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Bulletin 117

MAXIMUM APPLICATION RATES FOR LAND TREATMENT OF SEPTAGE

By

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J. L. Anderson
M. J. Hansel

May 1983

This project serves as the final completion report for Water Resources Research Center Project, A-045-Minn. Principal Investigators: C. J. Clanton, R. E. Machmeier, and J. L. Anderson.

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MAXIMUM APPLICATION RATES FOR LAND TREATMENT OF SEPTAGE

During 1980, septage was applied in rates of 1120 and 1500 kg of nitrogen per hectare to three different soil textures in an attempt to determine maximum loading rates. These rates resulted in increased concentrations of nitrates in the soil water for a Hubbard loamy sand, Waukegan silt loam and Lester clay loam, indicating that the application rates exceeded the maximum rate that the soils could treat.

The first year's results indicate that soil type, application rates and soil depth resulted in no significant difference in total Kjeldahl nitrogen, ammonia, fecal streptococcus and fecal coliforms in the soil water samples. Nitrate concentrations, however, were significantly different between the soils, application rates and soil depths. For the Hubbard loamy sand, rainfall had a larger effect on nitrate concentrations and movement within the soil profile than for the Waukegan silt loam or Lester clay loam. On the Waukegan silt loam and Lester clay loam there was relatively little change in the nitrate concentration in the soil profile during the period when septage was applied twice a week.

After the design loading had been applied to the soil and no further applications made, a sharp increase in nitrate concentrations was observed in the soil profile. This probably resulted from changing the anaerobic surface layer to an aerobic condition resulting in nitrification and subsequent movement of nitrates through the profile following a rainfall event.

With no additional septage application, the second year's data indicate a significant difference in nitrate-N between soils, application rates, and depths. Generally, the nitrate concentrations in the Hubbard loamy sand and Waukegan silt loam were less than the first year, but the concentrations in the Lester clay loam were higher than the first year. This indicates that nitrification and nitrate movement in the Lester clay loam are slower than the other two soils.

Application resulted in a significant increase in the concentration of soil water calcium, magnesium, sodium and potassium during the first year of the study. However, there was no increase in the phosphorus content of the soil water.

Key Words

Wastewater, Septage, Groundwater, Pollution, Land Treatment, Soils, Nitrates, Phosphorus, Salts

MAXIMUM APPLICATION RATES FOR LAND TREATMENT OF SEPTAGE

C. J. Clanton, R. E. Machmeier, J. L. Anderson, and M. J. Hansel

INTRODUCTION

Using data from the 1970 census, Machmeier and Moore (1981) reported that over 307,000 Minnesota homes (25.2 percent) had individual sewage treatment systems. Usually these individual sewage treatment systems consist of a septic tank and soil absorption unit. The septic tank separates settleable solids (sludge) and floating scum from the domestic raw sewage and discharges effluent to a soil treatment system. The accumulated sludge and scum together with the liquid present in the tank when it is pumped is known as septage.

Septic tanks perform two functions by providing some anaerobic digestion of the organic solids that are generated by the household and providing storage space for the separation of solids not readily decomposed. Both of these functions improve the effluent quality that leaves the septic tank to the soil treatment system preventing excessive soil clogging resulting in reduced long-term acceptance rates (Anderson, et al., 1982). Over time, the slowly decomposing sludge and scum accumulate reducing the detention time for proper solids separation. Thus, the septic tank has lost its ability to prevent carry-over of solids to the treatment system, and the tanks should then be cleaned.

A 3.8-m^3 septic tank serving a family of four would likely require solids removal every 2 to 3 years. Assuming that an average size for a septic tank is 3.8 m^3 and is pumped every three years, 386 million liters of septage needs to be treated and disposed of annually in Minnesota. Septage is usually removed from the septic tank by a hauler who has the responsibility to dispose of the septage in an environmentally sound manner. Generally, the septage is either hauled to a local municipal sewage treatment facility or applied to the land for treatment. Many sewage treatment plants in Minnesota are operating at or above design capacity and cannot accept a slug load of septage. Therefore, current practice is to haul septage to an isolated location and spread it on the land.

Four potential hazards are associated with land application of septage. The first hazard is an increase in nitrate-nitrogen concentration in the groundwater. Nitrates are water soluble and move readily through the soil profile along with water. Nitrate concentrations may increase in the top layer of a surficial aquifer and be contained in the water withdrawn by shallow domestic wells. Concentrations of nitrate-nitrogen in excess of 10 mg/L in drinking water can cause methemoglobinemia (Sawyer and McCarty, 1978). In addition, if water from a surficial aquifer moves into a lake, nitrates may contribute to eutrophication.

Secondly, a hazard from pathogen movement to either surface or groundwater is another public health concern. Pathogens may be carried by surface runoff when septage is applied at rates in excess of soil infiltration or when the soil is frozen. If rates of application are too high, pathogens may move through the soil with the water contaminating shallow aquifers.

Third, additional problems may be encountered in some areas due to excessive applications of sodium, potassium, calcium and magnesium resulting in an accumulation of soluble salts in soils which are detrimental to crop growth.

And fourth, phosphorus, suspended solids and associated nutrients may be transported in the runoff from an application site which could contribute to lake eutrophication.

Given these concerns and the potential volume of septage production in Minnesota, there is a need to investigate the results of septage application on the soil environment.

Beehler and Moore (1977), in a three-year study reported that septage applied to soils with a sandy loam texture at application rates of 56 and 255 kg/ha of nitrogen did not result in any significant increase in well water nitrates. During the last 11 weeks of that study nitrogen loading rates were increased to 11,200 kg/ha without any impact on the groundwater in the vicinity following this slug loading. These results do not agree with data from investigations evaluating nitrogen loading rates for sludge, chemical fertilizer, or animal wastes (Stewart and Weber, 1976).

The objectives of this study were to:

1. Evaluate maximum septage application rates based on nutrient movement through three different soils.
2. Evaluate the effect that land application has on the movement of fecal indicator organisms through the soils.
3. Evaluate the accumulation of phosphorus and salts in each soil.

EXPERIMENTAL DESIGN

Experimental plots were located at the Sand Plains Experiment Station, Becker, the University experimental plots, St. Paul, and on the Gene Fyle farm, Monticello. These locations were selected to provide a range in soil characteristics representative of those occurring in large areas of Minnesota.

The three soils involved in this study were a Hubbard loamy sand, Udorthentic Haploboroll at Becker; a Waukegan silt loam, Typic Hapludoll at St. Paul, and the Lester clay loam, Mollic Hapludalf at Monticello. Descriptions of these soils are presented in Appendix A.

A randomized block design of soil depths within application rates and application rates within soil texture was utilized as the experimental design. At each location, initially, a total of six level test plots 3 m x 3 m in size were installed. In the second year of the study two additional plots were installed at each location. Within each of the plots five suction lysimeters were installed to extract soil water samples at depths of 15, 30, 60, 105, and 150 cm using procedures described by Linden (1977). Using nitrogen as a nutrient limiting factor, septage was applied at rates of 1120 and 1500 kg/ha of total Kjedahl nitrogen. Control plots received well water equal to the average moisture application for the other two treatments. During the second year of the study an additional application rate consisting of 200 kg/ha/yr of total Kjeldahl nitrogen was applied to the new plots.

During the first year of the study, septage was applied every Friday and Monday over a 14-week period. Soil water extract samples collected from suction lysimeters on Friday and Monday were combined and served as the observation that week. All samples were stored at $4^{o}C$ and analyzed within one week of collection following the procedures by the American Public Health Association (1975). The septage and soil water samples were analyzed for total Kjeldahl nitrogen, ammonia-nitrogen, nitrate-nitrogen, fecal streptococcus, and fecal coliforms on a weekly basis. The septage and soil water samples taken in the spring and fall of each year were analyzed for phosphorus, calcium, sodium, magnesium, and potassium.

