NITRATE LEACHING HAZARDS: A LOOK AT THE POTENTIAL GLOBAL SITUATION

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PREFACE

The intensification of agricultural production is the principal way of increasing the food supply for mankind. The experience of developed countries demonstrates that the ever increasing amount of nitrogenous fertilizers applied may create serious problems with drinking water supply, because of its high nitrates content. The same problem can be expected in developing countries if the level of nitrogen loads reaches that of developed countries today. The present paper tries to assess the potential global picture with regard to nitrogen leaching in its dependence on climatic factors, which influence both directly and indirectly the processes of a local nitrogen cycle.

The Task "Environmental Problems of Agriculture" conducted most of its work at a field level. Methodologically, this is an attempt to use field level data to analyze the global situation.

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INTRODUCTION

The increasing inputs of nitrogenous compounds, primarily nitrates, into natural waters stands among the acute problems caused by technological progress within the past two decades. Higher nitrogen contents then increase the rate of eutrophication in water bodies and, more important, do not match health standards for drinking water. There are a number of major sources of nitrogen in natural waters, fertilizers being one of the most important. This is because nitrates usually travel down to surface and groundwaters, through leaching from the root zone.

The quantity of publications devoted to this problem continually grows. For instance, at the April 1979 conference on "Environmental Management of Agricultural Watersheds" organized by IIASA and the Czechoslovak Academy of Sciences, many papers discussed various aspects of the nitrates problem in Czechoslovakia, the United Kingdom, the USA, the German Democratic Republic, Finland, the USSR, and Italy (Golubev and Vasiliev, 1979; Golubev, 1980). According to studies carried out at the Thames Water Authority in England, one of the main factors contributing to the increase of nitrates concentration in surface waters of the Thames is the growth of fertilizer loads. In the most realistic scenario, a mean annual level of NO_3-N would reach the permitted health standard of 11.3 mg N/l by the beginning of the 1990's. This means of course, that before 1990, due to daily fluctuations of nitrates, the level of these chemicals will have surpassed the admissable standard for some periods within a yearly cycle (Onstad and Blake, 1979). The resulting limitations on usage of water, the quality of which has been affected by nitrates, would then further lessen the reliability of the water supply system for Greater London (Sexton and Onstad, 1980). Drinking water supply from wells in the Skåne Province of Sweden has also evidenced pollution problems because of increased concentrations of nitrates in groundwaters.

More evidence than can be cited exists which proves that the problem of nitrates water pollution, to a considerable extent associated with high fertilizer loads, is a common and acute problem of developed countries. It seems that in the West European countries with dense population and the highest levels of fertilizer application, nitrates water pollution is a more widespread problem than in larger countries with less fertilizer loads, such as the USA or the USSR, where the nitrates pollution problem so far appears only in spots. Nevertheless, the nitrate problem will remain serious in developed countries.

As trends indicate an increase of fertilizer application in developing countries, one could expect that the same problem will occur there. This leads to the main question of this paper: what would the world picture of nitrates leaching be if rates of fertilization were high everywhere? There are reasons to believe that the process of nitrates leaching, as a result of nitrogen balance in an agroecosystem, strongly depends on natural factors, including climate. Before attacking the major question, we shall address the problem of nitrogen balance in agroecological systems.

THE INCREASE IN FERTILIZER APPLICATION

All plants require a certain amount of nutrients which are taken from the soil. Some part of the nutrients consumed is returned to the soil in the form of the residual organic matter containing those nutrients (fruits, dead leaves, branches, stems, stocks, roots, etc.). Decomposition of the organic matter accumulated in/on the soil creates new portions of nutrients and the cycle closes. Some amount of the nitrogen is fixed from the atmosphere by microorganisms; some is brought with rain and dust. On the negative side of the balance are leaching and surface runoff of soluble nutrients, outflow with soil particles, due to erosion, and denitrification and volatilization of gaseous forms. In any case, the balance of nutrients in natural ecosystems is close to zero if regarded in terms of a human lifetime, or even that of the time lapsed since the development of human societies. Table 1 gives an example of the nitrogen balance for a natural steppe ecosystem in Eastern Europe, the data being taken from Evdokimova et al. (1976), and Pannikov and Mineev (1977).

Table 1. Balance of nitrogen in the steppe zone of the Russian Plain, prehistoric period.

Precipitation kg.ha.$^{-1}$yr.$^{-1}$	Runoff kg.ha.$^{-1}$yr.$^{-1}$	Balance kg.ha.$^{-1}$yr.$^{-1}$	Pool of nitrogen in 1m of topsoil	
			kg.ha.$^{-1}$yr.$^{-1}$	Balance as related to the pool,%
+4	-0.2	+3.8	about 30,000	0.01

Agroecosystems, including cropland systems, disrupt the natural, semiclosed balance of nutrients. The annual harvest removes some part of the nutrients contained in cropland products. A yield of 4 t/ha of wheat thus takes out of the system, via grain and straw, about 100 kg N/ha; the figures for corn are similar. Other crops usually carry away dozens or even over a hundred kilograms of nitrogen per hectare per year.

The higher the yield (or else intensity of agriculture), the higher is the removal of fertilizers with the harvest. This is illustrated in Figure 1, adapted from Frissel (1977), where 65 agroecosystems in various parts of the world were analyzed. According to Figure 1, extensive arable farming withdraws from 1 to 10 kg. of nitrogen per hectare per year from the soil. Intensive farming removes from 30 to 200 and even up to 400 kg N/ha per year.

