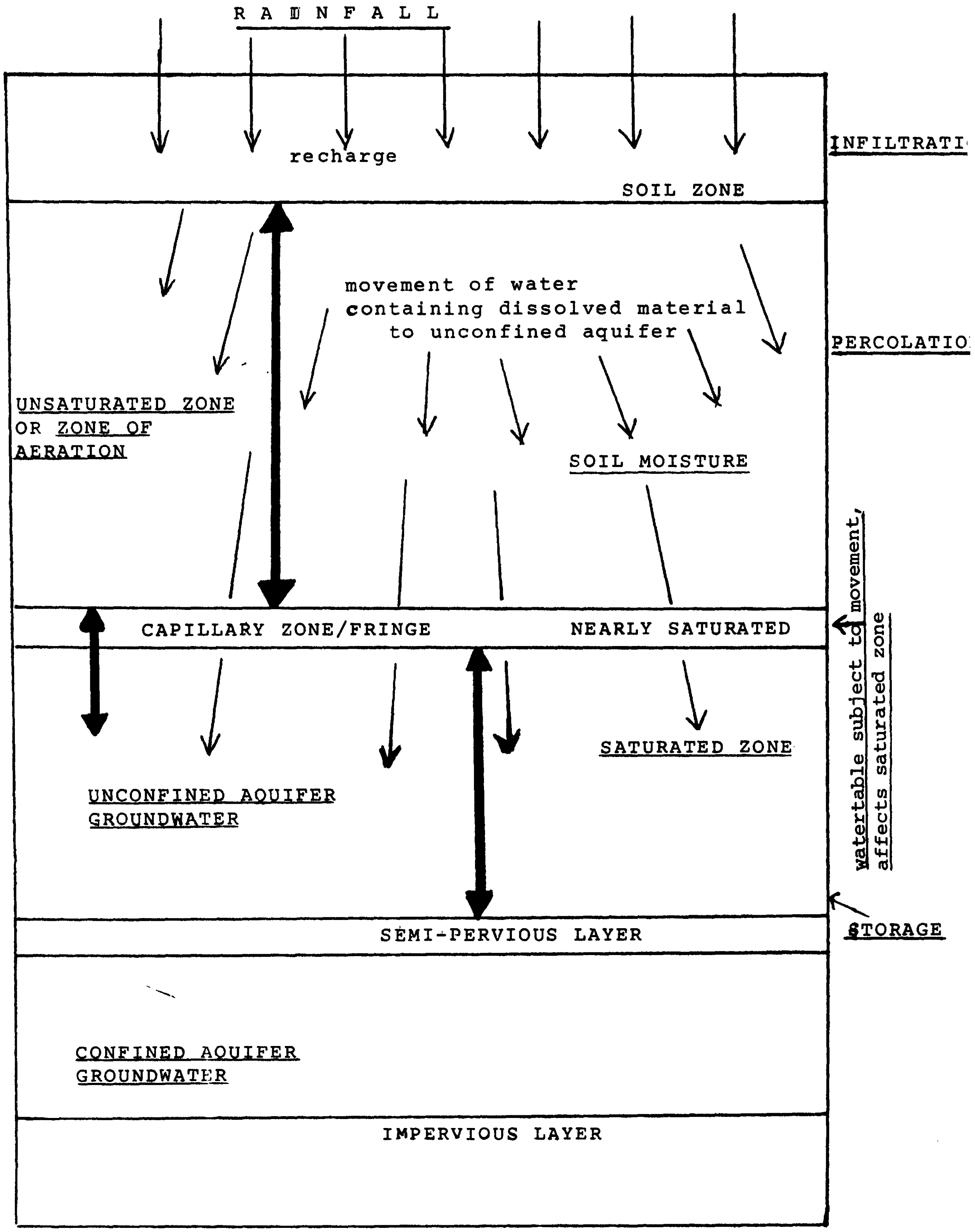
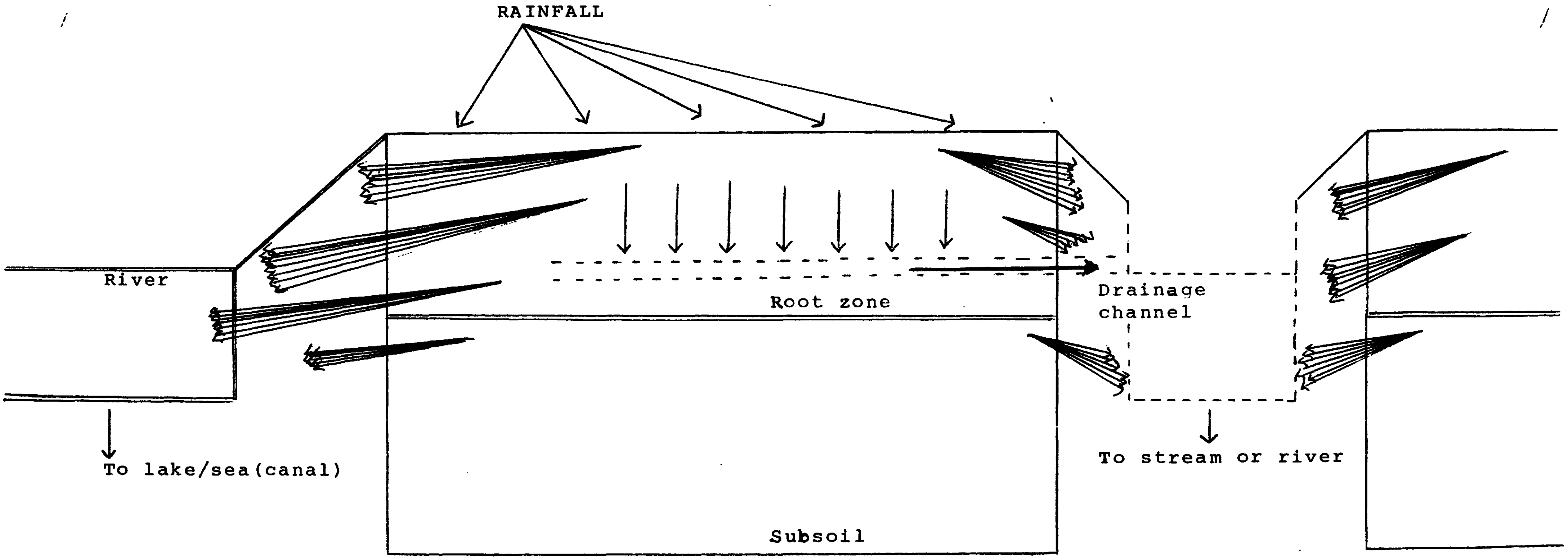


Figure 9: The Leaching Process Simplified.



to a river and a drainage channel.

Figure 10: Illustration of surface runoff.

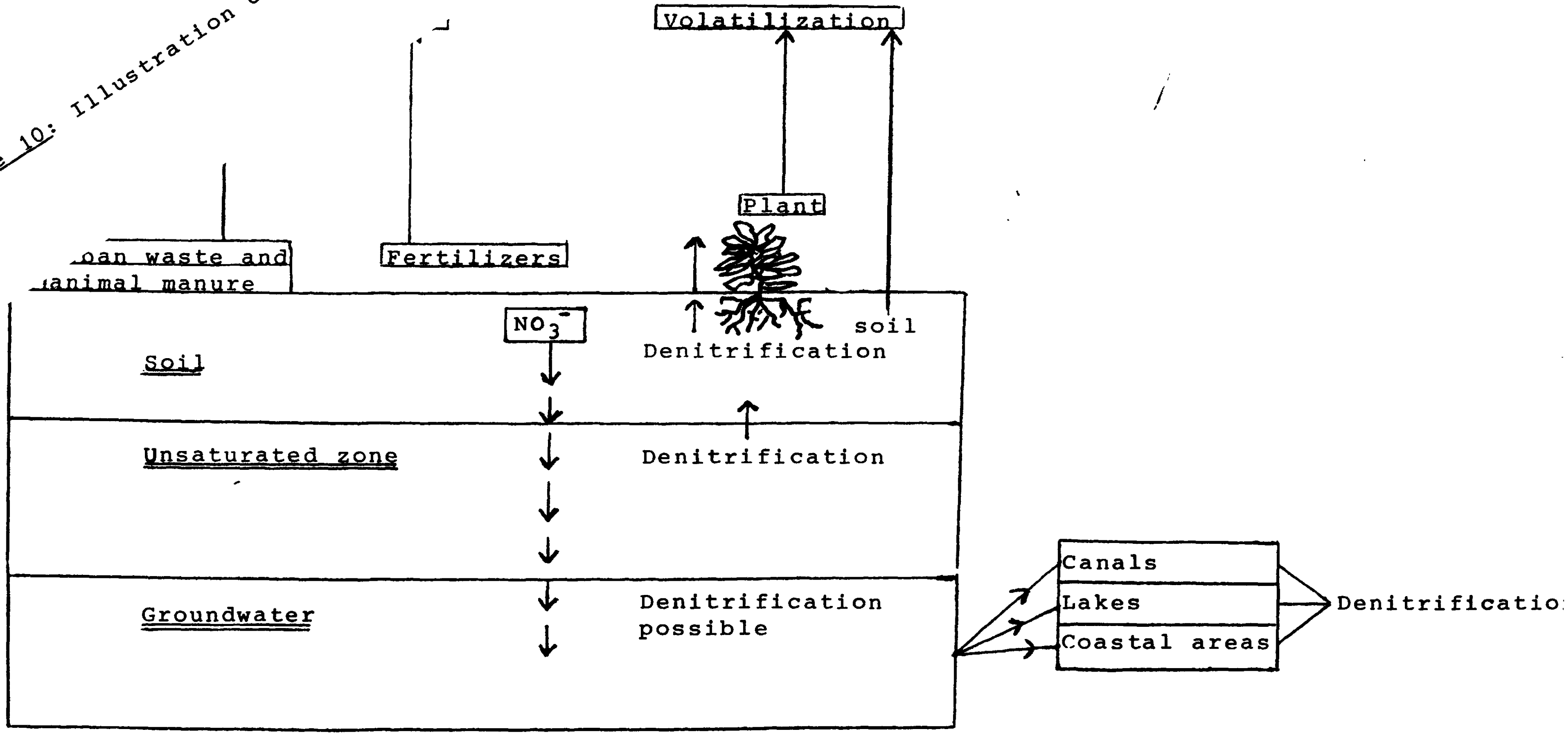


Figure 11: Losses to the atmosphere: - Volatilization of Ammonia and Denitrification.

