

**Sensitivity of a simulation model on nitrate out flow
from soil profile to parameters representing various climatic
and agrotechnical conditions¹⁾**

by J. Hagin, A. Amberger, E. Segall, and G. Kruh

Technion-Israel Institute of Technology, Haifa
T.U. München, Institut für Pflanzenernährung, Weihenstephan

(Eingegangen: 12. 2. 1975)

Introduction

A computer simulation model describing nitrogen changes and transport in soils was developed. The theoretical background for the model, an outline of it, and a comparison of computed results to those obtained in a lysimeter experiment have been presented in previous papers. (Hagin et al. 1976 a, b) A detailed description of the model and program is given in a mimeographed report.²⁾

The program is based on the Continuous System Modeling Program (CSMP), developed by IBM and used by De Wit and coworkers (1972) for simulating ecological processes and transport phenomena in soils.

The simulation allows the calculation of possible influences of climatic and irrigation factors, of plant uptake, of amounts and forms of nitrogen applications, and of soil characteristics on nitrate enrichment of waters leaving a defined area.

The present paper discusses the sensitivity of the proposed model to parameter changes corresponding to different practices.

Soil, Climate, and Plant Characteristics and Agrotechnical Data Used in Model

Soils (Table 1). Soil No. 1 is a heavy clay in which the top layer (0–10 cm) has slightly different properties than the uniform deeper layers. Its water-retention curve (soil moisture in percentage of soil volume, vs. suction in bars) was taken from Rijtema's (1965) work for the sticky clay soil. The water content of saturation

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).

Table 1: Parameters of Simulated Soils and Added Organic Manures
 Parameter der simulierten Böden und der zugefügten org. Substanz

Soils	No. 1		No. 2	
	Top	Deeper	All	
Soil layer	Heavy clay		Silty loam	
Texture	Heavy clay		Silty loam	
Water content of saturated soil, vol.	0.65	0.55	0.43	
Field capacity, vol.	0.47	0.49	0.31	

Characteristics of both soils in all layers:

Specific weight of solids	Heat capacity of solids (cal/day/cm ³)	pH	Organic C %	N %	Tortuosity factor
2.6	0.48	7.0	1.43	0.15	0.6

Characteristics of added manure:

Carbohydrate composition		C		N
Lignin	Cellulose (incl. Hemicell.)	Sugars		
% 15	83	2	42	2

Table 2: Air, Water, and Soil Temperatures Used in Simulation
 Luft-, Wasser- u. Bodentemperaturen in der Simulation

Hour of day	April	May	June	July	Depth of soil cm	Initial soil temp. C°
	Air temperature C°					
3	13.7	15.5	17.3	20.9	0	15.7
8	19.4	22.8	24.5	27.4	10	15.2
12	24.1	26.8	28.4	31.3	50	16.0
18	19.0	21.1	23.0	26.2	90	16.6
24	14.6	16.4	18.4	21.8		
	Water temperature C°					
	14.9	16.7	18.7	21.6		

was taken as that at the lowest suction, and the contents at the start of simulation and at the lower soil boundary were taken at field capacity (1/3 bar). The water conductivity coefficients were reproduced from the same source. Diffusivity coefficients were determined from the equation $D = -k\delta\Psi/\delta\Theta$ (Bear et al., 1968) where k = conductivity coefficient, Ψ = suction and Θ = volumetric soil moisture percentage. Thermal conductivity coefficients were calculated from data on Healy clay taken from the work of de Vrie's (1963).

Soil No. 2 is a silty loam described by de Wit and van Keulen (1972).

Climatic Characteristics (Table 2). Climatic characteristics are based on measurements taken from one of the inner valleys of Israel (Ashbel, 1955, 1965, 1968), with rather high air temperatures and with rain simulated during the first month

only. Irrigation water temperatures were taken as wet-bulb temperatures (Pair et al., 1969).

Plant Characteristics (Table 3). Water uptake by plant roots was estimated for 10-day periods, assuming that water is taken up at the same locations as P^{32} . The data was based on Hall's measurements of P^{32} uptake by corn roots at different ages (Kramer 1956). Class A open-pan evaporation data³⁾ are for the same region as the temperature data. The evaporation/evapotranspiration ratio was adapted from Denmead and Shaw (1959), and the transpiration/evapotranspiration ratio from Peters and Russel (1959).