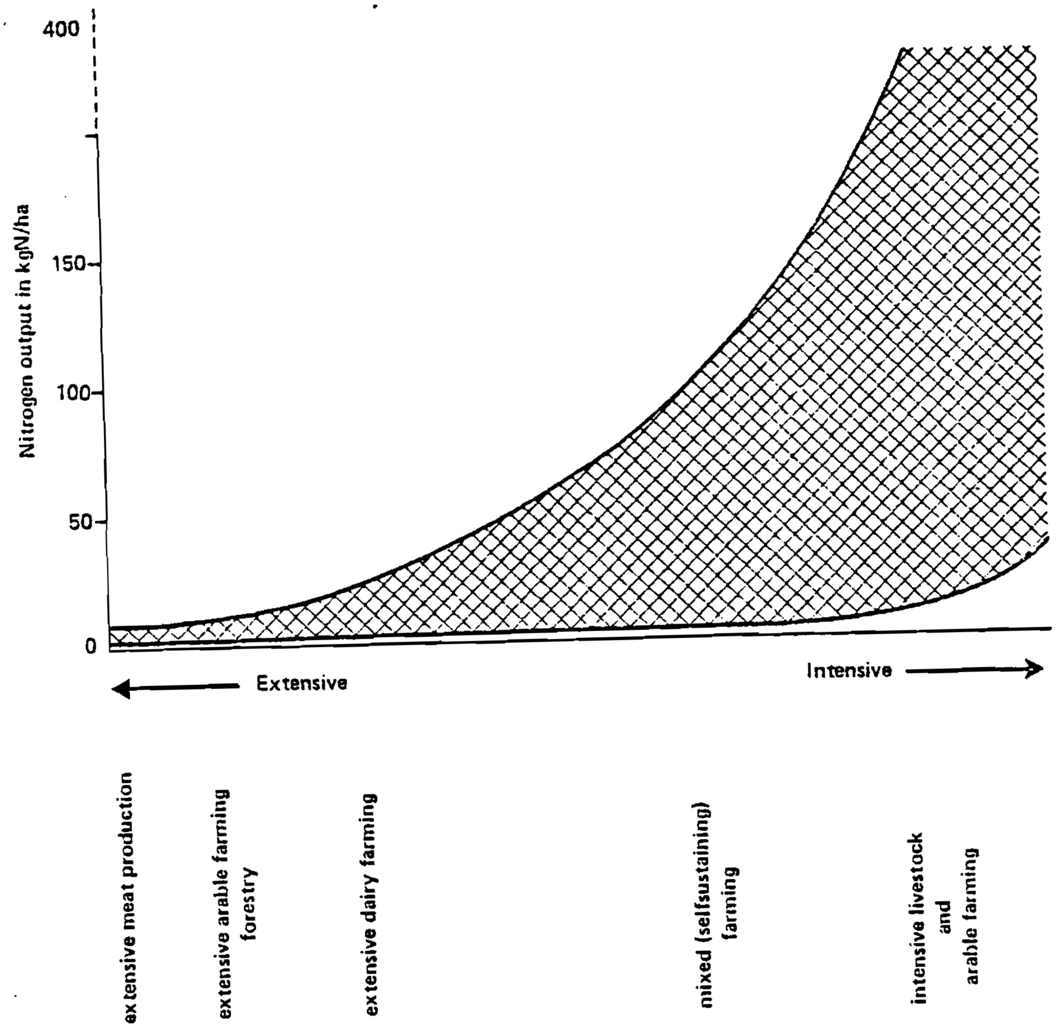

Figure 1. Nitrogen Output vs. Intensity of Agroecosystem

Nitrogen in soil is stored mainly in the form of organic compounds which are not soluble in water and therefore cannot be consumed by plants. Transformation of organic nitrogen into water soluble inorganic forms provides nutrient matters for the plants. The pool of organic nitrogen in soils is very large as compared with the annual amount of the soluble forms produced. Below is the total nitrogen content contained in typical soils of the USSR (Pannikov and Mineev, 1977).

Table 2. Pool of total nitrogen in soils of the USSR, in thousand kilograms per hectare.

Soil type	In layers from 0 to 20 cm	In layers from 0 to 100 cm
Podzol	3.3	6.6
Grey, forest-steppe	5.6	9.4
Dark grey, forest-steppe	6.7	14.0
Chernozem (various subtypes)	from 7.0-11.3	from 24.0-35.8
Dark chestnut	5.6	15.2
Sierozem	2.8	8.6
Red	4.7	10.5

Though a pool of nitrogen in soils is large, it can be exhausted in cropping systems in a few decades or centuries, if no additional fertilizer is applied.

In the United Kingdom, the natural storage of nitrogen in soils is about 100 million tonnes, but in 1973, for example, the crops removed 1.55 million tonnes (Cooke, 1976). Thus, one goal of modern agricultural methods is to sustain or increase soil fertility by applying fertilizers, most of which are manufactured. The production and use of fertilizers, including nitrogenous ones, has increased rapidly. In Table 3, the world production of fertilizers is detailed, compiled by the author from the FAO's Annual Fertilizer Reviews from 1971-1977.

Table 3. World production of fertilizers in million tonnes.

Year	1966-7	1967-8	1968-9	1969-70	1970-1	1971-2	1972-3	1973-4	1974-5	1975-6	1976-7
Nitrogen (N)	22.4	25.5	28.4	30.2	33.0	35.0	37.8	40.4	42.4	43.8	45.9
Phosphate (P_2O_5)	16.9	18.0	18.5	19.2	20.7	22.4	23.7	24.9	25.7	24.8	27.3
Potash (K_2O)	14.5	15.4	16.0	16.9	17.8	19.5	20.2	22.2	23.7	23.5	25.3
$N + P_2O_5 + K_2O$	53.8	58.9	62.9	66.3	71.5	76.9	81.7	87.5	91.8	92.1	98.5

How much fertilizer is needed in the world? R. White-Stevens (1977) computed some estimates, based on the nutritional needs of human beings. The requirements of protein for human beings can be expressed in terms of specific amino acids and, hence, in terms of nitrogen requirements. For one person, the annual minimal protein requirement expressed in nitrogen is 4 kg N. Assuming a certain conversion efficiency, White-Stevens then calculated that for human subsistence, the annual level is approximately 17.2 kg N per person. This constitutes 72 million tonnes for the present world population of 4.2 billion. (White-Stevens, for unknown reasons, gives the figure of the world nitrogen demand as 80 million tonnes.) Atmospheric precipitation brings to the arable land about 16 million tonnes of nitrogen. To maintain land in a fertile state, however, 56 million tonnes more must be supplied to arable land. Manufactured fertilizers provide 46 million tonnes of this, plus fixation of atmospheric nitrogen by crops is estimated at 79 million tonnes.