Steady Increase of N

Stagnation of P and K

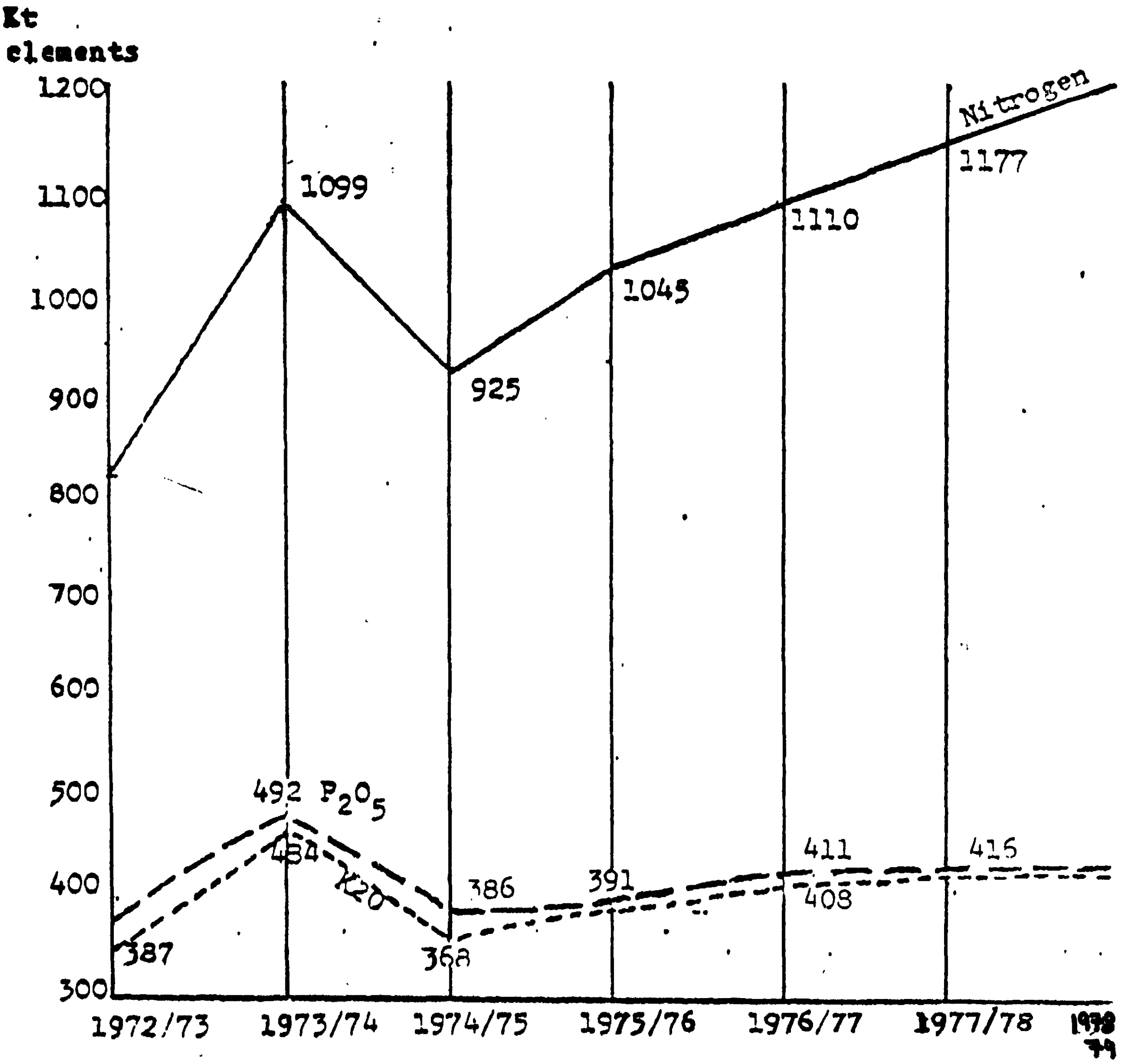


Figure 12: Comparison of the consumption of N,P and K fertilizers in the UK.
(Source: OECD)

Steady increase of N

P and K unchanged over the past 8 years, with even a downtrend for P_2O_5

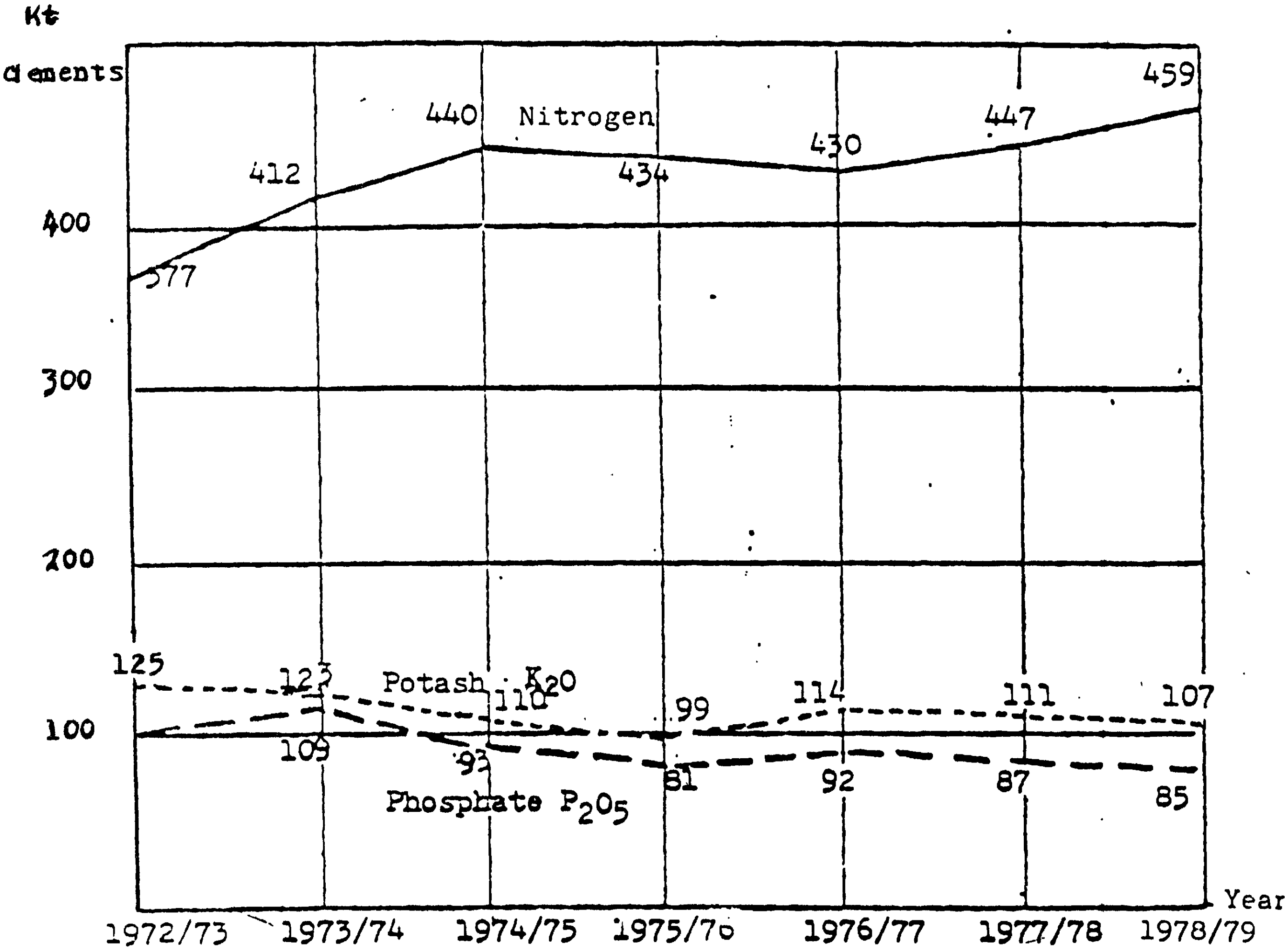


Figure 13: Comparison of the consumption of N,P and K fertilizer in the Netherlands.
(Source: OECD)

