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CROPLAND NITROGEN LEACHING MODELS

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PREFACE

One of the purposes of the joint REN and FAP task, Environmental Problems of Agriculture, is to collect, assess and classify the current agricultural-environmental models. In order to obtain information and establish scientific cooperation, special questionnaires were sent to many scientists in various countries. This paper contains a brief description, assessment and classification of twelve nitrogen leaching models, and a list of scientists contacted. The nitrogen leaching models can be used for solving some environmental problems related to the application of nitrogen fertilizers.

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It is widely assumed that modern agricultural practices can lead to deterioration in the chemical and biological quality of water bodies, i.e. rivers, lakes and groundwaters in rural areas. Nitrogen is one of the major plant nutrients which is applied to croplands as fertilizer and manure. Increase of the scale of nitrogen fertilizers application lead to various environmental effects. For example, nitrogen is one of the nutrients which can accelerate eutrophication of rivers and lakes. On the other hand, nitrogen in drinking water can be toxic for people. It is possible to formulate two main environmental problem associated with heavy nitrogen application to croplands. These problems are both an increase of nitrate concentration in the groundwater and an acceleration of water body eutrophication. Figure 1 illustrates a relation between nitrogen application and environmental effects. Both the nitrogen leaching and the nitrogen surface runoff are processes which are responsible for the nitrogen application environmental impact. For instance, a