Hence, the mean world nitrogen balance seems quite favorable. However, in reality it is an average of a rather favorable nitrogen balance in already developed countries and disequilibrium in many yet developing countries. Proceeding on the assumption that developing countries should at least meet the minimal protein requirements, while the level of developed countries remains unchanged, it can be said that, even for present world population, the lowest nitrogen needs should be considerably higher than 56 megatonnes.

The upper limit for protein requirements obtained from the study of developed countries is about 36 kg N per capita per annum (White-Stevens, 1977). For the present population, based on the aforementioned assumption, this yields about 640 megatonnes N per year of the nitrogen demand. Subtracting the value of natural nitrogen inputs, one obtains the upper limit of the present demand for nitrogen fertilizers, of more than 500 megatonnes.

In conclusion, it must be stressed that the production and use of fertilizers will grow (despite energy problems), creating a number of problems, including a deterioration in the quality of the environment.

THE NITROGEN BALANCE OF AN AGROECOSYSTEM

The nitrogen balance of a cropland agroecosystem can be written in the following form:

$$\Delta N = Fix. + Prec. + Fert. + Seeds - Crop - Leach.$$

$$- Volat. - Denitr. - Eros. - Runoff$$

where

ΔN is a change of nitrogen content in the system, mainly in the soil, for any time interval;

Fix. is nitrogen fixation by bacteria from the air;

Prec. is nitrogen brought by precipitation, dust, birds, etc.;

Fert. is nitrogen coming from mineral and organic fertilizers;

Seeds stands for nitrogen coming into the system with seeds;

Crop represents nitrogen removed with the harvest;

Leach. is nitrogen removed through infiltrating water;

Volat. is nitrogen coming into the atmosphere in the form of ammonia;

Denitr. is nitrogen escaping into the air in the form of nitrogen oxides or molecular nitrogen;

Eros. is nitrogen removed with soil particles;

Runoff is nitrogen removed from the system with surface and subsurface runoff.

Correspondingly, nitrogen leaching is a component dependent on a combination of other factors in the equation of nitrogen balance. Following is a brief discussion of the factors of the equation of nitrogen balance. This will provide an idea of the absolute and relative importance of each component.

Fixation. Symbiotic nitrogen fixation usually occurs through "*Rhizobium*" bacteria, which are associated with leguminous crops. Legumes can fix some hundreds kg N/ha, up to 500 kg N/ha.yr. Nonsymbiotic microorganisms can also provide some N-supply. Because of blue-green algae activity, the role of microorganisms can be considerable in special cases, as in rice paddies. According to M. Frissel's data (1977), cropland agroecosystems which do not contain many leguminous plants fix from the air between 0 to 20 kg N/ha.yr., and arable and livestock systems with legumes show values of N-fixation of the next order of magnitude.

According to Burns and Hardy (1975), global nitrogen fixation for terrestrial systems is 137 million tonnes per year, or about 10 kg/ha.yr., as an average for the land not covered by perennial ice. Agricultural systems fix 79 million per year with the following distribution for specific systems (Table 4).

Table 4. Nitrogen fixation rates for agroecosystems.

System	Global Rate,* in million tonnes/yr.	Specific rate,** in kg N/ha.yr.
Legumes	35	135
Rice	4	24
Other crops	5	5
Grasslands	45	15

* Taken from Birns and Hardy, 1978.

** Author's assessment.

Obviously, all systems, except legumes and rice, fix minor amounts of nitrogen as compared with some other sources of input, including fertilizers.

Precipitation. Nitrogen compounds reach the soil surface through atmospheric precipitation and dust. An assessment made by Söderland and Svensson (1976) shows the global values of amounts of nitrogen compounds falling to the land surface:

Ammonia: 30-50 megatonnes per year,
Nitrogen oxides: 13-30 megatonnes,
Organic nitrogen compounds: 10-100 megatonnes.

The total is calculated as being between 53 to 190 megatonnes, or on the average, between 3.6 and 12.8 kg N/ha.yr.

Numerous data for particular regions and points lie generally within these two values. There are scattered data indicating that in areas of high precipitation and of lower economic development, N-inputs from the air are lower than the average ones. In equatorial regions, for instance, precipitation brings between 1.5 and 8 kg N/ha.yr. (Greenland, 1977). On the average, however, the value is 11 kg N/ha.yr. for cropland agroecosystems.

Fertilizers. The current average amount of industrial nitrogenous fertilizer load is about 30 kg N per hectare of cropland in the world. However, nitrogenous fertilizer consumption varies considerably by country, from a few hundred kilograms per hectare in developed and densely populated countries as The Netherlands, Belgium, or Japan, to values close to zero in some developing countries. According to data from the FAO, from 1973-1976, the developing countries accounted for 29 percent of the world consumption of N-fertilizers.

According to Frissel (1977), there is a direct nonlinear relation between the input and output of nitrogen for all agricultural systems. Cropping systems exhibit a particularly good relation. The ratio of efficiency of a system (the output divided by input) changes from 30 to 100 percent. Moreover, when input is below 150 kg N/ha per year, the ratio is about 2/3, whereas under inputs of more than 150 kg N/ha, it is about 1/2.

Crop and Seeds. The nitrogen content of crops has already been mentioned. Seeds represent only a small portion when compared to the harvest. The amount of nitrogen removed from soils can be estimated in the following way. Given that grain production in the world approximates 1200 million tonnes and that nitrogen content in grain is approximately 25 kg N per one tonne of grain, we arrive at the figure of 30 million tonnes of nitrogen. According to some estimates, about 80 percent of food comes from cereal crops. Assuming on the one hand, that other cultivated products contain the same amount of nitrogen, and that, on the other hand, nitrogen is returned to the soil through seeds, one can state that, on a worldwide annual basis, 35 million tonnes of nitrogen is removed with the harvest. This is about 25 kg N per hectare of cropland per year.