Steady increase of N

Stagnation of P and K

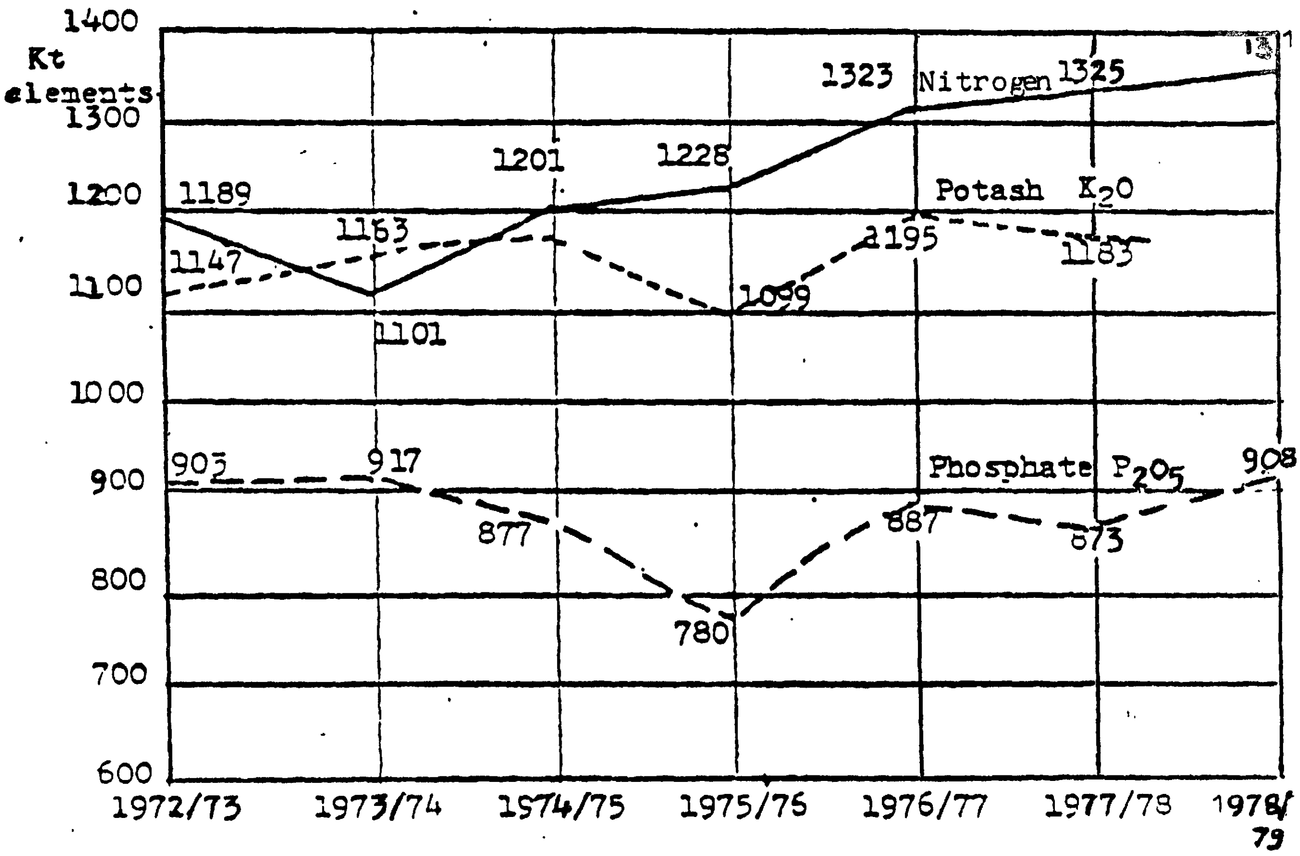
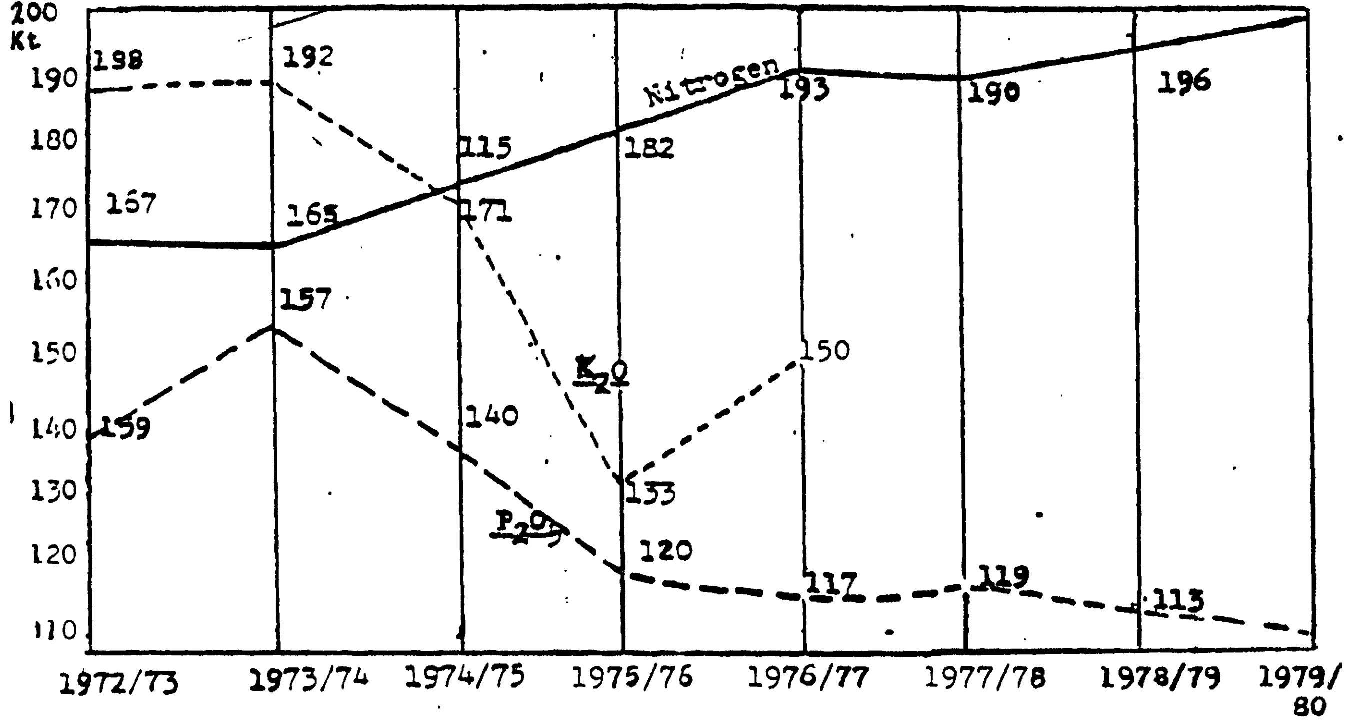
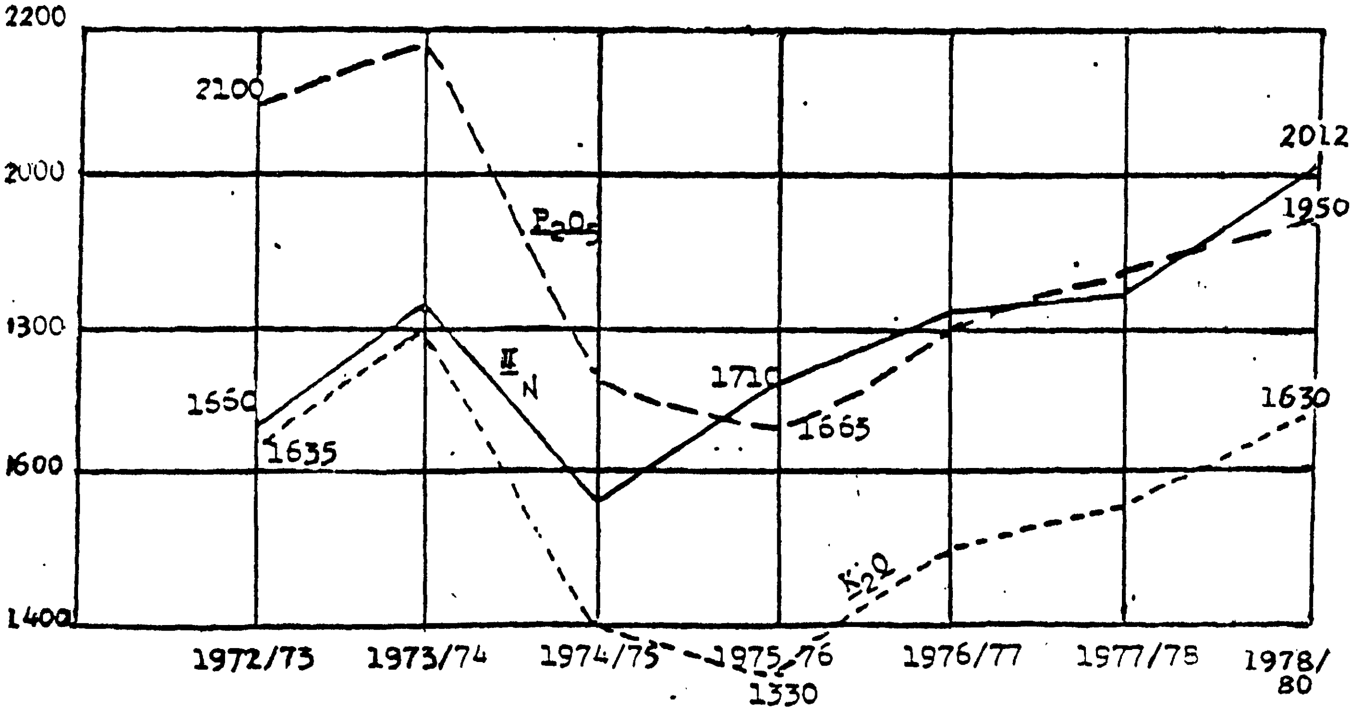


Figure 14: Comparison of the consumption of N,P and K fertilizers in Germany.
(Source: OECD)



A slight increase of N may be noted as well as the heavily reduced use of K_2O and P_2O_5

Figure 15: Comparison of the consumption of N,P and K fertilizers in Belgium.
(Source: OECD)



The decline in 1973/75 was followed by a marked rise for P and K while N is now in first place with P_2O_5

Figure 16: Comparison of the consumption of N,P and K fertilizers in France.
(Source: OECD)

AVERAGE APPLICATION RATES OF NITROGENOUS FERTILIZERS IN THE TEN FROM 1960 TO 1982 IN Kg / Ha OF PLANT NUTRIENT FOR ARABLE AND GRASSLAND EXCLUDING ROUGH GRAZING