During the second year soil water extract samples were collected on a biweekly basis and analyzed for the same parameters on the plots that had 1120- and 1500-kg/ha nitrogen loading rates except that the fecal indicators were analyzed in the top two depths instead of all five depths without additional septage application. The same parameters were evaluated for the additional plots with 200-kg/ha nitrogen applied. Information on the 200-kg/ha application will be reported at a later date.

RESULTS AND DISCUSSION

Septage Characteristics

The characteristics of septage used in this study varied greatly (Table 1). This variation is to be expected since the septage came from various locations. The characteristics of the septage in this study compare well with the previous study by Beehler and Moore (1979) and others (Kolega and Dewey, 1974; Metcalf and Eddy, 1979; Kolega et al., 1972).

Significance levels of soil water samples

Table 2 presents the significance levels of a randomized block design of soil depths within application rates and application rates within soil texture for the first year of soil water collection. Significance levels for the second year are located in Table 3. Phosphorus, calcium, magnesium, sodium and potassium for the second year will be reported at a later date.

Table 1. Characteristics of Septage[1/]

Measured Parameters	Mean ± Standard Deviation
Total Solids (percent)	1.47 ± 1.52
Total Volatile Solids (percent)	0.866 ± 0.984
Total Kjeldahl Nitrogen (mg/L)	375 ± 248
Ammonia-N (mg/L)	99.6 ± 45.5
Fecal Streptococcus (organisms/100 ml)	$3.05 \times 10^6 \pm 11.7 \times 10^6$
Fecal Coliforms (organisms/100 ml)	$5.84 \times 10^6 \pm 19.8 \times 10^6$

[1/] Nitrate, phosphate, calcium, magnesium, sodium, and potassium will be added at a later date.

Table 2. Significance levels of experimental treatments (1980)

Measured Parameters	Experimental Treatments		
	Soil Texture	Application Rate	Soil Depth
Total Kjeldahl Nitrogen	**[1/]	**	**
Ammonia-N	**	**	**
Nitrate-N	0.01	0.01	0.01
Fecal Streptococcus	**	**	**
Fecal Coliforms	**	**	**
Phosphate-P	**	**	**
Calcium	0.01	0.01	0.01
Magnesium	**	0.05	**
Sodium	0.05	0.01	0.01
Potassium	0.01	0.01	0.01

[1/] Nonsignificant

Table 3. Significance levels of experimental treatments (1981)[1/]

Measured Parameters	Experimental		
	Soil Texture	Application Rate	Soil Depth
Total Kjeldahl nitrogen	0.01	0.01	0.01
Ammonia-N	0.01	**[2/]	**
Nitrate-N	0.01	0.01	0.01
Fecal Streptococcus	**	**	**
Fecal Coliforms	**	**	**

[1/] Phosphate, calcium, magnesium, sodium, and potassium will be added at a later date.

[2/] Nonsignificant

Nitrate-Nitrogen

An analysis of variance indicated that nitrate concentrations in the soil water extracts were significantly different between experimental treatments. On the Hubbard loamy sand during the first year, nitrates increased sharply during the period from 9 to 14 weeks following the start of application and then decreased to relatively constant levels following the cessation of septage application after week 15 (Figure 1). The movement of nitrates in the Hubbard soil was influenced by rainfall events. During weeks 7 to 14, approximately 30 cm of rain were received at the Sand Plains Experiment Station. Peak nitrate concentrations on all treatments at all five depths occurred during this period.

After septage applications stopped on week 15, less than 2.5 cm of rain was received through week 20. This corresponds with the stabilizing of nitrate concentrations for all application rates at all depths.

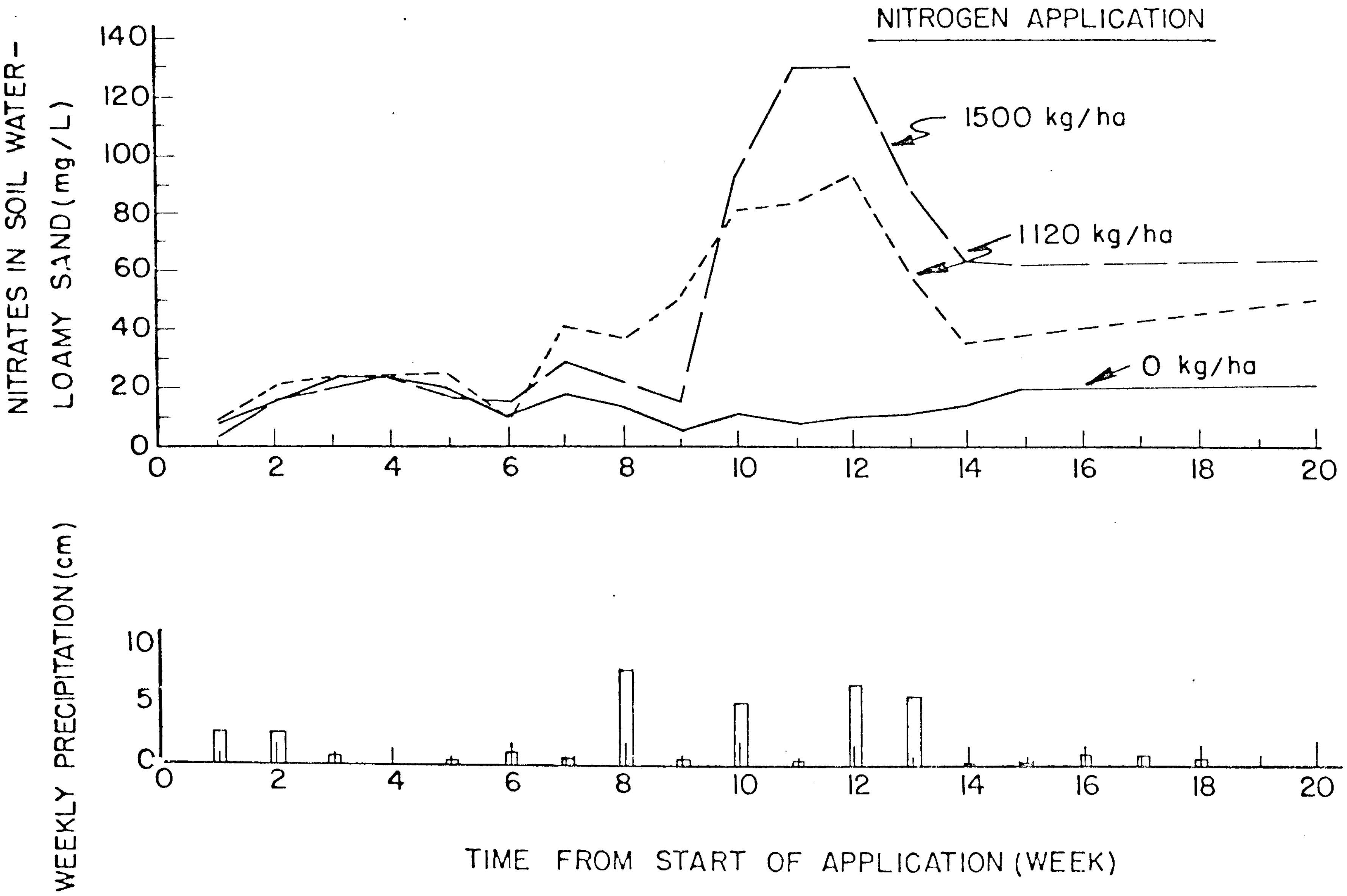

Figure 1. Comparison of nitrates in soil water with precipitation on the Hubbard sandy loam soil during 1980.

The dry conditions resulted in the formation of a dry organic mat at the surface. Even though some nitrification may have taken place in the conversion from organic nitrogen, no movement was apparent out of the organic mat and through the soil resulting in nearly constant concentrations at each of the depths.