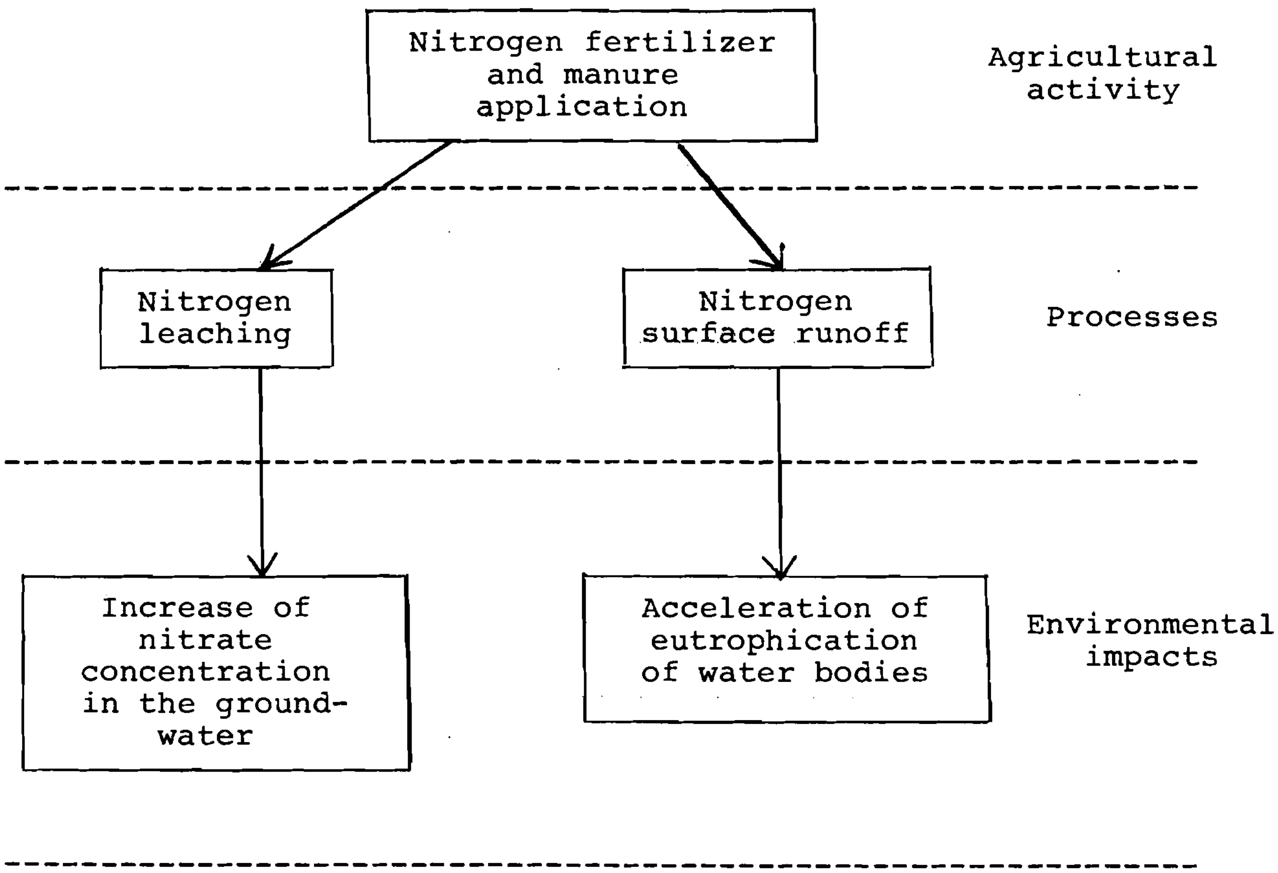

Figure 1. A relationship between nitrogen application and environmental effects.

quantity relationship between nitrogen fertilizer and manure application and an acceleration of eutrophication, related to nitrogen leaching, groundwater balance processes, nitrogen surface runoff and eutrophication.

It is not a goal of this paper to consider all these phenomena and we shall only concentrate on nitrogen leaching processes. The nitrogen leaching itself is a complex phenomenon including many hydro-biochemical processes. Figure 2 illustrates the main processes such as complex phenomenon as nitrogen leaching, and also the main relationships between these processes. They all play a different role in the nitrogen leaching phenomenon; some of them are very important while others are not. Sometimes it depends on concrete natural conditions. Various nitrogen leaching models pay great attention to different hydrobiochemical processes according to practical, agricultural and environmental situation. This paper is an attempt to collect, assess and clarify current nitrogen leaching models developed in the last 10 years. Twelve nitrogen leaching models described in this paper are divided into three groups according to the model assessment. Table 1 illustrates this classification. There are three classes: Class A contains models which can be used mostly for scientific understanding of nitrogen leaching problem (4 models). Class B contains models which can be used mostly for forecasting the amount of nitrogen leached (6 models). Class C contains models which can be used partly in the nitrogen fertilizer management practice (2 models). It should be noted that a comparative analysis ofthese models should be carried out in the future.