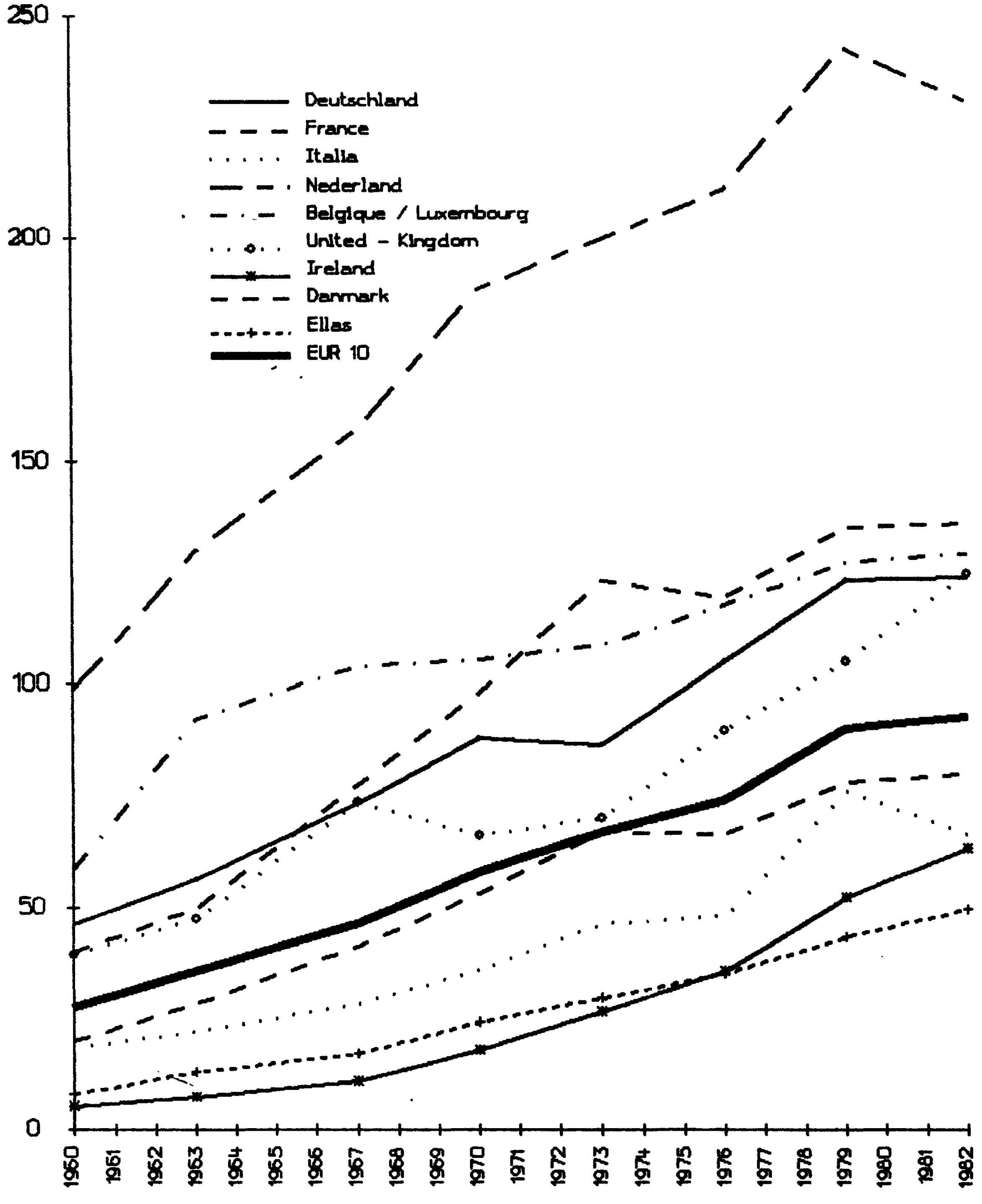


Figure 17

SOURCE : *FAO Yearbooks and CRONOS / EUROSTAT*

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AN INDEX OF THE AVERAGE N FERTILIZER APPLICATION RATE AND DEFLATED PRICES FOR THE EURO - TEN 1973 - 1982

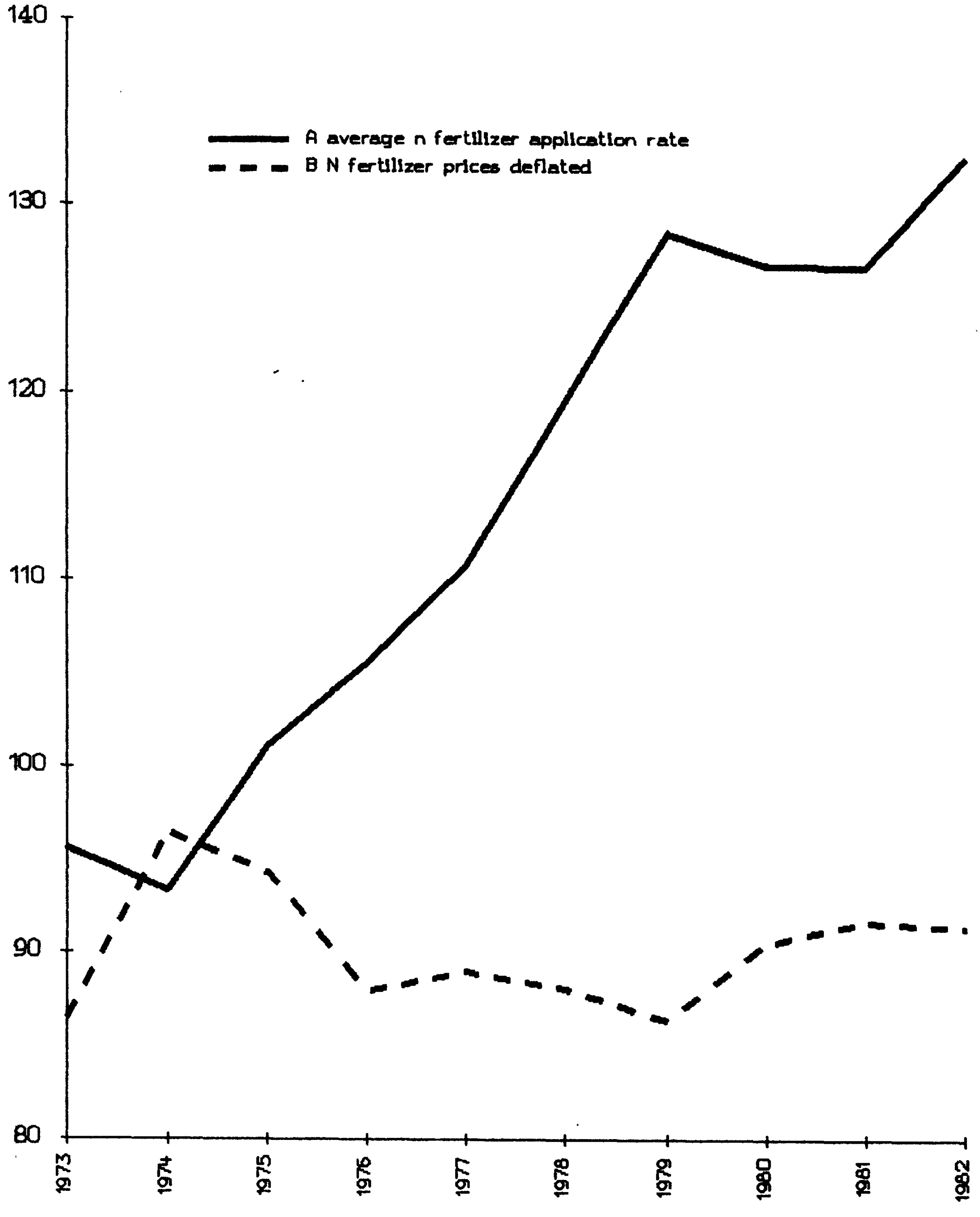

Figure 18
SOURCE : *FAO Yearbooks and CRONOS / EUROSTAT*
Base year = 1975

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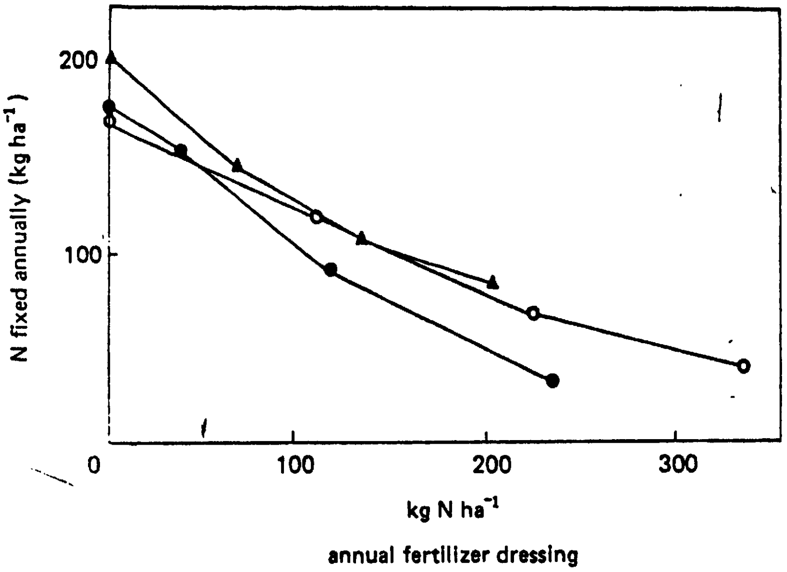


Figure 19: The relationship between the amount of N fixed symbiotically by white clover, grown in association with grass, and the amounts of fertilizer N applied. (Source: The Royal Society Report, p.70)

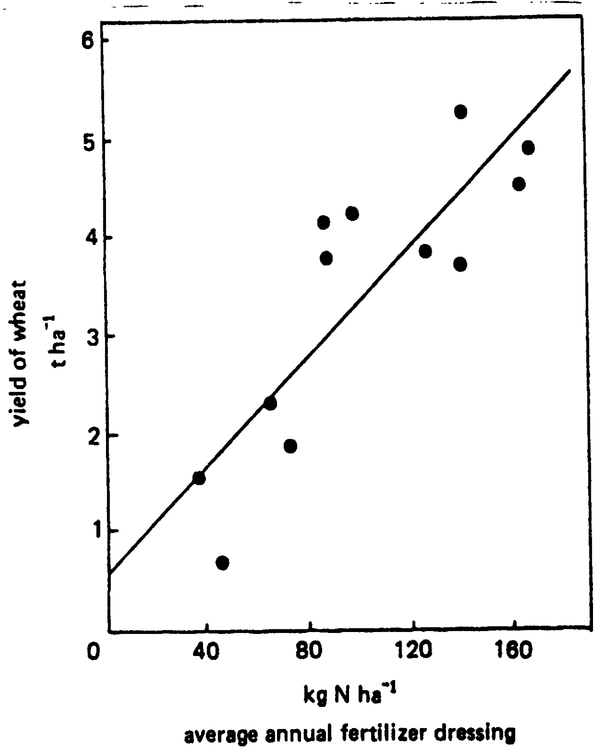


Figure 20: The average yield of wheat (1977 figures) produced in various countries of Western Europe plotted against the amount of fertilizer N applied to arable and permanent crops in each country. The data apply only to countries where the average annual application was less than 200kg N ha^{-1}.
(Source: The Royal Society Report, p.56)