On the Hubbard loamy sand (Figure 2), the plots where septage was applied showed increased nitrate concentrations when compared with the control plots. The 1120-kg/ha application rate showed an earlier increase in concentration than the 1500-kg/ha rate. However, the 1500-kg/ha application plots peaked at a higher concentration than the 1120-kg/ha plots. This was to be expected due to the increased application rate of nitrogen. It should be noted, however, that an additional 48 cm of water was applied with the high level of septage application which would dilute the nitrate concentration even though the total movement of nitrates was essentially the same.

The nitrate concentration observed in the soil water from the Hubbard loamy sand for the 1500-kg/ha rate at the five depths during the first year is presented in Figure 3. The data presented indicate the movement of nitrates through the soil profile. In general nitrate concentrations increased at later dates deeper in the profile. The exception to this was the 150-cm depth which had the highest concentration at the same time as the 60-cm depth. The 30-cm depth had a concentration approximately 75 mg/L higher than the 15-cm or 60-cm depths, respectively. The concentrations of nitrate at the bottom three depths were less than those at the 30-cm depth because of the dilution effect of the soil water and utilization by soil microorganisms.

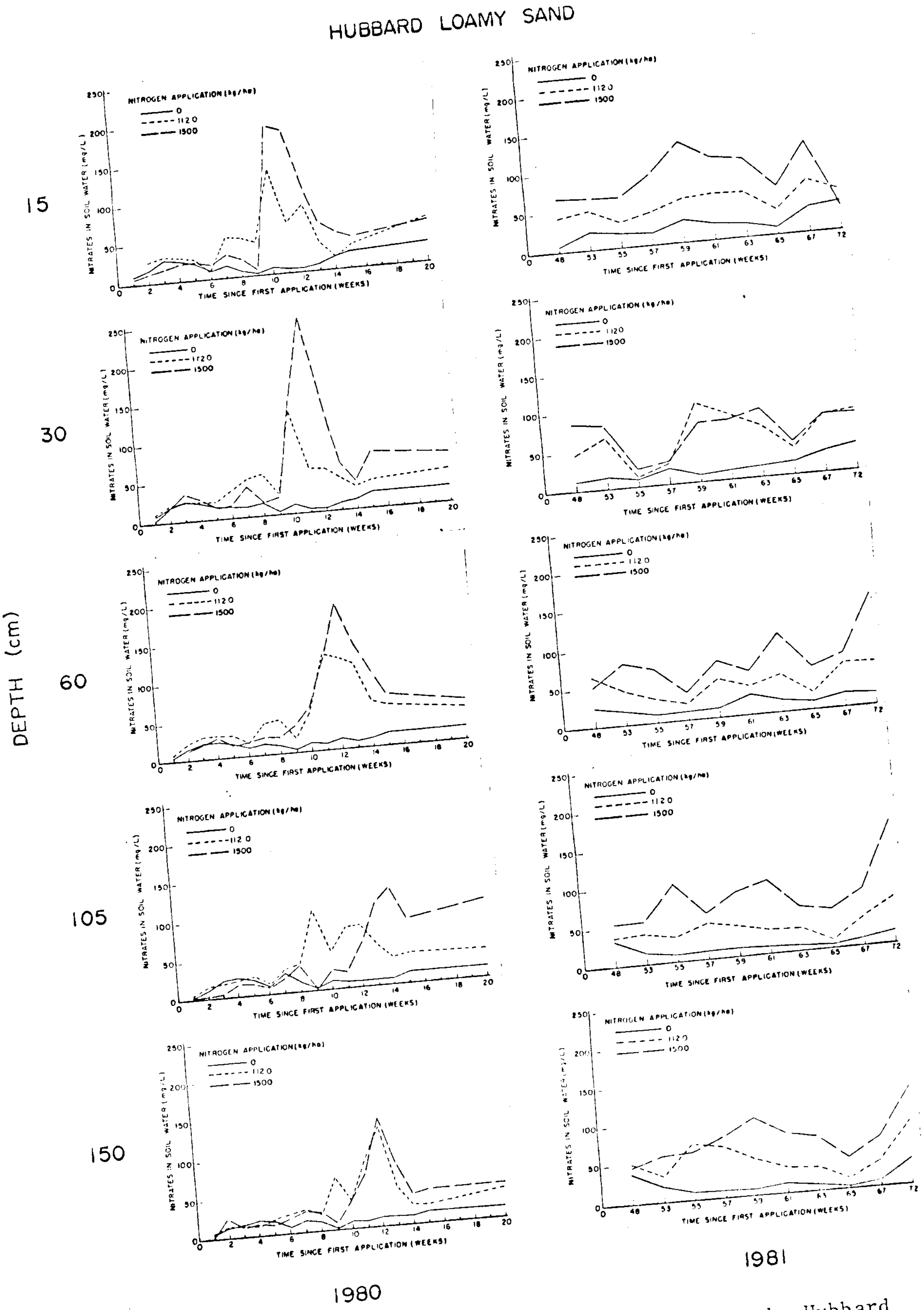

Figure 2. Comparison of nitrates in soil water for the Hubbard loamy sand.

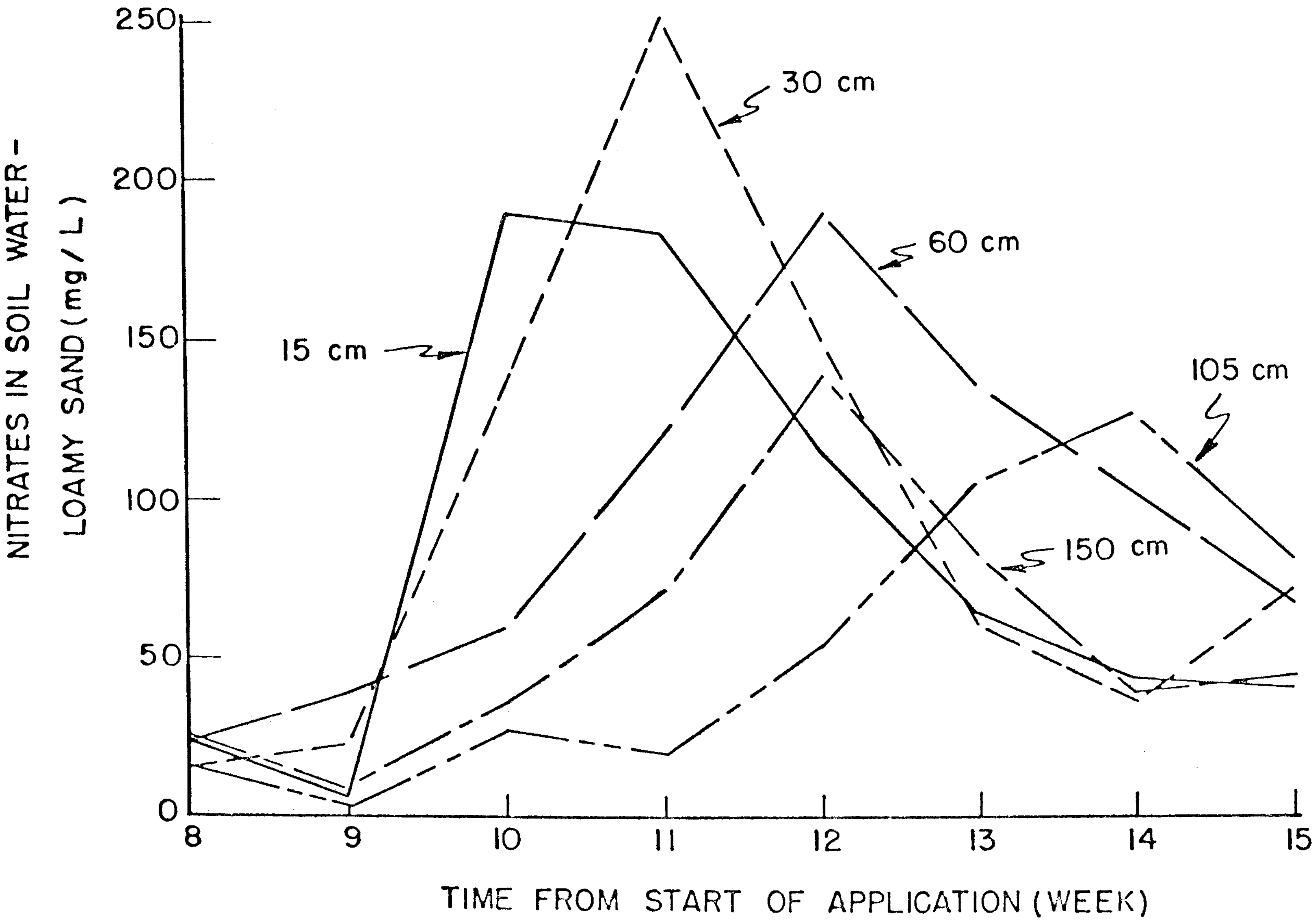

Figure 3. Nitrates in soil water at five depths in the Hubbard loamy sand for the 1500 kg/ha of nitrogen application rate during 1980.