Denitrification. Soil nitrates can be transformed into other nitrogen oxides (these are in a gaseous state) or into molecular nitrogen (which is also a gas). These gases are then returned to the atmosphere. Denitrification occurs under anaerobic conditions when certain bacteria split the nitrate molecule. Anaerobic conditions occur when there is high soil moisture, though in rather dry soils these conditions also exist inside soil aggregates. Conversely, acid soils, which are typical mostly in wet regions, reduce rates of denitrification. However, the process is speeded with increases in temperature. As a result, denitrification takes place mostly in boreal and temperate humid regions. A very rough estimation of R. Söderland and B. Svensson (1976) indicates that the global flux of N_2O to the atmosphere is between 16 and 69 megatonnes per year, or 1-5 kg N/ha.yr.

When nitrogenous fertilizers are applied, some portions of them are lost through denitrification. M. Frissel (1977) reported data for denitrification for 40 agroecosystems, including arable, livestock, mixed, and forested areas. The values of denitrification range from 0 to 192 kg N/ha.yr. In the latter case, a system's input was as large as 783 kg N/ha. In a total of 40 systems, 17 were arable. In most of the arable systems, denitrification was between 0 and 30 kg/ha, and three out of these 17 had denitrification rates of 70 and 71 kg/ha. One of these cases was a rice system (presumably with wet soils), while two others were systems with very high fertilizer application rates, (namely 319 and 346 kg/ha).

For all arable systems, losses of nitrogen to the atmosphere were between 3 and 30% of nitrogen inputs. Other authors estimate the loss of nitrogen from fertilizers via denitrification at 10 to 15%.

Nitrous oxide (N_2O) may have an effect on the ozone layer in the upper stratosphere since it enables ozone to convert into oxygen, thus reducing the effectiveness of the screen protecting the earth from ultraviolet radiation. This may possibly bear consequences for human health and ecosystems. According to Crutzen (cited from Frissel, 1977), a global increase of 20% in nitrous oxide discharges will reduce the total amount of ozone by 4%. Therefore, when the use of fertilizers increases, managing their application properly is important from the global point of view.

Volatilization. Ammonium is lost from soils due to its transformation into ammonia, a process called volatilization. The volatilization of manure and urine from livestock provides a major source of ammonia. On croplands, ammonium is lost not only from the manure applied as fertilizer, but also from ammonia fertilizer and the urea which is used. In 17 arable systems discussed by M. Frissel (1977), values of volatilization were close to zero in 16 cases, but in one case the rate reached 18 kg N/ha.yr. Corresponding values for livestock and mixed systems were between 2 and 98 kg/ha, which is between 20% and 66% of the N-inputs.

Erosion and Runoff. These components deserve a specially detailed discussion since they are, along with leaching, the source of water pollution. Here, only average global values will be mentioned.

Soil erosion carries away mostly organic nitrogen contained in detached soil particles. Hence, spatial variation of nitrogen transport is as big as that of erosion, that is, of a few orders of magnitude. Global nitrogen transport with sediments (Eros., G) can be assessed in the following way:

$$Eros.,\ G = ST \times Soil,\ N \times RE$$

where ST is the world sediment transport; $Soil,\ N$ is nitrogen content in the upper layer of the soil; and RE is the enrichment ratio of nitrogen in sediments.

River sediment transport in the world is between 12.7 and 51.1 billion tonnes per year, according to the estimation of nine different authors (Kovda, 1977; Lvovitch, 1974). M. Lvovitch's estimation (1974) of 22 billion tonnes seems to be the most reliable, as it uses the most complete data. The average nitrogen content in topsoil is taken as 0.002 by weight. The enrichment ratio, which is a proportion between nitrogen content in sediment and on topsoil, is between 1 and 3. The value of the enrichment ratio for the entire world requires special investigation, however. Then, global nitrogen transport with sediments lies between 40 and 130 million tonnes, or on the average for the entire land surface, between 3 and 10 kg N/ha per year.

The transfer of dissolved organic nitrogen by rivers from terrestrial to aquatic systems is, according to Svensson and Söderland (1976), about 10 million tonnes per year. The authors state that the transfer of dissolved inorganic nitrogen (mostly nitrates) reaches 8 million tonnes per year.

The concentration of nitrogen in runoff from cropland is usually between 1 and 10 mg N/l, and that from uncultivated land is between 0.1 and 1 mg N/l. It yields, respectively, from 0.1 to 10 kg N/ha for cropland and from 0.1 to 5 kg N/ha for uncultivated land (Control of Water Pollution from Cropland, 1976). Using 0.5 mg N/l as a mean concentration of nitrogen in river waters and 40,000 km^3 of water as annual worldwide runoff, one obtains a value of 20 million tonnes per year for dissolved nitrogen compound transport. One would arrive at a figure very close to this if one were to take the figure of 5 kg/ha.yr. as the yield from cropland and the figure of 1 kg/ha.yr. for uncultivated land. Cropland and uncultivated areas considered on a worldwide basis have an area of 14.3 million sq.km. and 119.0 million sq.km. The resulting value would be 19 million tonnes per year.

In Table 5, very approximate values of the components of the nitrogen balance equation are given in round numbers, both for worldwide land surface and for cropland. The value of leaching is taken as 10 percent of the nitrogen input, since according to M. Frissel (1977), leaching, on the average, makes up 10% of the nitrogen load when it is less than 150 kg N/ha.yr.

A number of conclusions can be drawn from these figures, despite their approximated values: 1) flux of nitrogen in cropland systems is much higher than in natural ecosystems, 2) the main sources of influx for cropland systems are nitrogen fixation and fertilization, 3) the major source of output is soil erosion, 4) leaching is not a very important component as compared with some others.

Leaching can be regarded as a result of eight other components of the balance, each changing considerably in space and time. The control of leaching requires control over the components of the balance equation. The most easily controlled factor is fertilization.

Table 5. Components of the global nitrogen balance equation.