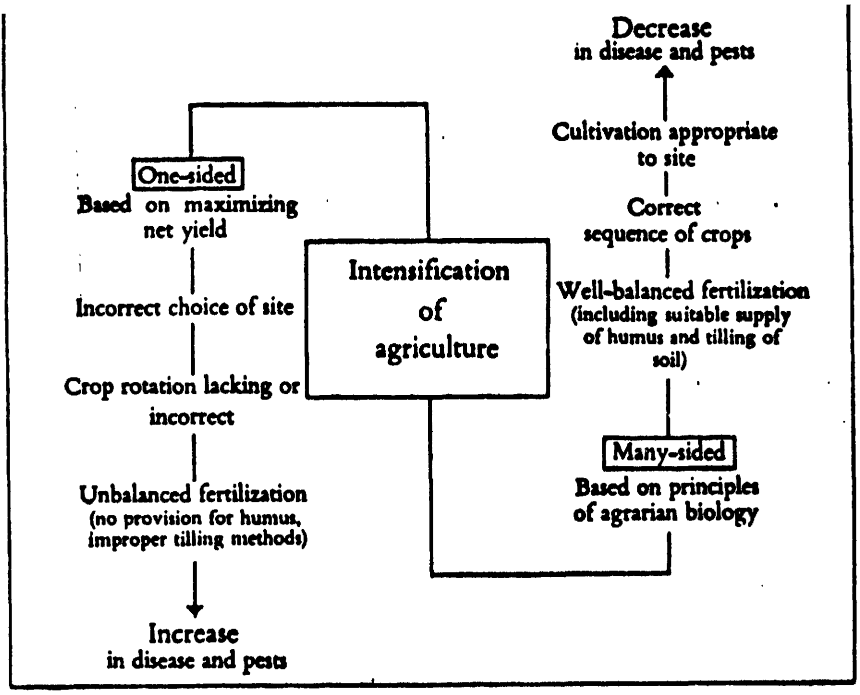


Figure 21: Two methods of agriculture producing different results; intensive profit-minded procedures result in an increase of disease and pests, while a more diversified approach can lead to a decrease.

(Source: W. SCHUPHAN, p.630.)

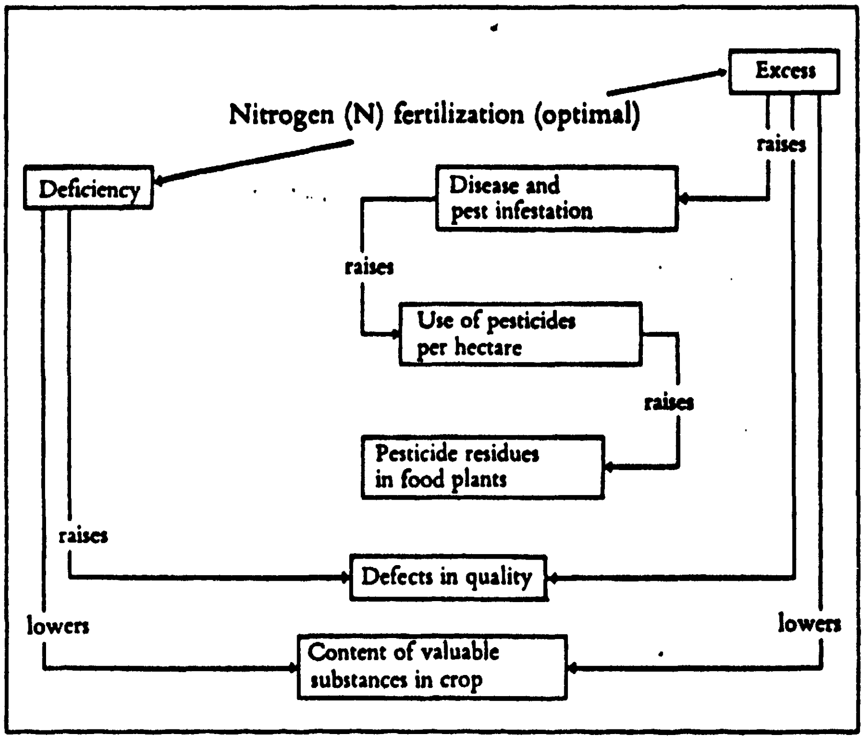


Figure 22: Schematic representation of the negative consequences of inadequate fertilization, and of excessive fertilization, with nitrogen. There are a few exceptions: for example, nitrogen application suppresses the pathogens that cause the bases of wheat stalks to turn black.

(Source:
W. SCHUPHAN,
p.632)

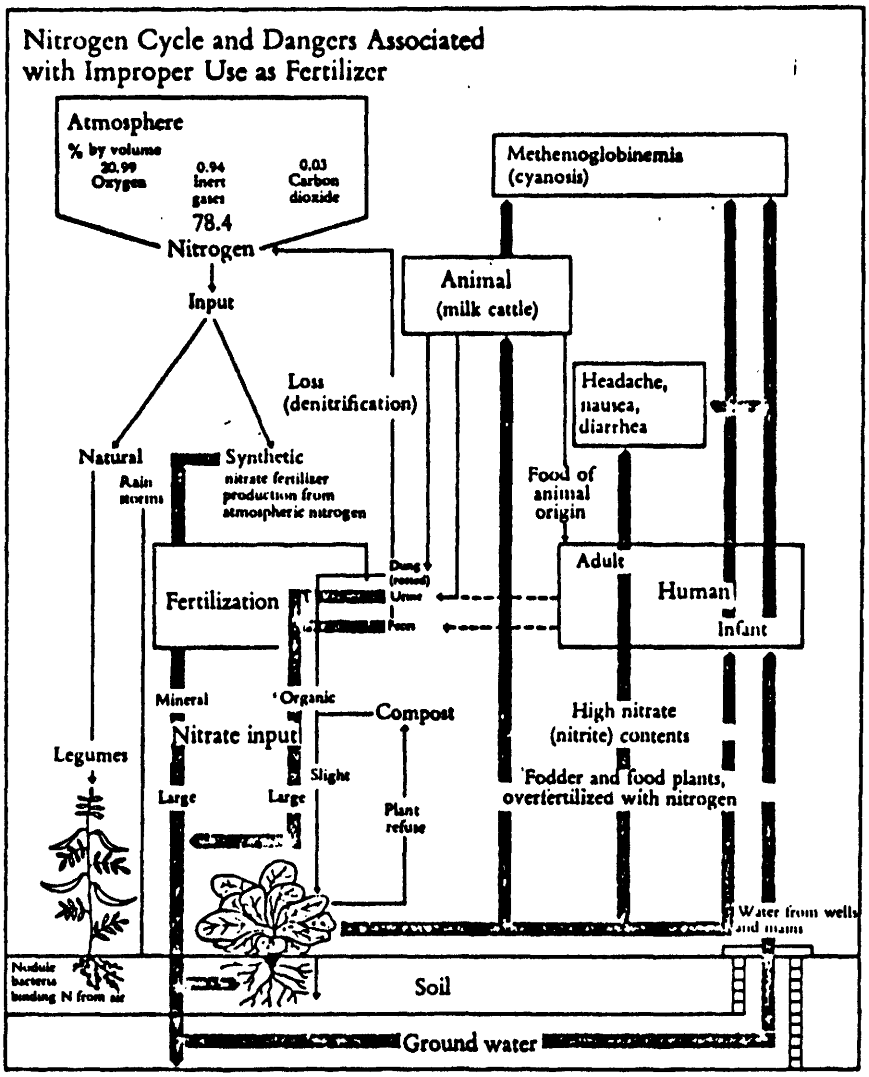
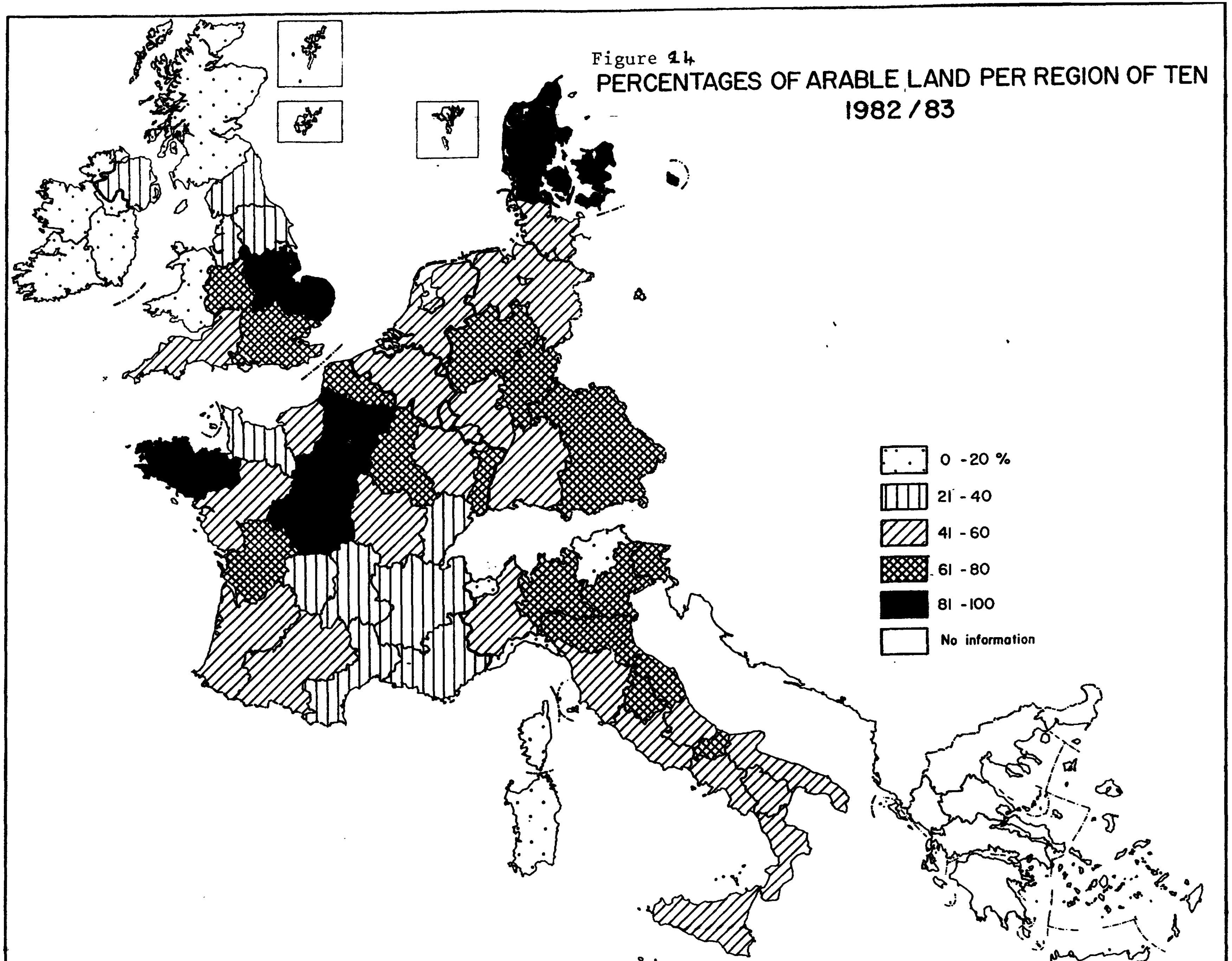


