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Comparison of nitrate leaching results in a lysimeter experiment to those predicted by a simulation model and estimates of influences of varying parameters on simulation results[1)]

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Introduction

The nitrate concentration in underground and surface waters is at the forefront of interest to those concerned with water quality (*Ambühl,* 1966; *Bernhardt,* 1969; *Viets,* 1971). The sources supplying nutrients to water are variant. In many cases, it is very difficult if not impossible to determine exactly the share of each possible source (*Amberger,* 1972). The soil system is very complex and experimentation techniques on the complete system would be very difficult and time consuming. A computer model could show relations between the various processes and parameters, as well as trend predictions under changing paramters.

Simulation techniques have recently been used to describe complicated systems. *De Wit* and coworkers (1972) used the Continuous System Modeling Program (CSMP), developed by IBM, for simulating ecological processes, and studying reactions and transport phenomena in soils. Our simulation of nitrogen processes and transport in soil was also programmed in CSMP. It took into account soil and climatic characteristics, organic nitrogen mineralization, ammonia nitrification, denitrification, plant uptake, flow of nitrates with water through the soil profile and , of it.

The theoretical background for nitrogen processes in soils and an outline of the simulation model have been presented in a previous paper (*Hagin* et al. 1976). A detailed description of the computer model may be found in a mimeographed report[2)].

1) This project was partially supported by the Deutsche Forschungs Gemeinschaft
2) J. Hagin and A. Amberger. Contribution of fertilizers and manures to the N- and P-load of waters – a computer simulation. (Obtainable from the authors at their respective addresses.)

Lysimeter Results

An important step in any simulation program is the verification of its validity by comparing the computed with experimental results. In the work presented here, a lysimeter experiment was chosen for that purpose. A full description of the lysimeter experiment is given in a doctoral thesis (*Schweiger*, 1973). Some data, relevant to the comparison will be given here.

The lysimeters have an area of 4 m^2 and a depth of 1 m. The amount of drainage water was measured monthly and the mineral content every three months. The results of the last crop in a rotation of six years (October 1965–September 1971) were chosen for comparison. The soil in the lysimeters was defined as a pseudogley brown soil, having a silty loam texture. Some soil and agrotechnical characteristics are presented in Table 1.

Table 1: Some Characteristics of the Lysimeter Experiment

Daten zum Lysimeterversuch

Soil		*Agrotechniques*	
pH (in KCl)	6.6	Crop	Summer Oats
N %	0.16	N applied as Ammonium nitrate kg/ha	40
C %	1.15	Dates of Fertilizer Application	5/4/71
Cation exchange capacity, m.e./100 g	20.2	Sowing	19 /4/71
Saturated water capacity	45.3	Harvesting	2/8/71

Table 2: Some Climatic Data for Weihenstephan and Drainage Measurements in Lysimeter Experiment

Klimadaten für Weihenstephan und Auswaschung im Lysimeterversuch

Month	Rainfall mm	Drainage Water l/m^2	N-leached kg/ha	Air temp. Average C°	Soil temp. (5 cm) Average C°
April	37.4	–		8.8	10.5
May	125.6	74.8	14.7	13.5	16.3
June	175.6	36.5		13.5	16.2
July	45.3	–		17.2	21.5
August	76.1	–	—	17.7	21.1
September	53.8	–		11.0	14.4

Table 2 shows some climatic data of the lysimeter site for the year 1971.[3])

The soil, climatic, and fertilizing characteristics of the lysimeter experiment were as far as available the basis for definition of parameters in the simulation. The measured amounts of drainage water and of nitrogen washed out with it were compared to the results computed in simulation.

Additional parameters, not included in the above work, had to be compiled from literature on similar soils and conditions. The climatic data in the simulation are much more detailed than those in Table 2. They include daily rain intensities and daily temperature fluctuations.

The functions and parameters, determining the water regime and thermal properties of the soil were taken from *De Wit* and *van Keulen* (1972) for Geary silt loam.