During the second year with no additional application of septage, nitrate concentrations were relatively constant at each depth for the different application rates for the Hubbard loamy sand soil (Figure 2).

The nitrate concentration patterns for the Waukegan silt loam and Lester clay loam were relatively constant throughout the first year until septage application was concluded (Figures 4 and 5). Soil extracts taken five weeks after septage application was stopped (week 20), displayed a sharp increase in nitrate concentrations in both soils. This reflects changes occurring at the soil surface during application where the nitrogen applied is apparently tied up by soil microorganisms, soil organic matter and organic solids from the septage. This condition parallels the situation that occurs during land application of other waste materials such as digested sewage sludge or animal manure. Nitrogen is released from the organic mat as the mat becomes better aerated and the organic matter is broken down by oxidation and microbial activity.

During the second year the analysis of variance showed significant variation in nitrate concentrations over the sampling period. In general, the Waukegan and Lester soils exhibited elevated levels of nitrate concentrations through all depths when compared with the first year (Figures 4 and 5). Nitrate concentrations were generally higher in the Lester clay loam than in the Waukegan silt loam. This may indicate that the maximum concentration of nitrate for the silt loam occurred during the late fall of 1980 or early spring of 1981 when samples were not collected.

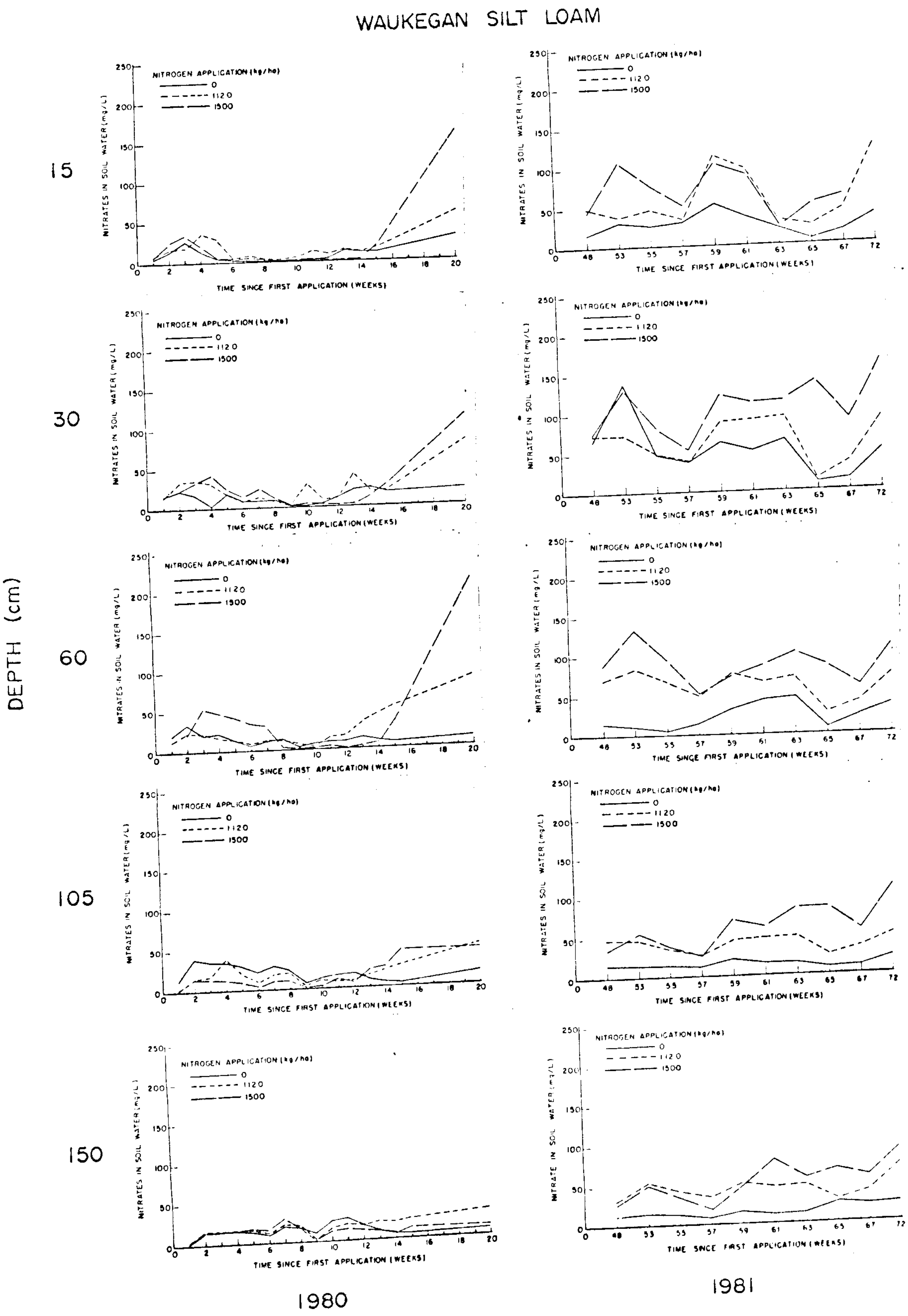

Figure 4. Comparison of nitrates in soil water for the Waukegan silt loam.