Table 3: Relative Root Activity, in Percentage, at Different Soil Depths and Daily Class A Open -Pan Evaporation and Transpiration (Corn) Rates

Relative Wurzelaktivität (%) in verschiedenen Bodentiefen und tägliche Evaporations- bzw. Transpirationsrate (mm)

Simulation Interval, in days	Relative Root Activity					Class A Open Pan Evaporation mm/day	Transpira- tion mm/day
	Soil Depth						
	0-10	10-20	20-30 cm	30-40	40-50		
1-10	0	0	0	0	0	3.92	0.00
11-20	93	4	2	1	0	4.37	0.03
21-30	65	19	9	5	2	5.47	0.18
31-40	47	25	15	10	3	5.85	0.56
41-50	33	30	20	14	3	7.40	1.66
51-61	28	32	22	15	3	8.12	2.84
62-71	25	33	23	15	4	9.15	4.18
72-81	24	34	22	15	5	9.30	4.75
82-91	23	33	22	15	7	9.12	4.82
92-101	23	33	21	15	8	9.34	4.68
102-111	22	32	21	16	9	9.56	4.02
112-121	22	32	21	16	9	9.25	2.82

Agrotechnical Parameters. These include the irrigation intensity in cm/hour, the amount of water applied per irrigation, the frequency of irrigation in days, and the amounts of nitrate, ammonia nitrogen, and organic compounds applied. The latter are characterized by their contents of carbon, nitrogen, lignin, cellulose and sucrose (Table 1).

3) Marnin, J., Agricultural Experiment Station, Neve Yaar, Israel (1970) unpublished data.

Simulation Results

Soil No. 1 (Table 4). In three of the runs (No. 1, 5, and 6), the frequency of irrigation and the water quantity per irrigation were varied, with the amount of water applied over the whole simulation period kept constant. The results show that as the frequency increases, both the amount of drained water and that of leached nitrates decreases, although the total amount of nitrates leached is very small. There is also an increase in nitrate uptake and a very noticeable decrease in denitrification.

Table 4: Variation Parameters and Some Results Obtained in Computer Runs at End of 120 Days of Simulation Heavy Clay Soil

Veränderung von Parametern und Ergebnisse von Computerläufen am Ende einer 120tägigen Simulationsperiode

	Run No.								
	1	2	3	4	5	6	7	8	9
<i>Irrigation</i>									
Frequency, days	14	14	14	7	7	1	14	14	14
Water/irrig., mm	75	75	75	75	37.5	5.35	75	75	37.5
<i>Water, mm (cumulative):</i>									
Total applied	552	552	552	1004	552	542	542	542	326
Drained below 1 m	42	42	42	213	24	21	21	21	22
Drained below 2 m	25	25	25	164	10	9	9	9	10
<i>Mineral N application:</i>									
NH ₄ -N kg/ha	400	200	1	400	400	400	1	1	400
NO ₃ -N kg/ha	50	50	50	50	50	50	50	50	50
<i>Manure added kg/ha</i>									
	1	10000	20000	1	1	1	10000	10000	1
<i>NO₃-N, kg/ha (cumulative)</i>									
Gained from NH ₄	346	186	22	337	347	352	16	64	346
Taken up by plants	232	124	35	139	317	324	15	55	291
Lost by Denitrification	138	96	38	211	3.7	1.5	23	51	1.5
Leached below 1 m	0.8	0.8	0.8	7.7	0.5	0.4	0.8	0.8	0.4
Leached below 2 m	0.5	0.05	0.05	0.6	0.02	0.02	0.05	0.05	0.02
Residual	49	33	18	57	97	97	11	27	124

Detailed results obtained over the course of simulation may provide explanations as to the above end results. Changes of water content in the upper (0–10 cm) soil layer in runs 1 and 6, which differ considerably in irrigation frequency (1 and 14 days), are shown in Figure 1. The irrigation regime after the 40th day is reflected in the pattern of water content changes. In parallel to the differences in water content, fluctuating and relatively low oxygen contents are found in the soil water of run 1, against the nearly constant and higher values in run 6. This may explain the differences between the two runs in the amounts of nitrates lost by denitrifica-