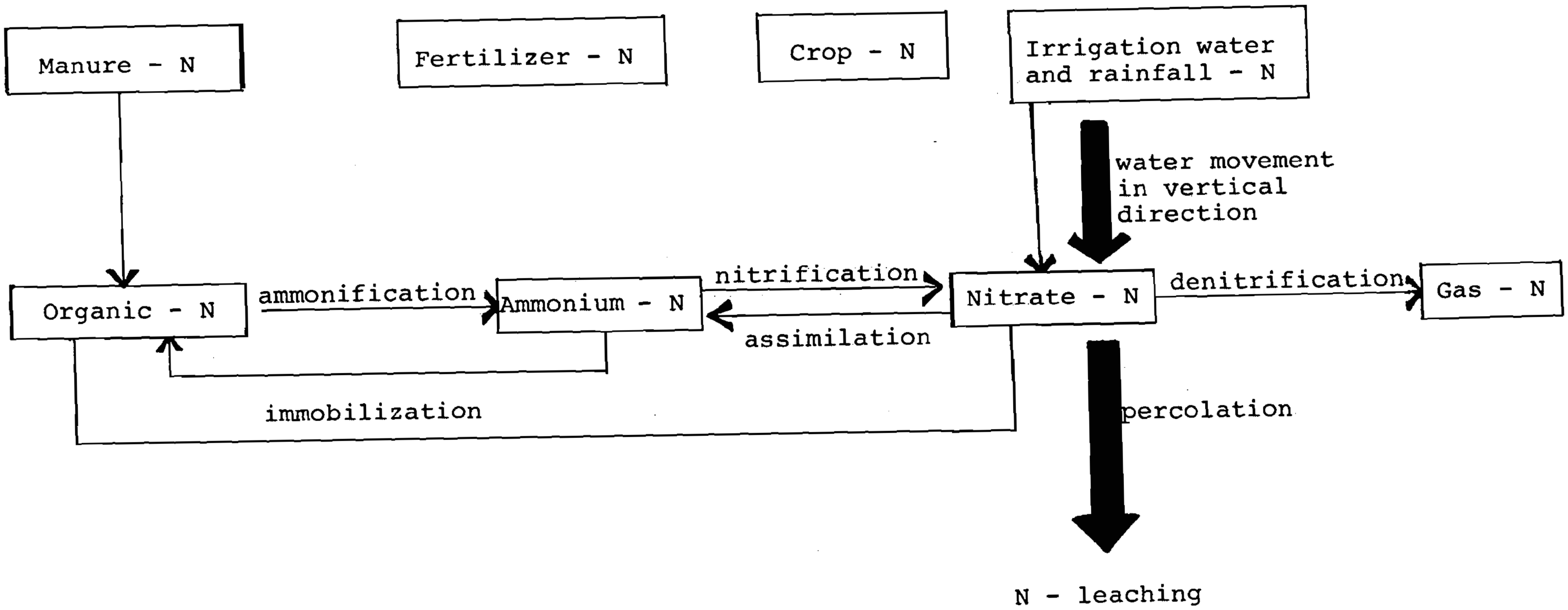

Figure 2. Conceptual scheme of nitrogen leaching from the root zone of croplands.

Class of models	A	B	C
Objective of model	Scientific understanding	Forecasting	Management

Table 1. Classification of models

LIST OF MODELS

Class A

1. J. A. Van Veen,"The behaviour of nitrogen in soil. A computer simulation model". Ph.D. dissertation, Department of Theoretical Production Ecology, Agricultural University, Wageningen, 1977, The Netherlands.

2. M.H. Frere; M.E. Jensen; J.N. Carter, "Modelling water and nitrogen behaviour in the soil-plant system". In Proc. 1970 summer computer simulation conference, pp.746-760.

3. T.M. Addiscott, "A simple computer model for leaching in structured soils". Journal of Soil Science, 1977, v.28, pp. 554-563.

4. J.Q. Reuss; G.S. Innis, "A grassland nitrogen flow simulation model". Ecology, v.58, 1977, pp. 379-388.

Class B

1. K.K. Tanji; M. Fried; R.M. van De Pol, "A steady-state conceptual nitrogen model for estimating nitrogen emissions from cropped lands". Journal of Environmental Quality, vol. G, No. 2, 1977, pp. 155-159.

2. J. Duffy; C. Chung; C Boast; M. Franklin, "A simulation model of biophysiochemical transformations of nitrogen in tile - drained corn belt soil". Journal of Environmental Quality, vol. 4, No. 4, 1975, pp. 477-486.

3. I.G. Burns, "An equation to predict the leaching of surface-applied nitrate". J. Agric. Sci., Camb. v.85, 1975, pp. 443-454.

4. M.J. Shaffer; G.R. Dutt; W.J. Moore, "Predicting changes in nitrogenous compounds in soil-water systems" . Water Pollution Control Research Series. 13030 ELY, 1969, pp. 15-28.

5. H. Laudelout; L. Germain; P.F. Chabalier; C.N. Chiang, "Computer simulation of loss of fertilizer nitrogen through chemical decomposition of nitrite". Journal of Soil Science, v. 28, 1977, pp. 329-339.

6. M.F. Walter; G.D. Bubenzez; J.C. Converse, "Predicting vertical movement of manurial nitrogen in soil". Transactions of the ASAE, v. 18, 1975, pp. 100-105.

Class C

1. B. Singh; C.R. Biswas; G.S. Selkhon, "A rational Approach for optimizing application rates of fertilizers nitrogen to reduce potential nitrate pollution of natural waters". Agricultural and Environment, v. 4, 1978, pp. 57-64.

2. K.E. Saxton; G.E. Schuman; R.E. Burwell, "Modelling nitrate Movement and Dissipation in fertilized soils". Soil Science society of American Journal, vol.41, 1977, pp. 265-271.