Computed Results and Comparison to Experimental Data

The lysimeter experiment conditions for the period of April 4 – August 1, 1971, were simulated. Figure 1 shows the cumulative rainfall distribution over a simulated period, the amounts of water lost by evapotranspiration, and the amount of

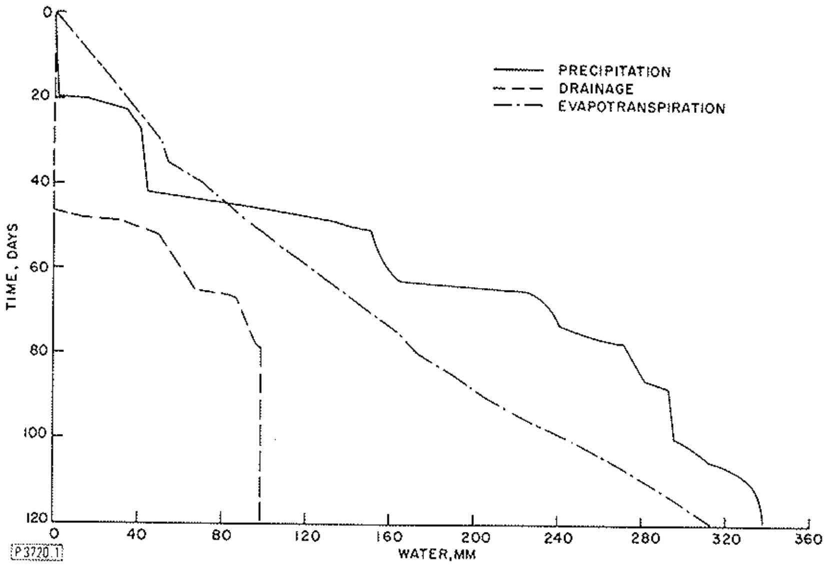

Figure 1: Simulated Rainfall and Calculated Water Losses (cumulative), According to Lysimeter Experimental Conditions

Niederschläge und Wasserverlust, simuliert entsprechend den Bedingungen des Lysimeterversuches

3) Obtained from the Weather Bureau at Weihenstephan.

water lost as drainage at a depth of 1 m. Comparison of this last curve to the drainage data in Table 2 shows a good agreement. There was no loss of water during the first simulated month, which coincides with April in the lysimeter experiment. During the second month, the simulation shows a loss by drainage of nearly 70 mm; in the third, nearly 30 mm; and no loss in the fourth month.

Figure 2 illustrates the calculated distribution of nitrates through the soil profile at some selected days of the simulation period. In the top soil layer, an initial value of 70 kg/ha of NO_3–N is stated. This is the sum of 50 kg assumed to be present in the top layer as residual and of 20 kg applied as fertilizer. An additional 20 kg/ha of N is applied as ammonium. The deeper nine layers, show an initial amount of about 5 kg/ha of NO_3-N each. The calculated values show at the 14th day, a high concentration of nitrates in the upper 20 cm of soil; whereas at the 56th day of simulation, a more even distribution is found with a peak at the depth of 35 cm. The nitrate concentration through the soil profile is evened out over the simulation period as illustrated by the curve for the 112th day.

Figure 3 shows calculated amounts of nitrates formed in the upper soil layer by oxidation of applied ammonia and of that produced from organic forms and nitrate losses from the soil profile by plant uptake, denitrification, and leaching. A very good agreement between the calculated and measured amounts of nitrates leached (Table 2) is found. It may be seen that the oxidation of ammonia to nitrate is rather

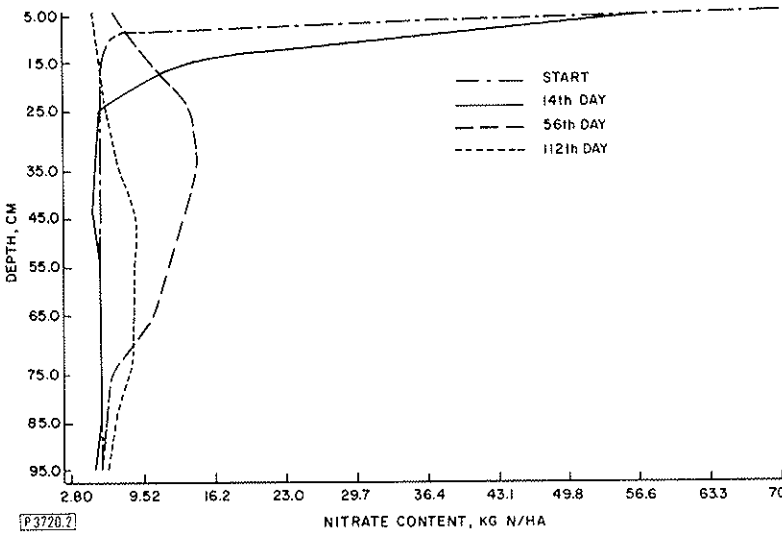

Figure 2: Simulated Distribution of Nitrates Through the Soil Profile at Some Day of Simulation Period

Nitratverteilung im Bodenprofil während der Simulationsperiode slow and quickens only in the fourth month of the simulation period. Denitrification is not an important factor in nitrate losses. Uptake by plants is a considerable factor in nitrate removed from the soil profile.