Component		Fix.	Prec.	Fert.	Crop	Leach.	Volat.	Denitr.	Eros.	Runoff
For total land (including cropland)	million tonnes per year	140	100	50	35	30	40	40	85	15
	kg/ha per year	11	7	4	3	2	3	3	6	1
For cropland	million tonnes per year	80	10	40	35	15	<5	20	40	10
	kg/ha per year	56	7	28	24	10	<3	14	28	7

CLIMATIC FACTORS OF NITROGEN LEACHING

Productivity of crop production depends on two principal factors: 1) natural fertility of the agroecosystem and 2) man's management of the agroecosystem with his technological means and concomitant skills. The natural fertility of the agroecosystem depends on climatic conditions, that is, on the combination of energy and water on the land's surface, and the natural fertility of the soil itself. The natural fertility of the soil is in turn determined, to a considerable extent, by climate, through the long-term interaction of soil and vegetation with the atmosphere. It is this interaction which forms the soil properties (humus and nutrients content, pH factor, sum of absorbed cations, etc.). By studying the climate in any given area, one can determine the soil properties there. Thus, to reiterate, climatic factors, namely the combination of energy and water, are the most important factors determining basic natural productivity of both natural and agricultural ecosystems.

Fertility of soils depends on their genetic type. For example, yields from various genetic types of soils of the European part of the USSR are shown in Figure 2 (Vadkovskaya, 1976). All kinds of chernozem soils are from two to four times more fertile than other types of soil distributed by fertility in decreasing succession to the north and south from rich chernozems. While chernozem soils occupy only 8.6% of the USSR, 80% of the grain is produced in this soil type. Figure 2 also shows that an increment in yield due to intensification of agriculture is higher in more fertile soils. Therefore, both the natural fertility of an agroecosystem and its reaction to the level of intensity of agriculture apparently follow the law of geographic zonality. One can expect that both impacts of agriculture on the environment and changes in impacts because of changes in agricultural technology should conform to the main features of natural (geographical) zonation as well. In particular, nitrogen leaching should also be described by the zonation laws.

Allocation of natural (landscape) zones on the earth is described quite well as a function of two mean annual climatic parameters representing energy and water conditions. The first is a net solar radiation (R) in cal/cm^2 per year. The second is

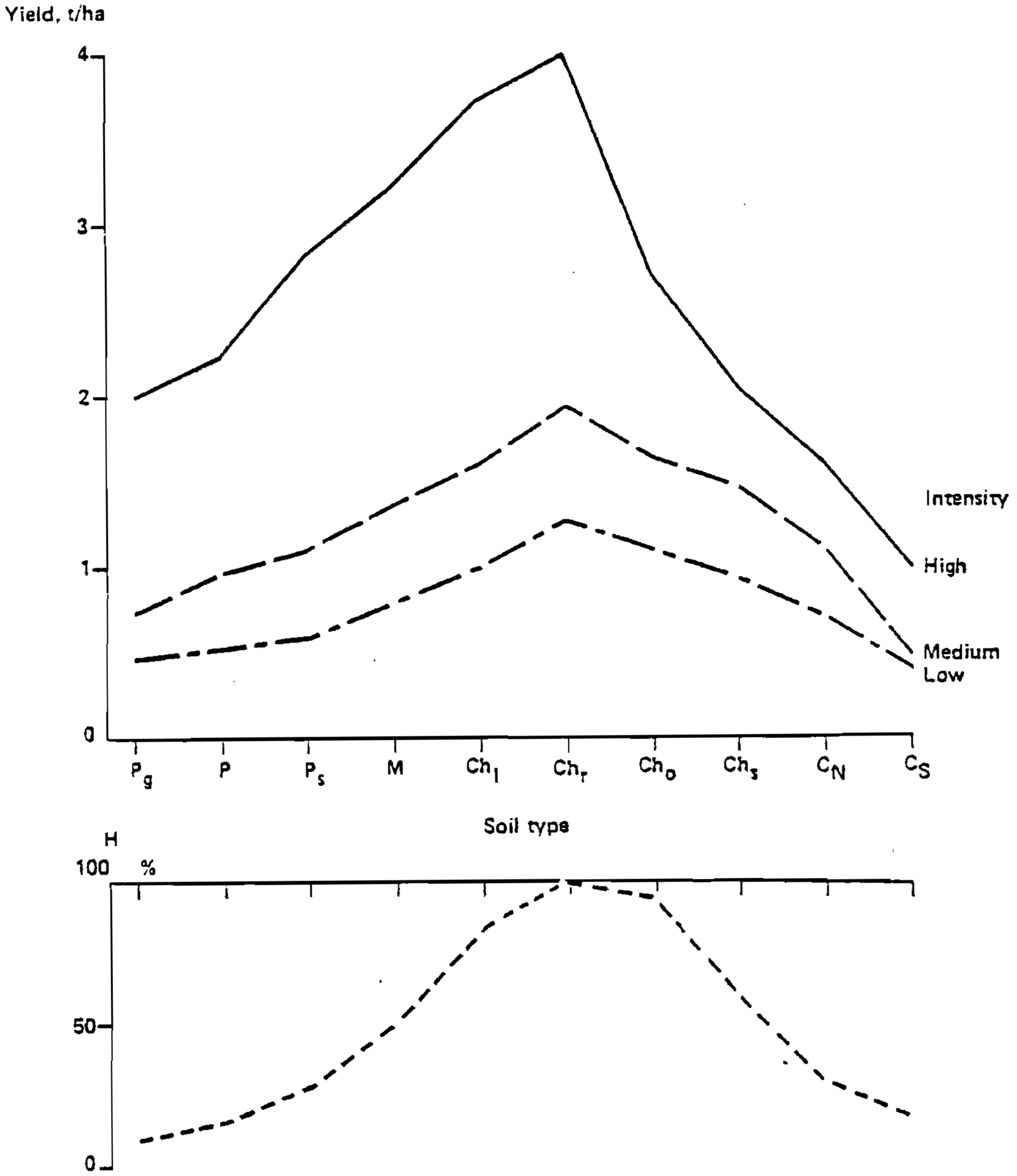

Figure 2. Cereal Yields vs. Genetic Types of Soil and Intensity of Agriculture

a ratio between net solar radiation and the amount of annual precipitation (r) expressed in energy needed to evaporate it ($\frac{R}{Lr}$). Here L is specific latent heat of evaporation in cal/g. Allocation of natural landscape zones adapted from M. Budyko (1977) is shown in Figure 3.