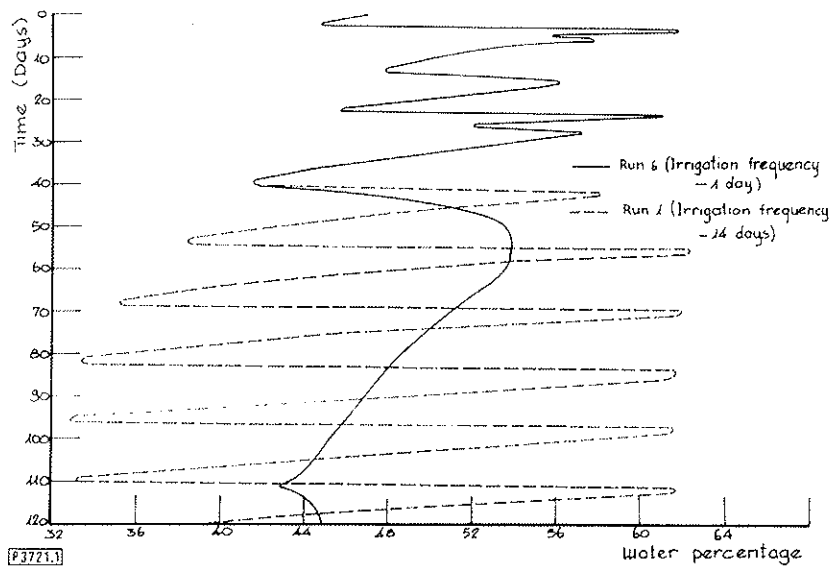


Figure 1: Water Content Changes over Simulation Period in Upper Soil Layer Heavy Clay Soil, Runs 1 and 6

Veränderungen im Wassergehalt der oberen Bodenschicht im Verlauf einer Simulationsperiode schwerer Tonboden, Lauf 1 und 6

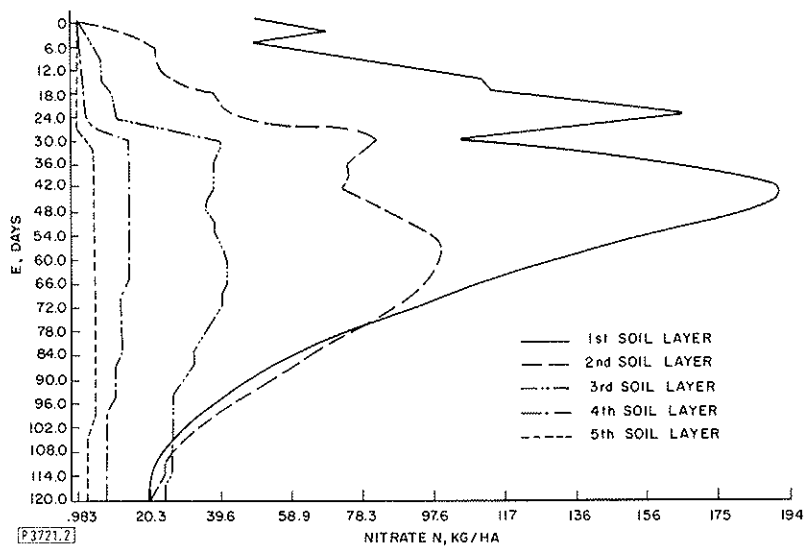


Figure 2: Nitrate Content of Some Soil Layers over Simulation Period Heavy Clay Soil, Run 6

Nitratgehalt einiger Bodenschichten im Verlaufe einer Simulationsperiode. Schwerer Tonboden, Lauf 6

tion. The more uniform water content in the soil over the simulation period accounts for the slightly higher nitrate uptake in the run with the high irrigation frequency. Nitrate changes in the upper layers in run 6 are shown in Figure 2. The nitrate distribution explains the very low amount leached out.

In another set of runs, the amount of water applied per irrigation was kept constant and the frequency of irrigation was 14 vs. 7 days, thereby doubling the total amount of water applied over the simulation period. The change of water input on the higher level of application (runs 4 and 1) increased considerably the loss of water by drainage, increased the amount of nitrates leached out about tenfold and increased losses by denitrification. On a lower level of water application (runs 5 and 9) the above output variables proved much less sensitive to the doubling of water input.