CLASS A: Model 1

Model reference	J.A.van Veen, "The behaviour of nitrogen in soil. A computer simulation model". Ph.D.dissertation, Department of Theoretical Production Ecology, Agricultural University, Wageningen, 1977, The Netherlands.
Modelling processes	Nitrification, volatilization of ammonia fixation of ammonium on clay minerals, mineralization and immobilization denitrification, microbes growth, ammonium transport in soil column.
Modelling techniques	Zero-order rate kinetics, first-order rate kinetics, Michaelis-Meuten kinetics. The diffusion mechanism is used to describe denitrification in the soil. The space scale of model is some uniform soil volume (for example $1 cm^3$).
Model input	The main model inputs are manure and nitrogen fertilizers application
Model output	Ammonium, nitrite and nitrate concentrations in the soil microbes biomass; denitrification and volatilization losses of nitrogen.
Model assessment	This model can be used to understand better the nitrogen transformation processes in the soil. It also enables us to simulate various situations in the soil under different natural conditions and find out the role of many natural and technological factors in nitrogen leaching from croplands.

CLASS A: Model 2

Model reference	M.H. Frere; M.E. Jensen; J.N. Carter, "Modelling water and nitrogen behaviour in the soil-plant system". In Proc. 1970 summer computer simulation conf. pp. 746-760.
Modelling processes	Water balance processes: evapotranspiration; drainage Nitrogen balance processes: nitrification, mineralization ammonification Plant growth
Modelling techniques	zero-order and first-order rate Kinetics, water balance modelling technique assumes that the hydraulic gradient during drainage is the same with or without evapotranspiration. The increase in accumulated dry matter during the season follows an S-shaped curve. The rooting depth increase is considered to follow the equation of a normal curve. The space scale of model is a root zone column of an agricultural field.
Model input	Daily climatic conditions (rain, minimum and maximum temperature, solar radiation, dew joint temperature, the windspeed); irrigation water, nitrogen fertilizer.
Model output	various nitrogen force concentration in the soil, soil water content, dry matter of crop; nitrogen leaching from root zone of soil.
Model assessment	Model can be used to better understand the behaviour of water and nitrogen in the soil-plant system.

CLASS A: Model 3

Model reference	T.M. Addiscott, "A simple computer model for leaching in structured soils". Journal of Soil Science, 1977, v. 28, pp. 554-563.
Modelling processes	The water and nitrate movement through the soil in the vertical direction, mineralization.
Modelling techniques	The soil profile is divided into finite layers. It is assumed that during water movement, the mobile fraction of the soil solution is displaced through the soil only. Simple balance equations are used to model water movement. For the mineralization modelling, a simple first-order rate equation is used. The temperature coefficient of the rate constant is given by an Arrhenius-type equation.
Model input	The amount of rainfall; the nitrogen fertilizer application.
Model output	The dynamic of nitrate concentration in the soil profile and in drainage water.
Model assessment	The model can be used to understand the influence of soil aggregates on leaching processes better. The model helps to investigate how solutes held in soil aggregates may be protected from leaching. The model connects nitrate leaching with such mechanical characteristics as porosity and bulk density.

CLASS A: Model 4

Model reference	J.Q. Reuss; G.S. Innis, "A grassland nitrogen flow simulation model". Ecology, v.58, 1977, pp. 379-388.
Modelling processes	Mineralization of soil organic nitrogen, oxidation of ammonium to nitrate, nitrogen uptake by live roots, the transfer of nitrogen from the live top to the litter, the transfer of litter nitrogen to soil organic matter, immobilization of nitrogen during decomposition of roots, root growth processes. Effects of temperature and soil water availability on the various processes are considered.
Modelling techniques	All nitrogen flows are described as a function of time, soil temperature, soil water content, nitrogen content, plant growth. Four depth layers are considered. Nitrogen uptake by live-roots is considered to be the sum of two processes, each of which is described by a maximum rate and a half saturation constant. (Michaelis - Meuten relationship).
Model input	The soil water and temperature data are required. Initial levels of different nitrogen forms in the soil is considered as main model input.
Model output	The live top biomass production and various nitrogen form concentrations with time are considered as main output of model.
Model assessment	The model can be used for understanding grassland ecosystem processes and fertilizer effects on grassland ecosystem.