The values of nitrogen leaching depend on a number of natural factors where the amount of infiltrated water seems to be quite important. The amount of water infiltrated below the root zone is, over a long-term average for a flat surface, the difference between precipitation and evapotranspiration. Hence, it can be indexed by a ratio $\frac{R}{Lr}$. The relation between nitrogen leaching and nitrogen load (fertilizer plus manure) for different levels of $\frac{R}{Lr}$ is shown in Figure 4. Values of nitrogen leaching and nitrogen load are taken from Frissel (1977), Bertilssar (1978), Bouldin and Selleck (1977), Jonston and Garner (1969), and Kjellerup (1975). Values of $\frac{R}{Lr}$ are taken from M. Budkyo (1977). Obviously, the more arid the place is, the less nitrate is leached. This figure can be applied to nonirrigated areas, but if they come under irrigation, the water balance shifts as though they have actually been transferred to a place with more humid conditions (lesser $\frac{R}{Lr}$).

Not only are absolute specific values of leaching important, but also concentrations of nitrate. To obtain concentrations, data on infiltration of water below the root zone is needed. It was assumed that base flow from a large area represents the average value of water leached below the root zone. Then, data on base flow for the landscape zones were taken from M. Lvovich (1974), and values of R and $\frac{R}{Lr}$ for each zone were supplied by M. Budyko (1977). In this way, a relation of base flow from R and $\frac{R}{Lr}$ was obtained (Figure 5).

POTENTIAL NITROGEN LEACHING HAZARD

What would the nitrogen leaching values be if there were heavy worldwide application of nitrogenous fertilizers? The values of concentration of nitrates in leached water as a function of R and $\frac{R}{Lr}$ were calculated for different N-loads from 50 to 200

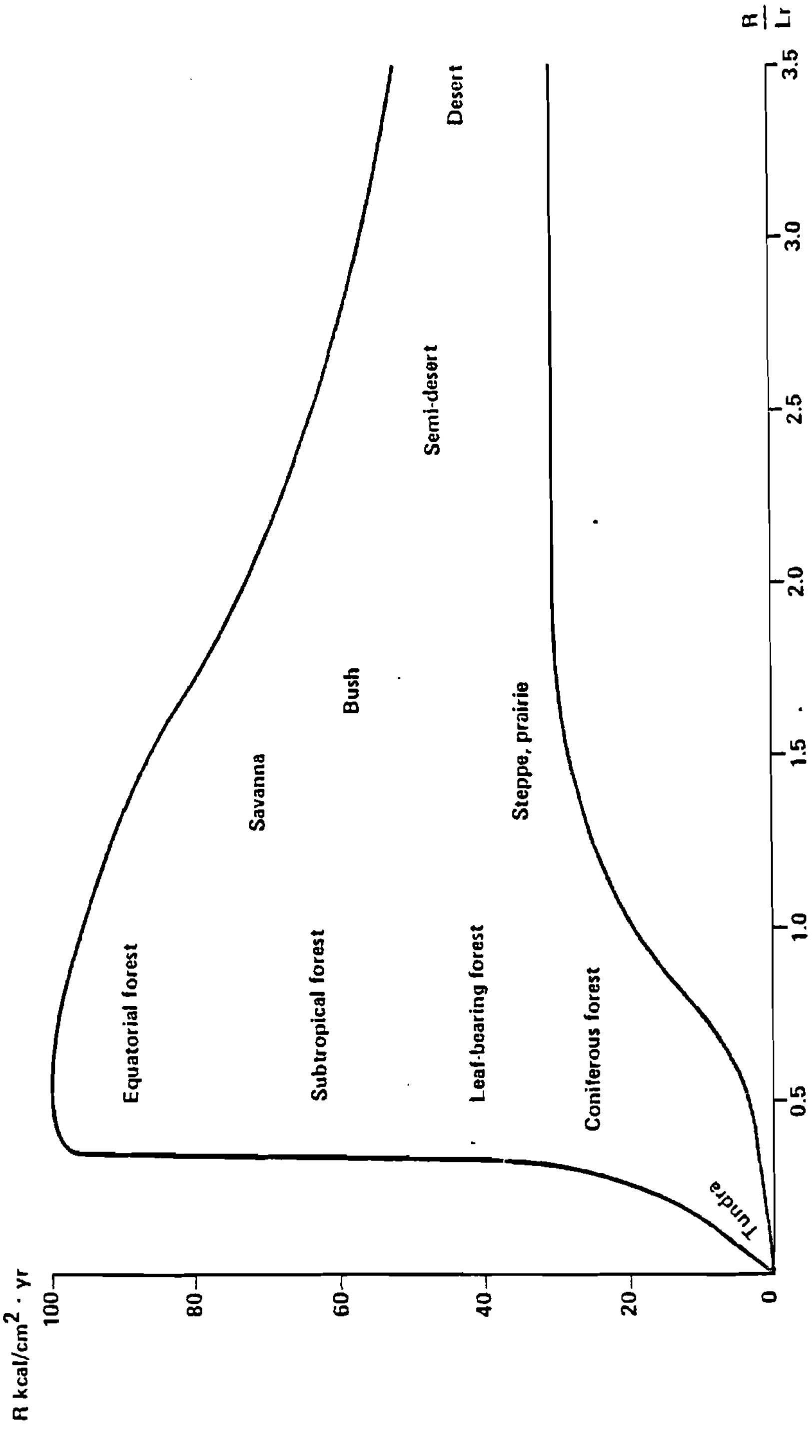

Figure 3. Geographical Zones and their Dependent Relationship to Net Balance of Solar Radiation (R) and Combination of Net Radiation and Precipitation ($\frac{R}{Lr}$). Adapted from M. Budyko (1976)

kg/ha per year. The concentration (c) was calculated as

$$c = \frac{\text{Leaching}}{\text{Percolation}} \quad ,$$

using Figures 4 and 5 to arrive at corresponding values. Some results are presented in Figures 6 and 7.