Application of ammonia vs. organic nitrogen was examined in runs 1, 2 and 8 with the total amount the same in all three. The amounts of nitrates – formed, taken up, denitrified and residual – are lower with the organic compounds. On the other hand, leaching is unaffected because of the slowness of the process.

The influence of the composition of organic manure was examined in runs 7 and 8. Run 7 received organic manure differing in composition from that in other runs and from those in Table 1. It contained 40 % C and 0.3 % N, whereas the composition of that applied in run 8 was 35 % C and 2.5 % N. Nitrification, denitrification and plant uptake are all higher in the variant richer in nitrogen.

Soil No. 2 (Table 5). The irrigation frequency was varied against a constant total amount of water in runs 11, 13, and 14. No appreciable effect on nitrogen transformation was observed. In all three runs, water did not drain below the 2-m depth, so that no leaching occurred. This is in contrast to the simulation results for the heavy clay soil. The difference in results is explained by the larger water holding capacity of the finer textured soil and identical transpiration rates for both soils. This allows for some water losses by drainage in the heavy clay soil. Doubling of the total amount of water applied (run 12, Table 5) included water losses by drainage and some nitrate leaching.

The influence of nitrogen application rates was examined in runs 11, 15 and 16. The influence is evident as regards both uptake and leaching below the 1-m depth, although the amounts leached are relatively small.

A common feature of runs 17, 18, and 19 is that transpiration and nitrate uptake, i.e., plant growth, were not included in the simulation. Contrary to the previous runs, water loss by drainage was observed in these runs. Runs 17 and 18 received identical fertilizer applications with variable irrigation frequencies and total amounts of water. Doubling the water input increased about twentyfold the amount of nitrates leached out below the 2-m depth, although the amount of drainage water at the same depth is only about double. Run 19 received „heavy“ irrigation, with residual nitrogen as the only source of nitrates. In these circumstan-

Table 5: Variation Parameters and Some Results Obtained in Computer Runs at End of 120 Days of Simulation Silty Loam Soil

Veränderung von Parametern und Ergebnisse von Computerläufen am Ende einer 120tägigen Simulationsperiode

	11	12	13	14	15	16	17	18	19
<i>Irrigation:</i>									
Frequency, days	14	7	1	7	14	14	14	7	7
Water/irrig. mm	7.5	7.5	0.535	3.75	7.5	7.5	7.5	7.5	7.5
<i>Water, mm (cumulative):</i>									
Total applied	552	1004	542	552	552	552	552	1004	1004
Drained below 1 m	0	323	0	0	0	0	340	751	751
Drained below 2 m	0	246	0	0	0	0	271	667	667
<i>Mineral N application:</i>									
NH ₄ -N kg/ha	400	400	400	400	200	1	400	400	1
NO ₃ -N kg/ha	50	50	50	50	25	1	50	50	1
<i>NO₃-N, kg/ha (cumulative):</i>									
Gained from NH ₄	356.6	339.4	359.8	357.6	195.3	25.4	330.4	296.5	6.8
Taken up by plants	298.6	149.1	341.0	318.0	156.7	16.1	0.0	0.0	0.0
Lost by denitrification	1.2	4.6	1.1	1.1	1.2	1.2	6.6	39.1	4.3
Leached below 1 m	2.3	131.4	0.0	0.0	0.9	0.0	153.9	302.4	11.3
Leached below 2 m	0.0	4.1	0.0	0.0	0.0	0.0	4.8	115.8	9.4
Residual	120.9	245.3	81.6	102.4	74.8	22.2	382.3	203.9	7.2

ces, nitrate losses in drainage water are considerable. Comparison of runs 19 and 12 shows that the simulated soil profile drains out more nitrates under conditions of no fertilization and no plant growth, than under fertilization with plants transpiring and taking up nitrates.