CLASS B: Model 1

Model reference	K.K. Tanji; M. Fried; R.M. Van de Pol, "A steady-state conceptual nitrogen model for estimating nitrogen emissions from cropped lands", - Journal Environmental Quality, vol. 6, No. 2, 1977, pp. 155-159
Modelling processes	- Hydrologic submodel: irrigation water flow, precipitation, water inflow to root zone, water outflow from root zone, evapotranspiration, surface return flow, deep percolation - Nitrogen submodel: irrigation water nitrogen inflow, precipitation nitrogen inflow, nitrogen fertilization, denitrification, nitrogen consumption of crop, nitrogen leaching
Modelling techniques	The model is based on two underlying principles: steady state and mass balance. The model has an annual or cropped cycle time scale. The space scale is any uniform field, plotter field (with focusing on the crop root zone of the soil-plant system).
Model input	N in irrigation water (mg N/liter); N in precipitation (mg N/liter); applied fertilizer (kg N/ha); N mass in N_2 fixation (kg N/ha); irrigation water flux (cm/yer), precipitation (cm/yer).
Model output	The main output data: - quantity of deep percolated water - nitrogen leaching losses
Model assessment	The model is applicable to croplands under intensive production located in humid regions or where irrigation has been practiced for a long period. The model can be used to predict and estimate the effect on long term leaching losses of proposed changes in agricultural practice.

CLASS B: Model 2

Model reference	J. Duffy; C. Chung; C. Boast; M. Franklin, "A simulation model of biophysiochemical transformations of nitrogen in tile-drained corn belt soil". Journal of Environmental Quality, vol. 4, No. 4, 1975, pp. 477-486.
Modelling processes	- Water movement: unsaturated flow, saturated flow, water table fluctuations, tile flow of water - Nitrogen transformations and movement processes: nitrification, mineralization-immobilization, denitrification, nitrate vertical movement, nitrate tile flow - Crop growth: root growth, plant growth, nitrogen uptake
Modelling techniques	The soil profile in the vertical direction is divided into eleven sections, each 15cm deep. The water flow rate between levels is calculated according to Darcy's equations. Zero and first order reactions are used to model nitrogen transformation processes. The soil moisture, temperature, nitrogen and light are taken into account through Leibig's "Law of Minimum Factor" to model actual plant growth. The space scale is field area.
Model input	The main inputs of the model are nitrogen fertilizers and rainfall.
Model output	The main outputs are the amount of water leaving the field as drain tile effluent and nitrate concentration in tile effluent.
Model assessment	The model is applicable to any typical field in the Corn Belt. Through this model, it is possible to predict nitrate concentrations in the tile effluent as a function of farm management practices (many use of N-fertilizers) and climatic conditions.

CLASS B: Model 3

Model reference	I.G. Burns, "An equation to predict the leaching of surface-applied nitrate". J. Agri. Sci., Camb. (1975), 85, pp. 443-454.
Modelling processes	Water and nitrate movement through soil. The nitrogen transformation processes are not considered.
Modelling techniques	The model assumes that rainfall will increase the water content of any soil layer until its field capacity is reached. It is assumed that the fraction of nitrate leached can be correlated with fraction of water percolated. The amount of nitrate leached below root zone can be calculated from simple equation. Equation is based on the assumption that the soil solution of each layer is an equilibrium with water percolated. The space scale is a field (practically some soil column).
Model input	The quantity of water draining through the soil (in cm)
Model output	The fraction of surface-applied nitrate leached below any depth.
Model assessment	This model can be used directly to calculate nitrate leaching under rainfall and irrigation conditions for a wide range of fallow or cropped soil. It is also appropriate to use this model as an integral part of other models describing nitrogen cycle at the agricultural field.

CLASS B: Model 4

Model reference	M.J. Shaffer, G.R. Dutt, W.J. Moore, "Predicting changes in nitrogenous compounds in soil-water systems". Water Pollution Control Research Series. 13030 ELY, 1969, pp. 15-28.
Modelling processes	Water balance processes are not considered. Nitrogen transformation processes: mineralization, immobilization (both ammonia and nitrate), nitrification, urea hydrolysis.
Modelling techniques	The nitrogen transformation rate equation for each pathway were chosen as follow: Rate = function (urea-N concentration, NH_3-N, organic-N, NO_3-N, C:N ratio, pH, temperature, moisture). The computerized multiple linear regression techniques were applied.
Model input	Initial soil conditions and nitrogen additions (urea, ammonia, organic, nitrate).
Model output	Concentrations of the nitrogenous species in the soil with time are considered as output from the model.
Model assessment	The model can be considered as a potential part of an integrated simulation model of nitrogen leaching after combining with a water balance model. To predict nitrogen leaching, the model has to be combined with a water percolation model.