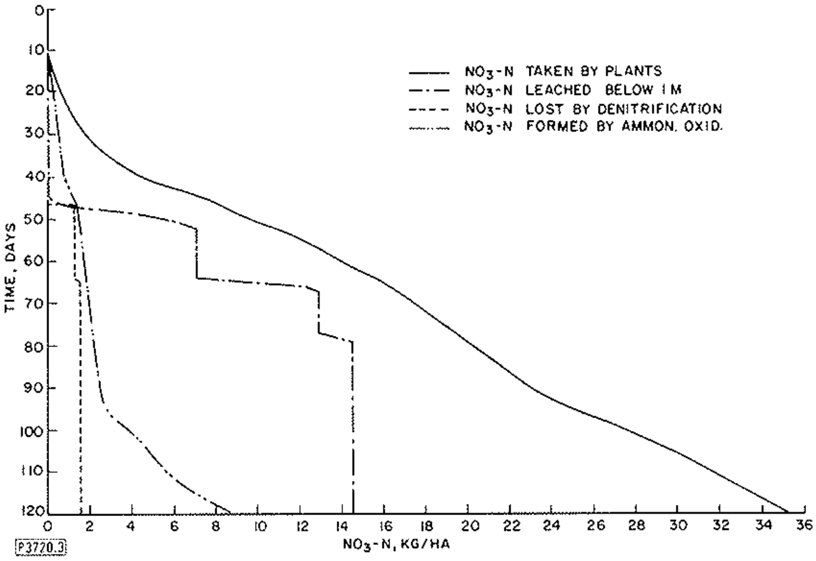

Figure 3: Nitrogen Changes and Nitrate Transport over the Simulation Period

Veränderungen des Stickstoffs während der Simulationsperiode

Additional Simulation Runs

A simulation program enables the estimation of influences of various parameters on the processes involved. The scope of such computer experiments is very large. To illustrate these possibilities, additional computer runs were obtained.

The influence of amounts of rain on the computed results was tested by doubling the simulated rain intensity of each rainfall in one run and cutting it in half in the other, in relation to the standard run discussed earlier. All other conditions were unchanged.

Doubling of rain intensity (Table 3, runs 1 and 2) results in a considerable increase in the amount of drainage water leaving the soil profile at the 1-m depth. The amount of nitrate leached out is also increased about fourfold. However, cutting the rain intensity in half (Table 3, runs 1 and 3) brings the amount of water and nitrates leached out to zero. The rainfall intensity is reflected in the results obtained for denitrification. The calculated nitrate uptake by plants shows a considerable dependence on the soil water content. This may be explained by the

Table 3: Cumulative Amounts of Precipitation, Drainage and Nitrate at End of 120 Days of Simulation and Initial Amounts of Nitrates

Gesamtmenge an Niederschlägen, Stickstoff zu Beginn und N-Auswaschung am Ende einer 120tägigen Simulation

	Run No.					
	1	2	3	4	5	6
Water, mm, cumulative:						
Precipitation	338	677	169	338	338	338
Drained	96	370	0	96	96	96
NO_3-N, kg/ha, initial						
residual in 0–10 cm	50.0	50.0	50.0	5.0	50.0	50.0
residual in 10–100 cm	50.4	50.4	50.4	50.4	18.0	50.4
Applied	20.0	20.0	20.0	20.0	20.0	40.0
NO_3-N, kg/ha at end of simulation						
Taken up by plants	35.2	10.0	65.9	18.7	30.7	44.4
Denitrified	1.5	25.7	0.0	1.0	1.1	1.6
Leached below 1 m	14.6	65.0	0.0	13.7	6.0	15.0

fact that in the simulation program, the nitrate uptake is a function of transpiration and nitrate concentration in the soil water.