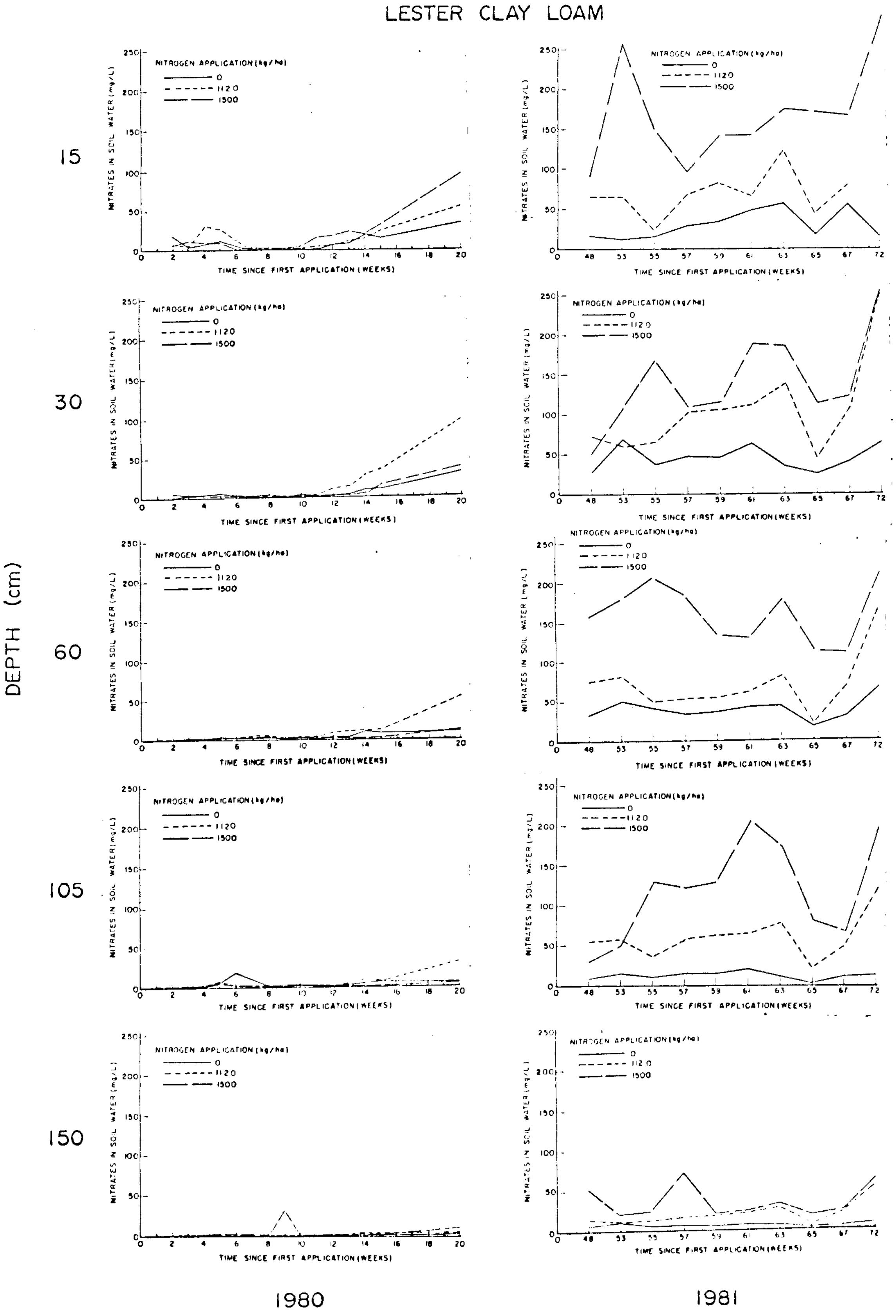

Figure 5. Comparison of nitrates in soil water for the Lester clay loam.

Kjeldahl and Ammonia-Nitrogen

During the first year the average concentration of total Kjeldahl nitrogen and ammonia-nitrogen in the soil water samples collected were 3.80 (±4.41) and 1.51 (±3.54) mg/L, respectively, with no significant difference between soil texture, application rates or soil depth as indicated by analysis of variance.

Total Kjeldahl nitrogen and the ammonia-nitrogen concentration during the second year averaged 2.65 (± 2.10) and 1.75 (± 1.91) mg/L, respectively. Even though total Kjeldahl nitrogen was significantly different among soils, application rates and soil depths, and ammonia-nitrogen was significantly different among soils, visual inspection of data indicated no distinguishable pattern.

Fecal Indicators

The average concentration of fecal streptococcus and fecal coliforms was 25 (±200) and 45 (±162) organisms/100 ml, respectively, during the first year. During the second year, the concentration increased to 108 (±1220) and 548 (±6970) organisms/100 ml for fecal streptococcus and fecal coliforms, respectively.

Phosphorus and Salts

During the fall of 1980, analysis of variance indicates no sigificant difference in soil water phosphates due to soil texture, application rate and depth. The average phosphates in the soil water samples taken were less than 0.50 mg/l which is the lower range of the sensitivity of the spectrophotometer.

Magnesium in the soil water was significantly different only between the septage application rates (Table 4). Soil water calcium, sodium and potassium were significantly different for soil texture, application rate and depth in the soil profile.

Soil water calcium was higher for the two septage application plots than for the control plots (Figure 6). This increase could be from the application of septage or from the increase in solubility of calcium carbonate in the nitrification process. The high application plots showed lower soil water calcium concentrations than the low application plots in several instances. In addition, calcium concentrations in the Hubbard loamy sand soil were half of those for the Lester clay loam.

Sodium concentration in the soil water were greater with applied septage than for the control plots with up to a 40-fold increase in some instances (Figure 7). Even though the sodium concentration was greater with higher application plot than with the lower, there was little difference in the concentration of sodium between the three soils.

Table 4. Soil water magnesium concentration pooled over soil textures and soil depths.

Nitrogen Application kg/ha	Concentration mg/L
0	17.0 ± 7.76[1]
1120	61.1 ± 56.6
1500	49.4 ± 27.7

[1] mean ± standard deviation

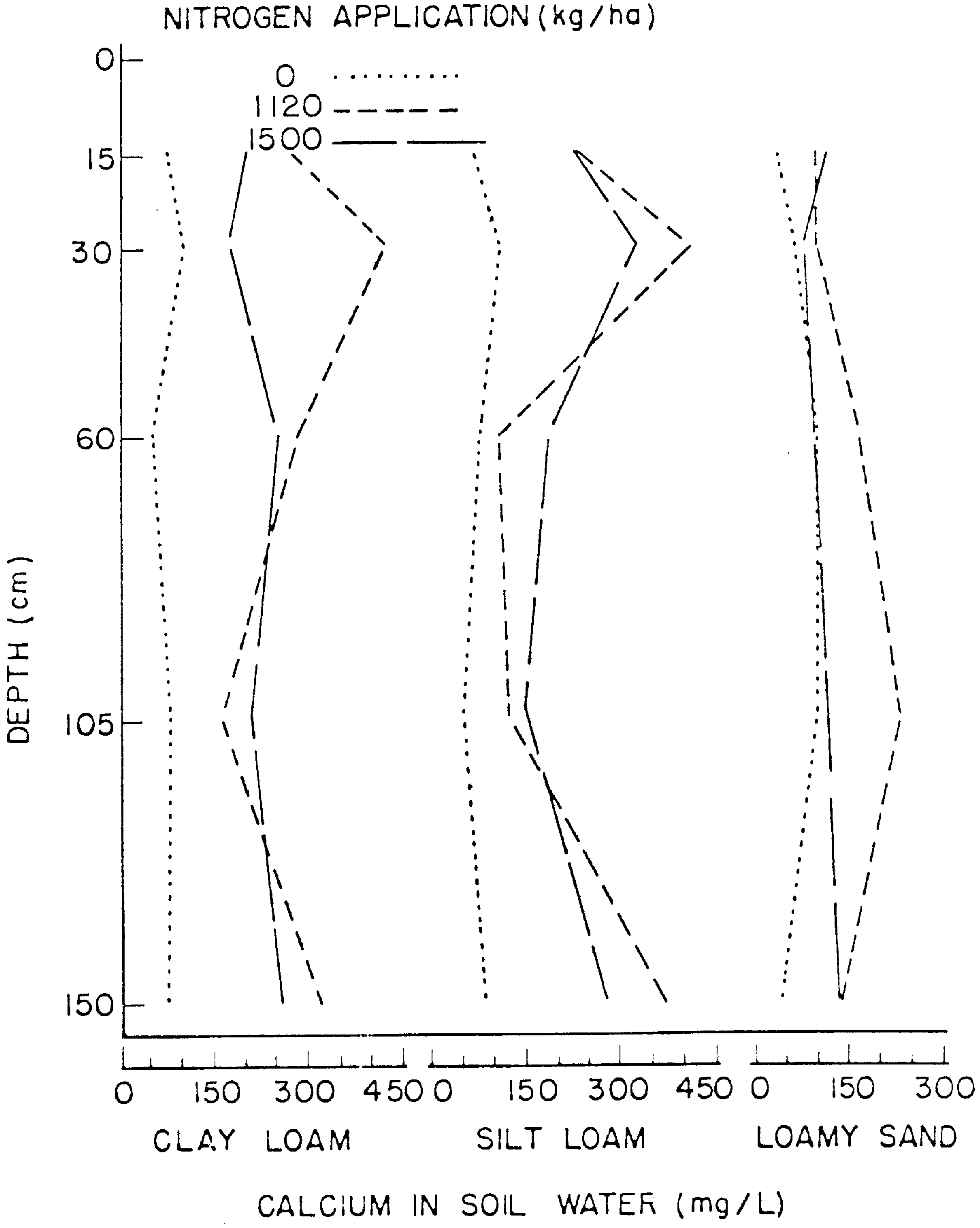

Figure 6. Calcium in soil water of the three soils after septage application stopped.