CLASS B: Model 5

Model reference	H. Laudelout, L. Germain, P.F. Chabalier, C.N. Chiang, "Computer simulation of loss of fertilizer nitrogen through chemical decomposition of nitrite". Journal of Soil Science, 1977, v. 28, pp. 329-339
Modelling processes	The ammonification, the oxidation of ammonium in soil and biochemical decomposition of nitrite. The water balance processes are not considered.
Modelling techniques	The first and second order rate kinetics are used.
Model input	The main input is nitrogenous additions
Model output	Concentrations of the nitrogenous species in the soil with time and nitrogen losses due to biochemical decomposition of nitrite are considered as model output.
Model assessment	The model can be used to predict the rate of loss of nitrogen from soil as a result of chemical decomposition of nitrite. The nitrogen loss may be calculated as a percent of nitrogen applied. The model helps us to understand the rôle of the two competing reactions in which nitrite is biologically oxidized to nitrate or is chemically decomposed at low pH (acid soil).

CLASS B: Model 6

Model reference	M.F. Walter, G.D. Bubenzer, J.C. Converse, "Predicting vertical movement of manurial nitrogen in soil", Transactions of the ASAE, v.18, 1975, pp. 100-105.
Model processes	This model describes processes associated with sub-surface nitrogen transformations and movement to the groundwater. The mineralization of soil organic nitrogen and nitrification processes are taken into consideration. Water balance processes: infiltration, percolation, drainage (water movement in unsaturated soil). The nitrate dispersion due to mass flow of soil solution is considered.
Modelling techniques	A simple empirical equations (zero-order kinetic) were used to model nitrogen transformation processes. The one-dimensional unsaturated flow equation for the soil profile was applied to model water movement.
Model input	The main model input is manure applications.
Model output	The dynamic of nitrate concentration in the soil is considered as model output.
Model assessment	The model can be used to predict nitrogen transformations and movement in the soil. It is valid for lands with heavy applications of livestock waste in early Spring. The model is not directly applicable to systems with appreciable living vegetation since it does not include plant uptake of nitrogen.

CLASS C: Model 1

Model reference	B. Singh, C.R. Biswas, G.S. Sekhon, "A rational approach for optimizing application rates of fertilizer nitrogen to reduce potential nitrate pollution of natural waters". Agricultural and Environment, 4, (1978), pp. 57-64.
Model processes	The nitrogen fertilizer application; nitrogen plant uptake, nitrogen leaching.
Modelling techniques	The steady-state model; Grain yield and nitrogen uptake for wheat and corn are described as a quadratic response function of nitrogen fertilizer applied.
Model input	The quadratic response functions are considered as a main model input.
Model output	An optimal rate of nitrogen fertilizer application corresponds to the greatest economic return and permissible nitrogen loss.
Model assessment	This modelling approach can be used to optimize the rate of nitrogen fertilizer application but it needs an experimental regression response function.

List of Persons and Institutions Contacted

1. Dr. K.E. Saxton
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4. Dr. I.G. Burns
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CLASS C: Model 2

Model reference	K.E. Saxton, G.E. Schuman, R.E. Burwell, "Modelling nitrate movement and dissipation in fertilised soils". Soil Science Society of America Journal, vol. 41, 1977, pp.265-271.
Modelling processes	The vertical water and nitrate ion movement in the soil; plant uptake of nitrogen; nitrification, mineralization.
Modelling techniques	The 1.8m soil profile was divided into 15-cm layers. Soil moisture - tension - conductivity relationships were used to describe moisture vertical movement. It was assumed that the nitrogen uptake from each soil layer was proportional to both the water uptake and the nitrate concentration of the water in the layer. The production of nitrate from applied ammonium fertilizer was considered uniform in the upper 15cm layer.
Model input	Daily precipitation and runoff; daily pan evaporation; plant canopy development; nitrogen fertilizer application.
Model output	Daily dynamic of nitrate movement and distribution within a 1.8m soil profile are considered as main output of model.
Model assessment	The model can be used to understand how to maintain optimum nitrate in the soil for crop use and to minimize a potential environment pollution. The model can be applied to agricultural watersheds with permeable soils and high-yielding corn.