The sensitivity of the simulation results to initial nitrate-nitrogen values in the profile was tested in runs 4 and 5 (Table 3). The initial nitrate content in the upper soil layer was diminished from 50 kg/ha in the standard run (No. 1) to 5 kg/ha in run 4. This change had very little influence on the amount of nitrates leached out at the end of the simulation period, although it had a considerable influence on the simulated nitrogen uptake by plants.

Reduction of initial values of residual nitrate-nitrogen in the deeper soil layers (run 5) reduced the amount of nitrate leached out.

In an additional run (Table 3, run 6) the amount of nitrogen applied was double that in the standard run. Increased fertilization enhances nitrogen uptake by plants, but it has no serious effect on the amount of nitrogen leached out over the simulated period.

In the two last runs, addition of 20 t/ha of organic matter to the top soil layer was simulated. In run 7, the organic matter contained 2 % nitrogen, 80 % cellulose, and 15 % lignin. The organic matter in run 8 differed from the previous only in that it contained 0.2 % N. All other conditions were as in the standard run.

Ammonium-nitrogen contents in the upper soil layer in these runs and in the standard one over the simulation period are presented in Figure 4. The run with a relatively low content of nitrogen in added organic matter shows a definite decrease until about 50 days from start of simulation, while in the other two runs a steady increase from the initial amount applied is noted.

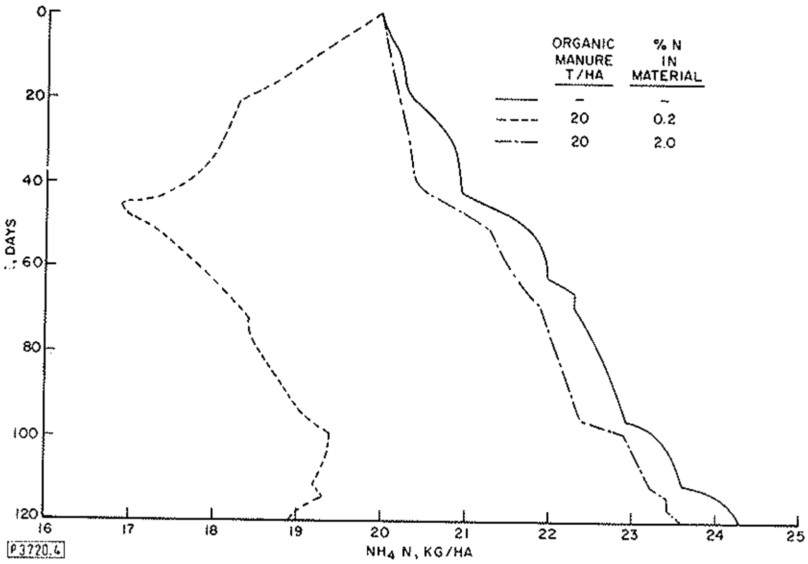

Figure 4: Influence of Organic Manure Addition and Nitrogen Content on Ammonium-Nitrogen Content of Top Soil Layer Over the Simulation Period

Wirkung der Zugabe von org. Substanz und Stickstoff auf den Ammoniumgehalt des Oberbodens im Verlaufe einer Simulationsperiode

Summary

A computer program simulating nitrogen transformations and transfer in soil is developed. The environmental parameters of the program were fitted to conditions of a lysimeter experiment. The computed results of water draining out of the soil at the 1-m depth and of the amounts of nitrate leached out with it were compared to measured results of the lysimeter experiment. The agreement between the computed and the measured results was good. Computations, simulating various rain intensities and nitrogen applications illustrated the use of the model for predicting trends induced by changes of these parameters.

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Vergleich der Nitratauswaschung zwischen den Ergebnissen von Lysimeterversuchen und den Vorausberechnungen durch das Simulationsmodell

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Ein Computerprogramm wurde entwickelt zur Simulation der Veränderung der Stickstoffformen und Bewegungen im Boden. Die Umweltparameter dieses Programmes wurden den Bedingungen des Lysimeterversuches angepaßt. Die durch Computer errechnete Wasserperkolation aus einer Bodentiefe von 1 m wurde verglichen mit den im Lysimeterversuch tatsächlich gemessenen Perkolationswerten und eine gute Übereinstimmung erzielt. Die Annahme verschiedener Regenintensitäten und Stickstoffapplikationen veranschaulichte den Gebrauch eines solchen Modells für die Voraussage von Trends, die durch Änderung solcher Parameter ausgelöst wurde.

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