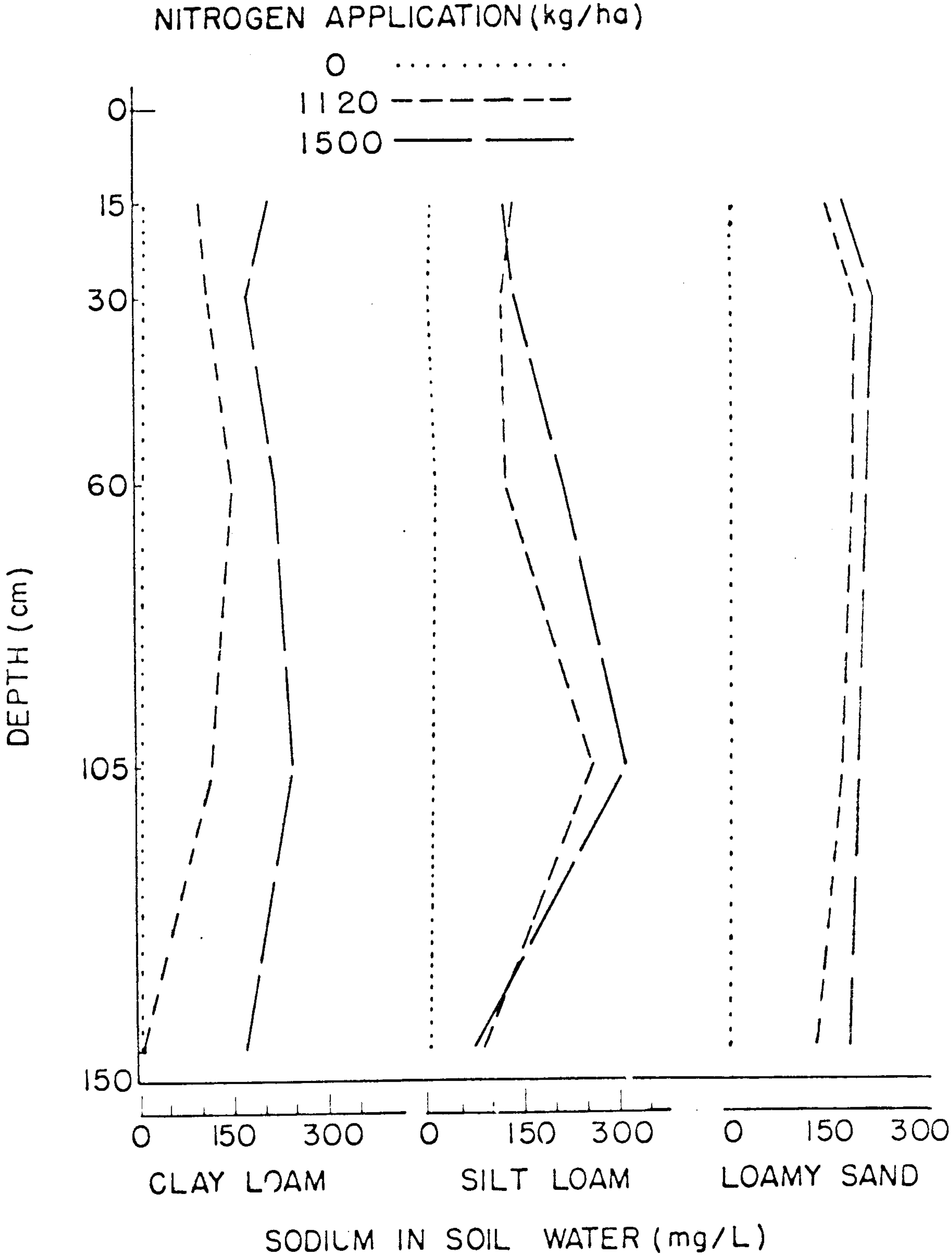

Figure 7. Sodium in soil water of the three soils after septage application stopped.

There was a slight increase in soil water potassium on the clay loam and loamy sandy soils for the septage applicated plots over the control plots (Figure 8). On the silt loam soil, there was almost a four-fold increase in soil water potassium where septage was applied versus no septage application. In addition, the potassium concentration in the water samples from the silt loam soil under the high level application averaged four times the concentration in the loamy sand soil and twice that in the clay loam soil.

The phosphorus and salt data collected during the second year will be reported at a later date.

CONCLUSIONS

Septage application rates of 1120 and 1500 kg per hectare of nitrogen resulted in increased concentrations of nitrates in soil water extracts for a Hubbard loamy sand, Waukegan silt loam and Lester clay loam. Nitrate movement is quite slow through the Lester clay loam so that negative impacts of high rates of application will not be as great when compared to the silt loam or loamy sand. However, if the objective is to prevent movement of high concentrations of nitrates through soils these application rates are too high. Results of the 200-kg/ha application rates will be reported later.

The application of septage did not affect the concentrations of fecal streptococcus and fecal coliforms in the soil water when comparing the treated plots to the control plots for both years. This indicates that the soils evaluated have the capability to reduce the high level of fecal organisms found in septage to levels found normally in soil water.

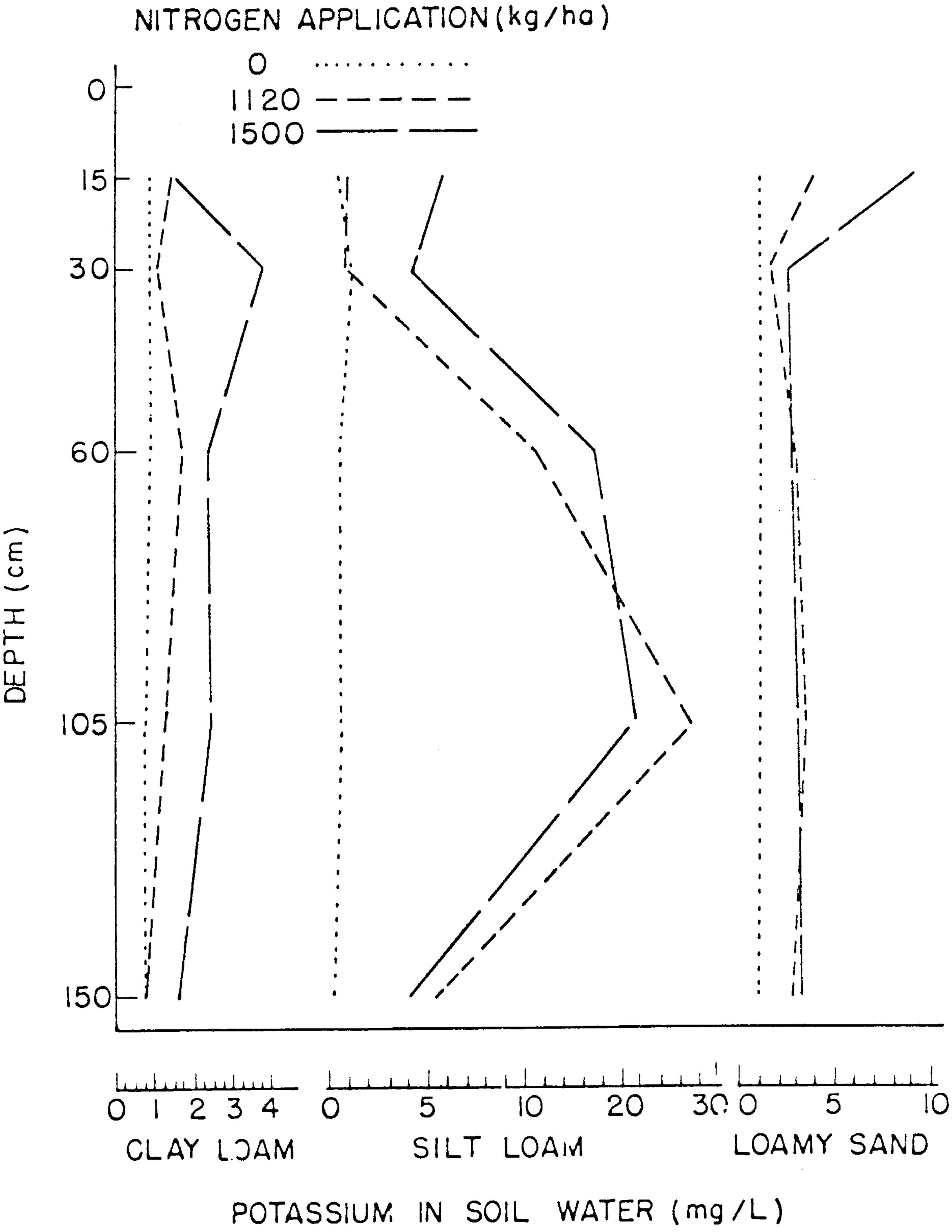

Figure 8. Potassium in soil water of the three soils after septage application stopped.