The principal conclusions drawn from the calculations are:

1) There are two landscape zones where the hazard of nitrate leaching is expected to be high (Fig.6). These zones are the coniferous forests and the dry steppes/semideserts, both of which are situated in areas with temperate climate. The zones of coniferous and deciduous forests include the countries of Northern and Central Europe. The level of nitrogenous fertilizer application here is already about 100 kg N/ha.yr. Thus, the conclusion for this part of the world (based on Fig. 6) confirms the actual situation, wherein nitrogen pollution is widespread throughout Western Europe.
2) A zone where the hazard of nitrate pollution is expected to be lower is that of light tropical forest and wooded savanna (Fig. 6). Hence, one might expect less problems with nitrate pollution in many developing countries situated in such zones, when and if the level of nitrogenous fertilizer application becomes so high.
3) The concentration of nitrates in leached water depends directly on the N-load and the value of the aridity index $\frac{R}{Lr}$. Moreover, in temperate latitudes, the growth of the nitrate concentration is more pronounced than in tropical latitudes (Fig. 7). Again, it can be said that under the same, but high nitrogen loads, more problems with nitrate pollution are expected in areas with temperate climates.

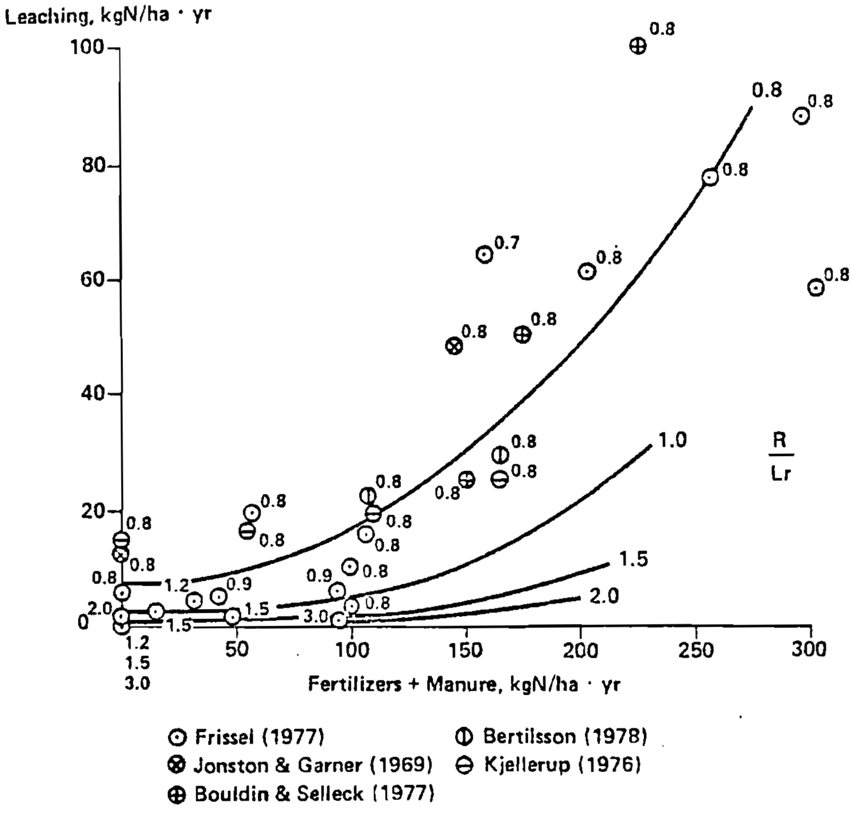

Figure 4. Relation of N-Leaching within N-Load and Aridity Index $\frac{R}{Lr}$

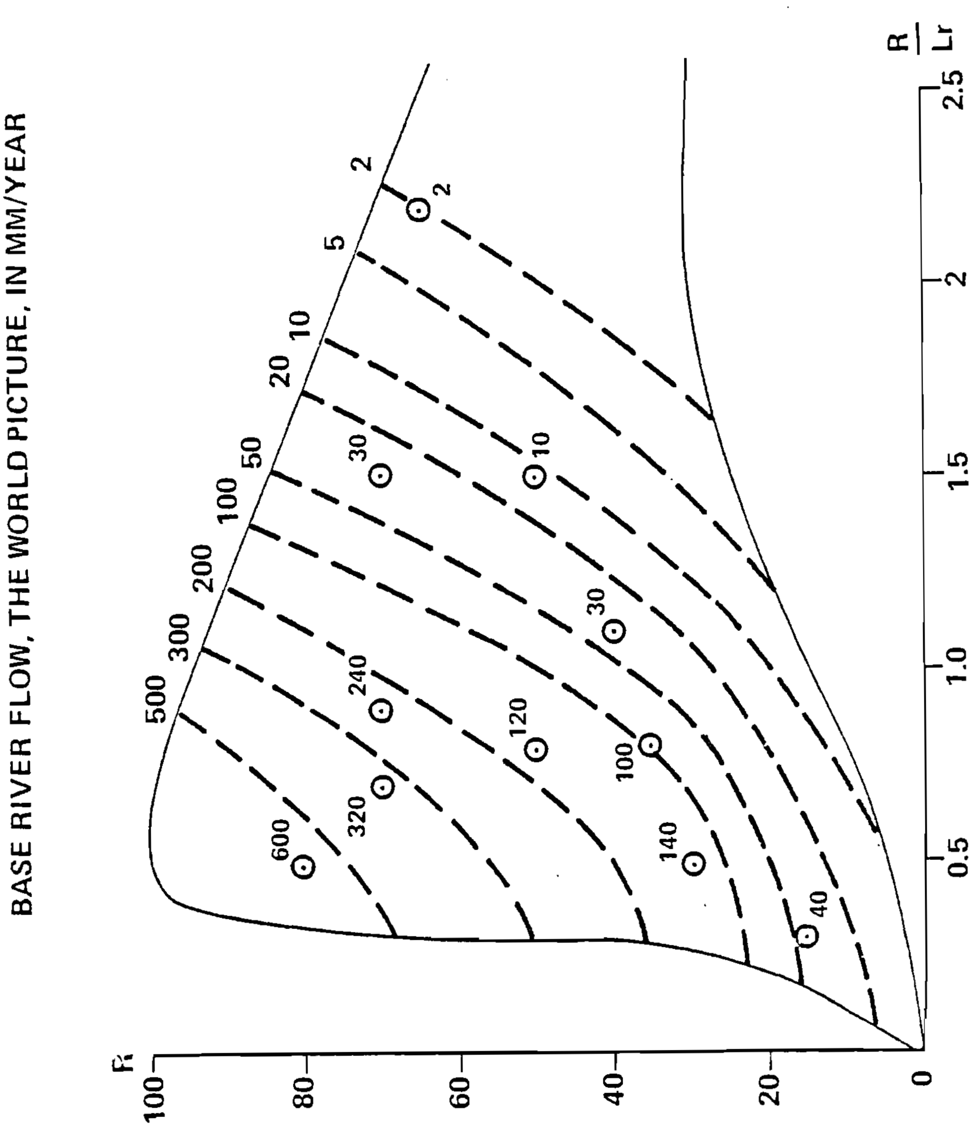

Figure 5. Base River Flow, The World Picture, in mm/year

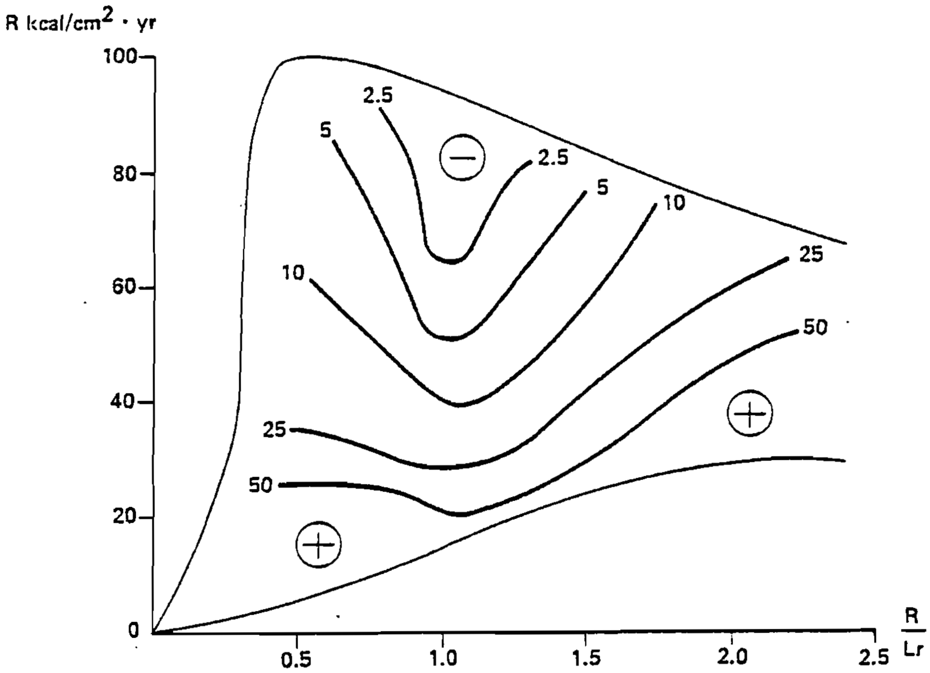

Figure 6. Nitrogen Concentration in Leached Water Under N/Load = 100 kgN/ha, in mg/l

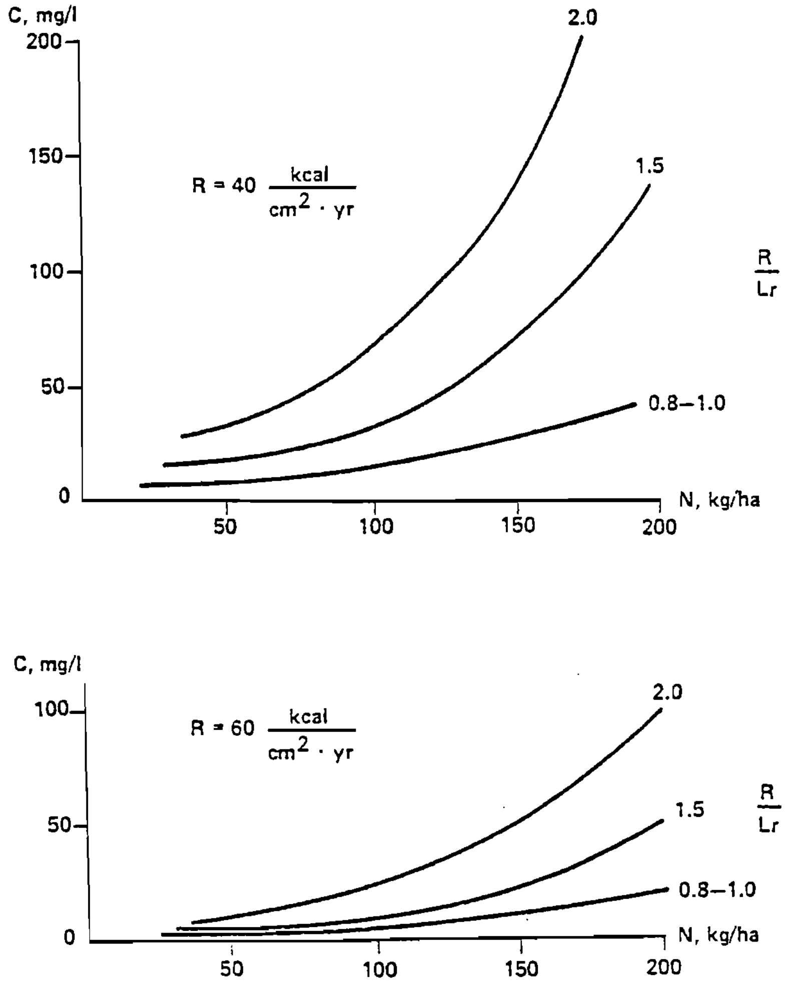

Figure 7. Nitrogen Concentration in Leached Water Depending on N-Load and Climate

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