Figure 23: Nitrogen cycle, through biotic and abiotic parts of an ecosystem, indicating possible damage due to improper use of nitrogens as fertilizer.

(Source: W. SCHUPHAN, p.635.)

Figure 14

PERCENTAGES OF ARABLE LAND PER REGION OF TEN 1982/83



(Source: M. ONIDI , DG VI A2)

Table 1: N_2-FIXING MICROORGANISMS

Chemoheterotrophic bacteria [19, 21, 22, 32]

Agrobacterium[b]
Alcaligenes
Aquaspirillum
Arthrobacter
Azomonas
Azospirillum[c]
Azotobacter
Bacillus
Beijerinckia
Campylobacter
Citrobacter
Clostridium
Derxia[c]
Desulfotomaculum
Desulfovibrio
Enterobacter
Erwinia
Escherichia[b]
Frankia
Klebsiella
Mycoplana [33]
Propionibacterium
Rhizobium[c]

Chemoautotrophic bacteria and phototrophic bacteria [19, 20, 21, 32]

Amoebobacter[d]
Chlorobium[d]
Chromatium[d]
CO-utilizing organism
Ectothiorhodospira[d]
Methylobacter
Methylococcus
Methylocystis
Methylomonas
Methylosinus
Mycobacterium
Pelodictyon[d]
Prosthecochloris[d]
Rhodomicrobium[d]
Rhodopseudomonas[d]
Rhodospirillum[d]
Thiobacillus
Thiocapsa[d]
Thiocystis[d]
Xanthobacter

Cyanobacteria

Anabaena
Calothrix
Chlorogloeopsis
Chroococcidiopsis
Cylindrospermum
Dermocarpa
Fischerella
Gloeothece
LPP – group A
LPP – group B
Myxosarcina
Nodularia
Nostoc
Oscillatoria
Pleurocapsa group
Pseudanabaena
Scytonema
Synechococcus
Xenococcus

[a] Not all strains necessarily fix N_2.

[b] Genetically manipulated in laboratory to fix N_2.

[c] May also grow chemoautotrophically.

[d] Phototrophic bacteria.

(Source: Royal Society Report 1983, pp.41-42.)

Table 2: PLANTS WHICH DEVELOP IN SYMBIOSIS WITH N_2-FIXING MICROORGANISMS

Microorganism	Plant
Rhizobium	Legumes (e.g. *Pisum* (peas), *Trifolium* (clover)), *Parasponia*[a], *Fagonia*[b], *Tribulus*[b], *Zygophyllum*[b]
Frankia[c]	*Alnus, Casuarina, Ceanothus, Cercocarpus, Chamaebatia, Colletia, Coriaria, Cowania, Datisca, Discaria, Dryas, Elaeagnus, Hippophaë, Myrica, Purshia, Rubus, Shepherdia, Trevoa*
Bacteria other than *Rhizobium* and *Frankia*[d]	Barley, *Digitaria*, Maize, Millet, Oats, *Panicum, Paspalum*, Rice, Rye, *Setaria, Sorghum*, Wheat and other tropical and temperate Graminae.
Cyanobacteria	*Anthoceros*[e], *Azolla*[f], *Blasia*[e], *Bowenia*[g], *Cavicularia*[e], *Ceratozamia*[g], *Cycas*[g], *Dioon*[g], *Encephalartos*[g], Fungi (lichens)[h], *Gunnera*[i], *Macrozamia*[g], *Microcycas*[g], *Rhizosolenia*[j], *Rhopalodia*[j], *Sphagnum*[k], *Stangeria*[g], *Zamia*[g].

[a] Member of the Ulmaceae; [b] Member of the Zygophyllaceae, preliminary data only; [c] All species of any genus infected by *Frankia* are generally nodulated except for *Dryas, Ceanothus* and *Rubus*; [d] Genera reported in associative symbiosis include an *Achromobacter*-like organism, *Aquaspirillum* (with aquatic plants), *Azospirillum, Azotobacter, Bacillus, Beijerinckia, Campylobacter, Derxia, Enterobacter, Klebsiella* and *Rhodopseudomonas*; [e] liverwort with *Nostoc* as symbiont; [f] fern with *Anabaena* as symbiont; [g] gymnosperm bearing root nodules infected by a cyanobacterium (*Nostoc*); [h] N_2-fixing lichen genera include: *Collema, Dendriscocaulon, Ephebe, Leptogium, Lichina, Lobaria, Massalongia, Nephroma, Pannaria, Parmeliella, Peltigera, Placopsis, Placynthium, Polychidium, Pseudocyphellaria, Solarina, Stereocaulon, Sticta*; [i] angiosperm with *Nostoc* in leaf glands; [j] diatom; [k] loose moss association with various cyanobacteria, particularly *Fischerella*.

Table 3: Estimated inputs of N in agricultural land of the UK in 1978.

Inputs	N(K$^+$)
Rain	275
Seeds	14
NF	1150
Sewage	26
Livestock excreta	1020
Silage effluent	9
Straw	15
Feed waste	9
Biological N_2 fixation	150

(Adapted from: The Royal Society Report 1983, p.57)

Table 4: Origin and quantity of N in France.

Origin of nitrogen	Quantities released or contributed in France (millions of tonnes of nitrogen per annum)
Mineralization of organic matter in the soil	3.0
Inorganic fertilizers	2.0
Atmospheric contributions	0.5
Domestic sewage	0.2 - 0.25
Farm wastes (livestock rearing)	2.0
Symbiotic and non-symbiotic fixation	1.3
Nitrogen of an industrial origin	0.1
"Import-export" balance of food products	0.1
Total	9.2

(from: S. Henin, WRC, paper 12: Water Quality-The French Problem. June 1985)

Table 5: Inputs of nitrogen in Denmark, 1981-82.

	1000 tonnes in
Commercial fertilizers	376
Imported feed and fish products	180
Precipitation	44
Dry deposition	16
Biological N-fixing	30
Total	646

(Adapted from: The NPO Report. August 1984)

Table 6: Consumption of Nitrogenous Fertilizers in the Ten and the Twelve from 1953 to 1982 in metric tonnes of **plant nutrient.**

Year	B-L	DK	FR	FRG	GR	IRL	IT	NL	UK	E-10	E-12
1953/54	100321	78528	295300	440000	37321	12037	209024	172900	245900	1557741	1709805
1954/55	97015	76108	347925	452463	43800	14700	237895	187000	252638	1566944	1767166
1955/56	88988	88737	381100	471610	41573	13609	253874	184300	236400	1760191	1975691
1956/57	91409	96278	402900	527300	55864	15890	273306	193700	307670	1964317	2183392
1957/58	92363	98454	488900	566600	62550	17985	268660	209100	315100	2119712	2357836
1958/59	101356	104200	520000	574800	70796	20600	298327	209100	348100	2247279	2587526
1959/60	103113	122831	504800	624600	69548	21749	350769	212100	421600	2431110	2735954
1960/61	105110	123978	565100	618400	73123	24579	322603	223600	463000	2519493	2858500
1961/62	109132	133481	624700	621100	83348	28856	347749	242900	496900	2688166	3083737
1962/63	148655	142167	682821	773761	96667	33486	376504	293750	541500	3089311	3489874
1963/64	161642	152795	790672	746513	115933	34695	374984	289700	584000	3250934	3670813
1964/65	127614	168692	860500	784606	131060	29624	403647	293723	596000	3395466	3868323
1965/66	153477	191595	870600	873823	133929	31900	461767	310827	689700	3717618	4190644
1966/67	160527	214856	990017	888619	145103	47828	475340	337397	759800	3874987	4418619
1967/68	177899	232631	1133668	950210	156792	53300	479701	343470	908800	4178921	4758325
1968/69	176033	247988	1243125	932668	182121	64100	513595	339200	855300	4412595	5082004
1969/70	188404	270213	1241347	1084576	190107	71900	550402	387412	690300	4474149	5193509
1970/71	177725	289341	1453446	1130822	200640	86500	594547	405260	800800	5139081	5793725
1971/72	179427	308252	1524827	1131134	205699	98300	624874	373643	930100	5376256	6133731
1972/73	179843	329476	1588051	1189022	212465	131700	691806	376263	789200	5487826	6307522
1973/74	179225	365148	1833083	1100841	244293	130200	672178	411974	874400	5811342	6667521
1974/75	185100	300445	1554800	1200939	251500	133000	672195	434952	927000	5659931	6500520
1975/76	182485	339088	1707800	1228142	275080	152739	724337	452696	1045000	6107367	6970521
1976/77	189039	349497	1815000	1323051	291310	168159	699726	429852	1110000	6375634	7342620
1977/78	191795	373710	1817000	1324702	294000	230466	817300	446681	1177000	6672654	7476168
1978/79	196657	379884	1978000	1354054	241200	263600	1042654	443340	1222000	7221389	8230596
1979/80	197758	393900	2134800	1477489	356100	247500	1106810	486130	1314000	7714487	8777693
1980/81	194279	374099	2146500	1550815	333300	275100	1006011	482803	1246000	7608907	8647296
1981/82	195300	375972	2193000	1323001	373289	275200	987968	477273	1386000	7589003	8550136
1982/83	197000	391392	2193000	1464524	408000	296000	967833	456718	1560000	7937867	8875559

(Source: FAO Fertilizer Yearbooks.)