Septage application resulted in a significant increase in the concentration of soil water calcium, magnesium, sodium and potassium during the first year.

There was no increase in the phosphorus concentration in the soil water.

REFERENCES

American Public Health Association. 1975. Standard methods of the examination of waste and wastewater. 14th Ed. Washington, D.C. 1193p.

Anderson, J. L., R. E. Machmeier, and M. J. Hansel. 1982. Long-term acceptance rates of soils for wastewater. Proceedings of the Third National Symposium on Individual and Small Community Sewage Treatment. Am. Soc. of Ag. Engr. 345p.

Beehler, G. R. and J. A. Moore. 1979. A study of the characteristics and pollution potential of land spread domestic septage on groundwater quality. Agricultural Engineering Department, University of Minnesota, St. Paul, Minnesota.

Kolega, J. J. and A. W. Dewey. 1974. Septage disposal practices. Proceedings of the National Home Sewage Disposal Symposium. Am. Soc. of Ag. Engr. 242p.

Kolega, J. J., B. J. Conzenza, A. W. Dewey and R. L. Leonard. 1972. Septage: Wastes Pumped from Septic Tanks. Transactions of ASAE. 53(6):1124.

Linden. D. R. 1977. Design, installation, and use of porous ceramic samplers for monitoring soil-water quality. Tech. Bull. 1562. ARS-USDA. Minnesota Ag. Expt. Sta. 11p.

Machmeier, R. E. and J. A. Moore. 1981. Land treatment of septage. Individual Onsite Wastewater Systems. Proceedings of the Seventh National Conference. National Sanitation Foundation. Ann Arbor, Michigan. 355p.

Metcalf and Eddy, Inc. Revised by George Tchobanoglous. 1979. Wastewater Engineering: Treatment Disposal Reuse. McGraw-Hill Book Company. New York. 920p.

Sawyer, C. N. and P. L. McCarty. 1978. Chemistry for environmental engineering. 3rd Ed. McGraw-Hill Book Company. New York. 532 p.

Soil Survey Staff. 1951. Soil survey manual. USDA Handbook No. 18.

Soil Survey Staff. 1975. Soil taxonomy. USDA Handbook No. 436. 743 p.

Stewart, B. A. and L. R. Weber. 1976. Consideration of soils for accepting waste. In Land Application of Waste Materials. Soil Conservation Society of America Special Publication. Ankegy, Iowa. pp.8-21.

Appendix A. Analytical and morphological data for soils located at three septage application sites (preliminary information).

Site	Soil and Classification*	Horizon and Depth (inches)	pH	Textural Class**	Structure**	OC %	CCE %	Munsell Color
University of Minnesota	Waukegan	A1 0-9	6.4	Sil	2fabK	2.0	N.D.	10YR 2/1
Experimental Plots,	Silt loam	B 9-21	6.1	Sil	2fabK	0.7	N.D.	10YR 3/4
St. Paul	fine loamy over	IIB3 21-24	6.1	Sl	1fabK	N.D.	N.D.	10YR 3/3
	sandy skeletal,	IIC1 24-36	8.2	S	Sg	N.D.	4.3	10YR 5/4
	mixed	IIC1 36±42	8.5	Cs	Sg	N.D.	8.3	10YR 4/3
	mesic Typic Hapludol							
Sand Plains	Hubbard loamy	Ap 0-9	5.1	LCos	Sg	1.3	N.D.	10YR 2/2
Experiment Station,	sand	B1 9-15	5.2	LCos	Sg	1.4	N.D.	10YR 3/4
Becker	sandy, mixed	B2 15-27	7.8	Cs	Sg	0.8	N.D.	10YR 4/4
	mexic							
	Udorthentic	C1 27-50	7.1	Cs	Sg	0.4	N.D.	10YR 4/3
	Haploborolls	C2 50-60	5.8	Cs	Sg	N.D.	N.D.	10YR 4/3
Gene Fyle Farm,	Lester clay loam	AP 0-9	N.D.	1	M	2.0	N.D.	10YR 3/1
Monticello	fine loamy mixed,	B21 9-17	N.D.	C1	2msbK	0.6	N.D.	10YR 4/2
	mesic mollic	B22 17-24	N.D.	C1	1msbK	0.4	N.D.	10YR 4/3
	Hapludalf	B23 24-32	N.D.	1	1msbK	0.4	N.D.	10YR 4/4
		B31 32-36	N.D.	1	m	0.4	N.D.	10YR 4/4
		C11 34-46	N.D.	1	m	N.D.	N.D.	2.5Y 5/4
		C12 46+	N.D.	1	m	N.D.	N.D.	2.5Y 5/4

* Classification from Soil Taxonomy 1975

** Structure and texture notations of Soil Survey Staff 1951

N.D. = not determined

LAND TREATMENT OF SEPTAGE

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December 1984

This project serves as the final completion report for Water Resources Research Center Project, A-045-Minn. Principal Investigators: C. J. Clanton, R. E. Machmeier, and J. L. Anderson.

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LAND TREATMENT OF SEPTAGE

C. J. Clanton, J. L. Anderson, R. E. Machmeier, and M. J. Hansel
Assoc. Member ASAE
Senior Member ASAE
Assoc. Member ASAE

The 1970 census reported over 307,000 Minnesota homes (25.2 percent) had individual sewage treatment systems. The septic tank separates settleable solids (sludge) and floating scum from domestic raw sewage and discharges effluent to a soil treatment system. The accumulated sludge and scum together with the liquid in the tank during cleaning is known as septage.

Septage is normally removed from the septic tank every 2 to 3 years and must be disposed in an environmentally sound manner. Generally, local municipal sewage treatment facilities have accepted septage; however, overloading of these facilities has created a need for land treatment.

Three potential hazards are associated with land application of septage. First, nitrate concentrations may increase in the top layer of a surficial aquifer and be present in water drawn by shallow domestic wells. Second, with high application rates, pathogens may move through the soil, contaminating shallow aquifers. Third, excessive applications of phosphorus, potassium, sodium, calcium and magnesium result in an accumulation of nutrients which may be detrimental to crop growth in certain soils.

OBJECTIVES

The objectives of this study were to: (1) evaluate septage application rates based on nitrate movement through three different soils, (2) evaluate the effect of land application on fecal indicator organisms, and (3) evaluate the accumulation of phosphorus and salts.

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EXPERIMENTAL DESIGN

The three soils studied were Hubbard loamy sand, Udorthentic Haploboroll; Waukegan silt loam, Typic Hapludoll, and Lester clay loam, Mollic Hapludalf. Soils were classified according to Soil Survey Staff (1951, 1975).