Summary

A simulation model for the influence of agrotechniques on nitrate leaching was illustrated for a heavy clay and a silty loam soil. It was shown, for the simulated system, that an increased frequency of irrigation, with a constant total amount of water applied, reduces the amount of water drained and of nitrates leached out, as well as losses by denitrification. Furthermore, doubling of the total water applied increases considerably both the amount of water drained and the losses of nitrates by denitrification and increases ten- to twentyfold the amount of nitrates leached out. The forms of nitrogen applied, organic vs. mineral, and the rates of application have only a slight influence. For one of the soils, it was shown that more nitrates are leached out under conditions of no fertilization and no plant growth than under fertilization with plants transpiring and taking up nitrates.

References

- Ashbel, D.: Meteorological data (Stations with self-recording instruments) (1950–1954). Meteorological Inst. of the Hebrew Univ. Jerusalem, p. 57 (1955).
- Ashbel, D.: Soil temperature in different latitudes and different climates. Hebrew Univ. Jerusalem, p. 232. (1965).
- Ashbel, D.: Climate of Israel – The Esdraelon Valley. Hebrew Univ. Jerusalem (in Hebrew). p. 265. (1968).
- Bear, J., Zaslavsky, D. and Irmay, S. (edit): Physical Principles of Water Percolation and Seepage. Unesco (Arid zone research series 29) Paris, p. 307–345 (1968).
- Denmead, O.T. and Shaw, R.H.: Evapotranspiration in relation to the development of the corn crop. *Agronomy J.* **51**: 725–6. (1959).
- Hagin, J., Amberger, A., Kruh, G. and Segall, E.: Outlines of a computer simulation model on residual and added nitrogen changes and transport in soils. *Z. Pflanzenern. Bodenk.* **1976**, 443–455.
- Hagin, J., Amberger, A., Kruh, G. and Segall, E.: 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. *Z. Pflanzenern. Bodenk.* **1976**, 457–464.
- Kramer, P.J., in Ruthland, W. (ed.): *Encyclopedia of Plant Physiology*, Springer Berlin, Vol. 3 p. 200–201. (1956).
- Pair, C.C.H., Wright, J.L. and Jensen, M.E.: Sprinkler irrigation spray temperatures. *Trans. ASAE* **1969**: 314–315. (1969).
- Peters, D.B. and Russell, M.B.: Relative water losses by evaporation and transpiration in field corn. *Soil Sci. Soc. Amer. Proc.* **23**: 170–173 (1959).
- Rijtema, P.E.: *An Analysis of Actual Evapotranspiration*. Centre for Agricultural Publications and Documentation, Wageningen, Netherlands, pp. 5 (1965).
- Vries de, D.A.: Thermal properties of soils. In van Wijk, W.R., edit. *Physics of Plant Environment*. North Holland Publ. Co. Amsterdam, p. 210–235 (1963).
- Wit de, C.T. and Van Keulen, H., ed.: *Simulation of transport processes in soils*. Centre for Agricultural Publication and Documentation, Wageningen, Netherlands, pp. 100. (1972).

Empfindlichkeit eines Simulationsmodelles über die Nitratbewegung im Bodenprofil entsprechend verschiedenen klimatischen und ackerbaulichen Bedingungen

Von J. Hagin, A. Amberger, E. Segall und G. Kruh

Ein Simulationsmodell über den Einfluß von ackerbaulichen Maßnahmen auf die Nitrat- auswaschung wurde dargestellt für einen schweren Lehm und einen schluffigen Lehm- boden. In einem simulierten System reduzierte eine zunehmende Häufigkeit der Beregnung bei konstanter Gesamtwassermenge die Menge an Perkulationswasser sowie die Verluste durch Nitrat- auswaschung und Denitrifikation. Eine Verdoppelung der Gesamtwassermenge er-

höhte die Menge an Perkulationswasser sowie die Denitrifikation beträchtlich, die Stickstoffauswaschung aber um das 10–20fache. Die angewandte Stickstoffform (organisch oder anorganisch) sowie die Applikationsrate waren von geringer Bedeutung.

Für einen der Böden konnte gezeigt werden, daß mehr Nitrat ausgewaschen wurde ohne mineralische N-Düngung und Pflanzenbesatz als wenn das Wasser durch einen normalen Pflanzenbestand transpiriert und Nitrat aufgenommen wurde.

[3721]