K.J.McCARTHY DG VI A2 March 1985.

Table 7:
Average application rates of Nitrogenous Fertilizers in the Ten and the Twelve from 1955 to 1982 in Kg per hectare of Plant Nutrient for Arable and Grassland excluding Rough Grazing.

Year	B-L	DK	FR	DE	IRL	IT	NL	UK	GR	E-10	E-12
1955	49.53	28.67	14.52	35.20	2.90	14.62	82.08	19.00	4.79	19.18	15.47
1956	50.70	31.02	14.68	39.25	3.38	15.70	86.34	24.72	6.42	21.52	17.17
1957	51.47	31.62	17.81	42.26	3.80	15.42	93.22	25.35	7.12	23.17	18.51
1958	56.37	33.45	18.84	43.00	4.37	17.16	93.28	28.03	7.98	24.55	20.31
1959	58.09	39.53	18.25	46.81	4.62	20.24	94.40	35.81	7.84	26.77	21.51
1960	58.97	40.07	20.31	46.46	5.41	18.70	99.16	39.50	8.21	27.77	22.45
1961	61.61	42.69	22.42	46.86	6.34	20.42	107.85	42.41	9.36	29.71	23.92
1962	84.40	45.73	24.50	58.52	7.26	22.16	131.02	46.13	10.86	34.15	26.79
1963	92.35	49.96	28.43	56.55	7.52	22.22	130.00	47.53	13.01	35.83	28.10
1964	73.42	55.46	31.20	59.58	6.36	23.97	133.03	48.41	14.58	37.51	30.23
1965	88.92	63.70	31.62	67.15	6.80	27.44	141.39	56.10	15.05	41.22	32.86
1966	93.58	71.58	36.05	68.57	10.05	28.38	154.00	61.40	16.05	42.95	34.77
1967	104.35	77.62	41.41	73.53	11.15	28.70	157.25	73.84	17.21	46.38	37.47
1968	103.93	82.92	45.17	72.89	13.35	30.96	155.78	69.98	19.93	49.07	40.18
1969	111.89	91.11	45.08	84.95	14.94	33.12	179.03	57.73	23.08	50.30	41.38
1970	105.77	98.09	53.33	87.99	18.05	36.06	188.48	66.44	24.33	58.10	46.40
1971	107.60	105.39	55.97	88.46	20.39	42.55	178.95	77.09	24.92	62.12	49.64
1972	108.49	112.44	58.21	93.09	27.29	47.60	181.36	65.51	25.75	63.54	51.21
1973	108.84	123.36	67.25	86.51	26.90	46.45	199.79	70.30	29.70	67.08	54.19
1974	113.40	103.14	57.03	94.96	27.44	46.46	211.82	74.60	30.61	65.46	52.97
1975	113.00	116.03	62.78	97.36	32.60	50.06	221.65	84.63	33.64	70.95	57.07
1976	117.86	119.73	66.62	105.13	35.85	48.35	211.09	89.96	35.19	74.00	60.26
1977	120.70	128.26	66.73	105.64	48.83	56.55	202.77	95.48	36.13	77.65	61.47
1978	124.95	130.54	72.65	108.35	55.80	71.69	220.68	98.21	29.45	83.85	67.63
1979	127.38	135.52	78.38	123.55	52.27	76.16	243.33	105.45	43.44	90.15	72.53
1980	126.27	129.38	78.64	130.35	58.60	69.32	243.02	99.37	40.79	88.96	71.56
1981	127.79	130.38	80.23	111.66	58.81	68.23	241.30	111.10	45.55	88.86	70.84
1982	129.45	136.37	80.20	124.12	63.43	66.77	231.44	125.03	49.76	93.00	73.58

(Source: FAO Yearbooks and CRONOS/EUROSTAT.)

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Table 8: An index of the average Nitrogenous Fertilizer application rate per hectare in the Ten and the Twelve from 1955 to 1982. (Base year 1955)

Year	B-L	DK	FR	DE	IRL	IT	NL	UK	GR	E-10	E-12
1955	97.95	94.20	92.66	90.48	86.31	95.89	94.11	82.52	78.39	90.10	90.73
1956	100.26	101.91	93.68	100.89	100.59	102.97	98.99	107.36	105.07	101.08	100.70
1957	101.78	103.88	113.65	108.62	113.09	101.13	106.88	110.10	116.53	108.83	108.56
1958	111.47	109.90	120.23	110.53	130.05	112.54	106.95	121.74	130.60	115.31	119.12
1959	114.87	129.87	116.46	120.32	137.50	132.75	108.24	155.53	128.31	125.74	126.15
1960	116.61	131.65	129.61	119.42	161.01	122.65	113.69	171.56	134.37	130.43	131.67
1961	121.83	140.25	143.07	120.45	168.69	133.93	123.66	184.20	153.19	139.54	140.29
1962	166.90	150.24	156.35	150.42	216.07	145.34	150.22	200.36	177.74	160.40	157.12
1963	182.63	164.14	181.43	145.36	223.81	145.73	149.06	206.44	212.93	168.29	164.80
1964	145.19	182.21	199.10	153.14	189.28	157.21	152.53	210.26	238.62	176.18	177.30
1965	175.84	209.28	201.78	172.60	202.38	179.97	162.12	243.66	246.31	193.61	192.72
1966	185.06	235.17	230.05	176.25	299.10	186.13	176.57	266.68	262.68	201.73	203.93
1967	206.36	255.02	264.26	189.00	331.84	188.23	180.30	320.71	281.66	217.84	219.76
1968	205.53	272.43	288.25	187.36	397.32	203.06	178.61	303.95	326.18	230.48	235.66
1969	221.27	299.34	287.68	218.36	444.64	217.22	205.27	250.74	377.74	236.26	242.69
1970	209.16	322.27	340.33	226.17	537.20	236.51	216.11	288.57	398.19	272.89	272.14
1971	212.78	346.26	357.17	227.38	606.84	279.07	205.18	334.83	407.85	291.78	291.14
1972	214.54	369.42	371.47	239.28	812.20	312.19	207.95	284.53	421.44	298.45	300.35
1973	215.24	405.30	429.16	222.37	800.59	304.65	229.08	305.34	486.08	315.07	317.83
1974	224.25	338.86	363.94	244.09	816.66	304.72	242.87	324.01	500.98	307.46	310.67
1975	223.46	381.21	400.63	250.26	970.23	328.33	254.14	367.58	550.57	333.25	334.72
1976	233.07	393.37	425.14	270.23	1066.96	317.11	242.03	390.73	575.94	347.58	353.43
1977	238.69	421.40	425.84	271.54	1453.27	370.90	232.49	414.71	591.32	364.72	360.52
1978	247.10	428.89	463.62	278.51	1660.71	470.20	253.03	426.56	481.99	393.84	396.65
1979	251.90	445.25	500.19	317.58	1555.65	499.51	279.00	458.01	710.96	423.43	425.39
1980	249.71	425.08	501.85	335.06	1744.05	454.65	278.65	431.60	667.59	417.84	419.70
1981	252.71	428.36	511.99	287.01	1750.30	447.50	276.67	482.55	745.49	417.37	415.48
1982	255.99	448.04	511.80	319.04	1887.80	437.93	265.37	543.05	814.40	436.82	431.55

(Source: FAO Yearbooks and CRONOS/EUROSTAT.)

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Table 9: Estimated N fertilizer application rates per hectare in the Ten and the Twelve from 1955 to 1982 according to statistical analysis, and extended to 2000.

Year	B-L	DK	FR	DE	IRL	IT	NL	UK	GR	E-10	E-12
1955	52.53	21.78	9.05	32.40	2.84	14.25	78.26	20.21	6.20	14.47	11.74
1956	55.70	26.39	11.78	35.81	3.21	15.18	84.67	23.58	6.72	17.35	14.05
1957	58.88	31.00	14.52	39.23	3.62	16.17	91.08	26.95	7.29	20.23	16.35
1958	62.05	35.62	17.26	42.65	4.09	17.22	97.48	30.31	7.40	23.11	18.66
1959	65.23	40.23	19.99	46.06	4.61	18.34	103.89	33.68	8.56	25.99	20.96
1960	68.40	44.84	22.73	49.48	5.21	19.54	110.30	37.05	9.29	28.87	23.27
1961	71.58	49.46	25.47	52.90	5.87	20.81	116.71	40.42	10.07	31.75	25.57
1962	74.75	54.07	28.21	56.31	6.63	22.17	123.12	43.79	10.92	34.63	27.68
1963	77.93	58.68	30.95	59.73	7.48	23.62	129.52	47.15	11.84	37.51	30.19
1964	81.10	63.30	33.68	63.15	8.44	25.15	135.93	50.52	12.84	40.39	32.49
1965	84.28	67.91	36.42	66.56	9.53	26.79	142.34	53.89	13.92	43.27	34.80
1966	87.45	72.52	39.16	69.98	10.75	28.54	148.74	57.26	15.10	46.15	37.10
1967	90.63	77.14	41.90	73.40	12.14	30.40	155.15	60.63	16.37	49.03	39.41
1968	93.80	81.75	44.64	76.81	13.70	32.38	161.56	63.99	17.75	51.91	41.72
1969	96.98	86.36	47.38	80.23	15.46	34.49	167.97	67.36	19.25	54.78	44.02
1970	100.15	90.98	50.11	83.65	17.45	36.74	174.37	70.73	20.87	57.66	46.33
1971	103.33	95.59	52.85	87.06	19.69	39.13	180.78	74.10	22.63	60.54	48.63
1972	106.50	100.21	55.59	90.48	22.22	41.69	187.19	77.47	24.54	63.42	50.94
1973	109.68	104.82	58.33	93.90	25.08	44.40	193.60	80.83	26.61	66.30	53.25
1974	112.85	109.43	61.07	97.31	28.51	47.30	200.00	84.20	28.85	69.18	55.55
1975	116.03	114.05	63.80	100.73	31.95	50.38	206.41	87.57	31.29	72.06	57.86
1976	119.20	118.66	66.54	104.15	36.06	53.66	212.82	90.94	33.92	74.94	60.16
1977	122.38	123.27	69.28	107.56	40.70	57.16	219.23	94.30	36.78	77.82	62.47
1978	125.55	127.89	72.02	110.98	45.93	60.88	225.63	97.67	39.89	80.70	64.78
1979	128.73	132.50	74.76	114.40	51.84	64.85	232.04	101.04	43.25	83.58	67.08
1980	131.90	137.11	77.50	117.81	58.50	69.08	238.45	104.41	46.90	86.46	69.39
1981	135.08	141.73	80.23	121.23	66.03	73.58	244.86	107.78	50.85	89.34	71.69
1982	138.25	146.34	82.97	124.65	74.52	78.37	251.26	111.14	55.14	92.22	74.00
1983	141.43	150.95	85.71	128.06	84.10	83.48	257.67	114.51	59.79	95.10	76.30
1984	144.60	155.57	88.45	131.48	94.92	88.92	264.08	117.88	64.83	97.98	78.61
1985	147.78	160.18	91.19	134.90	107.13	94.72	270.49	121.25	70.30	100.86	80.92
1986	150.95	164.79	93.92	138.31	120.90	100.89	276.89	124.62	76.22	103.74	83.22
1987	154.13	169.41	96.66	141.73	136.45	107.46	283.30	127.98	82.65	106.62	85.53
1988	157.30	174.02	99.40	145.15	154.00	114.47	289.71	131.35	89.62	109.50	87.83
1989	160.48	178.63	102.14	148.56	173.80	121.93	296.12	134.72	97.17	112.36	90.14
1990	163.65	183.25	104.88	151.98	196.13	129.87	302.52	138.09	105.37	115.26	92.45
1991	166.83	187.86	107.62	155.40	221.38	138.34	308.93	141.46	114.25	118.19	94.75
1992	170.00	192.48	110.35	158.81	249.85	147.35	315.34	144.82	123.89	121.02	97.06
1993	173.18	197.09	113.09	162.23	281.97	156.95	321.75	148.19	134.33	123.90	99.36
1994	176.35	201.70	115.83	165.65	318.24	167.18	328.15	151.56	145.66	126.78	101.67
1995	179.53	206.32	118.57	169.06	359.16	178.07	334.56	154.93	157.94	129.66	103.98
1996	182.71	210.93	121.31	172.48	405.35	189.68	340.97	158.29	171.25	132.54	106.26
1997	185.88	215.54	124.05	175.90	457.47	202.04	347.38	161.66	185.69	135.42	108.59
1998	189.06	220.16	126.78	179.31	516.30	215.20	353.78	165.03	201.35	138.30	110.89
1999	192.23	224.77	129.52	182.73	552.70	229.23	360.19	168.40	218.33	141.18	113.20
2000	195.41	229.38	132.26	186.15	657.63	244.17	366.60	171.77	236.73	144.06	115.51

(Source: Computer Programme TSP NITROGEN, N. ROBSON DG VI A2, and NITROGEN DATA, K.J.McCARTHY DG VI A2

Table 10: Example of Fertilizer Recommendations in the UK.

Wheat (winter). Average summer rainfall less than 16 in.: recommended rates of nutrients in units per acre

Crop	Nutrient Index		N					P				K				Mg	
			0	1	2	3	4	0	1	2	Over 2	0	1	2	Over 2	0	Over 0
	Soils		Units N Spring Top Dressings					Units P_2O_5				Units K_2O				Units Mg	
	Texture	Depth (a)															
Wheat—winter	Sands Loamy coarse sands Loamy sands Coarse sandy loams		140(c)	100	60	30	Nil	60	30	30	Nil	60	30	0)*	Nil	50(b)	*Nil*
	Loamy fine sands Loamy very fine sands Sandy loams	Less than 9 in.	140(c)	100	60	30	Nil	60	30	30	Nil	60	30	(30)*	Nil	50(b)	*Nil*
		More than 9 in.	120(c)	80	50	30	Nil	60	30	30	Nil	60	30	(30)*	Nil	50(b)	*Nil*
	Fine sandy loams Very fine sandy loams Silty loams	Less than 9 in.	120(c)	80	50	30	Nil	60	30	30	Nil	60	30	(30)*	Nil	50(b)	*Nil*
		9–24 in.	100(c)	70	50	30	Nil	60	30	30	Nil	60	30	(30)*	Nil	50(b)	*Nil*
		More than 24 in.	80(c)	50	30	Nil	Nil	60	30	30	Nil	60	30	(30)*	Nil	50(b)	*Nil*
	Other textures	Less than 9 in.	100(c)	70	50	30	Nil	60	30	30	30	60	30	(30)*	Nil	50(b)	*Nil*
		More than 9 in.	80(c)	60	40	Nil	Nil	60	30	30	30	60	30	(30)*	Nil	50(b)	*Nil*

[a] Depth to rock or other root restriction.

[b] 50 units/acre Mg once in 5 years for continuous cereals. When cereals are grown in rotation with roots 75 units/acre Mg should be applied for the root crop.

[c] Where take-all is expected to be a factor limiting yield or on droughty sands e.g., the Breckland, crop response is unlikely to justify nitrogen applications greater than those recommended at N index 1.

Notes. 1 Phosphate and potash should be combined drilled at P & K index 0, but if broadcast at this index the rate should be increased by 20 units per acre.

2 On fields in long term cereals where yields are regularly in excess of 2 tons per acre, recommendations of 30 units P_2O_5 should be increased to 45 units to avoid depletion of phosphate reserves.

3 There is no need for nitrogen in the seed bed except for late sown crops or poor seed beds when 20 units should be applied.

4 Where the N index is greater than 0 top dressings should be reduced by 20 units when winter leaching has been much less than normal for the area and increased by 20 units when it has been much greater than normal. (For average winter rainfall in any area, see Appendix ii.)

5 Where N indices are 0 and 1, part of the top dressing should be applied early: at higher indices the top dressing should be delayed to minimize lodging.

6 Some varieties are sensitive to excess nitrogen and care should be taken not to exceed the recommended dressings.

(Source: Fertilizer Recommendations. MAFF UK 1973, p. 30)

Table 11: Applications of fertilizer N to different grassland systems in England and Wales in 1981.
(Source: The Royal Society Report, p.92)

Predominant management	area receiving N (per cent of total)	annual amount[a] (kg N ha^{-1})
paddock grazed	96	247
paddock grazed and mown	91	221
strip grazed	98	221
strip grazed and mown	94	218
set stocked	83	230
set stocked and mown	95	187
cut for seed	79	154
cut for silage	98	205
cut for hay	73	96
cut for hay and grazed[b]	86	98
other grazings	67	110

[a] Excludes area of grass given no N.

[b] Excluding fields intensively grazed as in the first six categories above.

Table 12: Nonagricultural practices for nitrate pollution control.

Practice	Characteristics
Development of a new water supply	Less expensive; short time implementation; modification to distribution system; water quality may change.
Blending of two or more water supplies	Less expensive; short time implementation; extensive modifications may be required for blending
Connect to an approved water supply	Less expensive; short time implementation; few modifications; no control over water supply; dependent on another utility.
Water treatment methods	
- chemical coagulation	not effective
- lime softening	not effective
- chemical reduction	has potential, but not practical
- biological denitrification	has potential, but not accepted
Ion exchange	effective
Reverse osmosis	effective, but costly
Electrodialysis	effective, but costly

(Source: SORG, 1980 in DE HAEN, p.458)

Table 13: Agricultural practices for nitrate pollution control.

Nutrient control practice	Characteristics
I. Increase of fertilizer efficiency	
Eliminating excessive fertilization	
- checking availability in soil and nutrient supply from manure	may cut nitrate leaching: no yield effect; lower fertilizer costs.
- avoiding over-intensive manure spreading	may cut nitrate leaching appreciably; possibly positive yield effect; higher costs of manure transport.
II. Leaching control	
Timing nitrogen application	
- more and smaller doses	reduces nitrate leaching; increases fertilizer efficiency; ideal timing may be costly and less convenient.
- leave fertilization	
Using crop rotations	substantially reduces nutrient inputs; not compatible with many farm enterprises; reduces erosion and pesticide use.
Using animal wastes for fertilizer	economic gain for some farm enterprieses; slow release of nutrients; spreading problems.
Plowing-under green legume crops	reduces use of nitrogen fertilizer; not always feasible.
Using winter cover crops	uses nitrate and reduces percolation; not applicable in some regions; reduces winter erosion.
Controlling fertilizer release of transformation	may decrease nitrate leaching; usually not economically feasible; needs additional research and development.
III. Control of nutrient loss through runoff and erosion	
Improving the management of fertilizer surface applications	
- incorporating into soil	decreases nutrients in runoff; no yield effect; not always possible; adds costs in some cases.
- timing according to weather and soil condition	not always technically feasible; reduces erosion and nutrient loss.
Using legumes in haylands and pastures	replaces nitrogen fertilizer; limited applicability; difficult to manage.
IV. Control of N contamination in food stuff	
Reducing fertilizer intensity for endangered products(e.g. vegetables)	reduces leaching; may reduce nitrates/ nitrites in food (more research needed); negative yield effect; lower gross margins.
V. Research and development	
Developing new kinds of fertilizer with slower solubility	potential cut of nitrate leaching in the long run
breeding of plants with lower or more effecient use of mineral fertilizer	no or limited immediate effect

(Source: Adapted from STEWARD et al, 1975 in DE HAEN, p. 456)