A randomized block design of soil depths within application rates and application rates within soil texture was utilized as the experimental design. At each location, initially, six level test plots 3 m x 3 m in size were installed. Five suction lysimeters were installed in each of the plots to extract soil water samples at depths of 15, 30, 60, 105, and 150 cm using procedures described by Linden (1977). Using nitrogen as the nutrient limiting factor, septage was applied at rates of 1120 and 1500 kg/ha total Kjeldahl nitrogen twice weekly over a 14-week period. Control plots received well water equal to the average moisture application of the other two applications. In the second year of the study, an additional set of plots were installed at each location. Total Kjeldahl nitrogen was applied at the rate of 225 kg/ha to these plots.

During the first year, soil water extract samples were collected twice weekly from each lysimeter, combined and analyzed for total Kjeldahl nitrogen, ammonia-nitrogen, nitrate-nitrogen, fecal streptococcus and fecal coliforms following procedures set by the American Public Health Association (1975). Samples taken in the spring and fall were analyzed for phosphorus, potassium, sodium, calcium, and magnesium.

Second year soil water extract samples, without additional septage application, were collected biweekly and analyzed for the same parameters on plots with 1120 and 1500 kg/ha nitrogen loading rates with the exception that fecal indicators were analyzed only in the top two depths. The same parameters were evaluated for the additional plots with 225 kg/ha nitrogen applied. Samples collected in the third year were analyzed only for nutrient concentrations. Nutrient concentrations as presented are the average of five sampling depths.

RESULTS AND DISCUSSION

Septage Characteristics

The characteristics of septage used in this study varied greatly (Table 1) since the septage originated at various locations.

Table 1. Characteristics of Septage

Measured parameter	Mean + standard deviation
Total solids (percent)	1.47 ± 1.52
Total volatile solids (percent)	0.866 ± 0.984
Total Kjeldahl nitrogen (mg/L)	375 ± 248
Ammonia-N (mg/L)	99.6 ± 45.5
Phosphorus (ppm db)	7520 ± 1820
Sodium (ppm db)	103,000 ± 62,300
Potassium (ppm db)	10300 ± 5470
Calcium (ppm db)	45300 ± 10600
Magnesium (ppm db)	8300 ± 3300
Fecal streptococcus (organisms/100 ml)	$3.05 \times 10^6 \pm 11.7 \times 10^6$
Fecal coliforms (organisms/100 ml)	$5.84 \times 10^6 \pm 19.8 \times 10^6$

Nitrate-nitrogen

An analysis of variance at the 0.01 alpha level indicated nitrate concentrations in soil water extracts were significantly different between soils, application rates and sampling depths for nitrogen application rates.

In the first year, nitrates increased sharply in Hubbard loamy sand during the period 9 to 14 weeks following the start of application, then decreased to relatively constant levels following the cessation of septage application after week 15 (Fig. 1). During weeks 7 through 14, approximately 30 cm of rain fell on the Hubbard soil; thus, the formation and movement of nitrates were influenced by rainfall events. Peak nitrate concentrations occurred in week 11, when 1120 and 1500 kg/ha application rates showed 11.5- and 19.5-fold increases (83 and 141 mg/L), respectively, over plots which received no septage.

Less than 2.5 cm of rain fell in weeks 15 through 20, and nitrate concentrations for all application rates stabilized at all depths. A dry organic mat formed at the surface and no nitrate concentration changes occurred in the soil profile.

Throughout the second year, nitrate concentrations in the Hubbard loamy sand were relatively constant. Over the yearly collection period, 1120 and 1500 kg/ha application rates averaged 2.9 and 4.7 times the levels (47 and 74 mg/L) found in the control plots. In the third year, nitrate concentrations in septage-applied plots were similar; however, they continued to be approximately 3.0 times the level (54 mg/L) of plots receiving no septage.

Nitrate concentrations for Waukegan silt loam and Lester clay loam were relatively constant throughout the first year until septage application was concluded (week 14). Soil water extracts taken six weeks later displayed a sharp increase in nitrate concentrations in both soils. This suggests that changes occurred at the soil surface during initial application when first applied nitrogen was bound by soil microorganisms, soil organic matter and septage organic solids under anaerobic conditions. When application ended, nitrogen was released from the organic mat as the soil became better aerated, resulting in oxidation and decomposition of organic matter.

For the Waukegan silt loam, 1120 and 1500 kg/ha application rates resulted in 3.5- and 6.0-fold (63 and 108 mg/L) increases in nitrate concentrations over control plots in the last collection period (week 20). However, the 1120 kg/ha rate on Lester clay loam produced a 2.9-fold increase (49 mg/L), while the 1500 kg/ha rate resulted in only a 2.0-fold increase (33 mg/L). This may indicate that following the lighter application rate, the soils became aerobic sooner than following heavier application rates, producing increased nitrification and resulting in a higher nitrate concentration.

During spring of the second year, the Waukegan soil exhibited lower nitrate concentrations than those observed at the end of the first year. This indicates that some nitrates were leached during winter and spring before sampling. Nitrate concentrations in the Lester soil, however, continued to increase from the first year into the second and were generally higher in the Lester clay loam than Waukegan silt loam. This indicates that the maximum silt loam nitrate concentration occurred during late fall of the first year or early spring of the second year when no samples were collected. Generally, for the Waukegan silt loam, 1120 and 1500 kg/ha application rates resulted in 2.3- and 3.2-fold increases (55 and 74 mg/l) over control applications, and Lester clay loam showed increased concentrations of 2.4- and 4.5-fold (63 and 119 mg/L) with 1120 and 1500 kg/ha application rates.

During the third year, nitrate concentrations in the silt loam were similar to those measured the previous year. However, nitrate concentrations in the clay loam were slightly less in the spring of the third year than those of the fall of the second year, following the silt loam pattern. The septage-applied plots continued to have greater nitrate concentrations than the previous year. In addition, the plots receiving no septage contained greater nitrate levels than those of the previous two years--a condition which could be attributed to nitrification of organic nitrogen in the soil humus and the fact that no crops were planted to utilize soil nitrogen.

Analysis of variance indicates that there was no significant difference between plots receiving 225 kg/ha of nitrogen from septage and plots receiving no septage during the first year. However, analysis of variance indicates that these two application rates produced significantly different results in the second year, at an alpha level of 0.05.

Nitrate concentrations for Hubbard loamy sand increased at the 225 kg/ha application rate (Fig. 2). During the fall of the first year (week 12), this application rate resulted in a 3.7 fold increase (68 mg/L) over control plots. During the second year, the nitrate concentrations maintained approximately twice those of the control plots (29 mg/L), although these concentrations were lower than those observed in the first year.

In Waukegan silt loam and Lester clay loam trials, a 225 kg/ha nitrogen application rate resulted in lower nitrate concentrations than in plots receiving no septage for the majority of the two-year collection period. This indicates that these two soils could have been stimulated at the low application rate of septage to bind nitrogen, presumably as organic nitrogen.

Kjeldahl and Ammonia-nitrogen

Analysis of variance indicated that septage application significantly affected total Kjeldahl nitrogen and ammonia nitrogen in the soil water at a 0.01 alpha level, but no detectable pattern was observed.

Fecal Indicators

Analysis of variance indicates that septage application did not change the concentration of fecal streptococcus or fecal coliforms in soil water. This indicates that the soils evaluated have the capability to reduce the high level of fecal organisms found in septage to levels normally found in soil water.

Phosphorus and Salts in the Soil Water

The majority of soil water phosphorus levels were below the detection level of 0.5 mg/l. Analysis of variance indicates soil water concentrations of the salts of potassium, sodium, calcium and magnesium for the three soils were significantly affected by application rates at the 0.01 alpha level.

Even though potassium concentrations differed significantly between application rates, relatively little difference in concentrations was observed (Fig. 3). Sodium, however, showed a distinct increase in all three soils due to septage application. This increase was approximately 28-fold (200 mg/L) for the 1500 kg/ha application rate during the fall of first year (week 14) in both Lester clay loam and Hubbard loamy sand.

Calcium and magnesium concentrations patterns were relatively similar (Fig. 4). The largest concentration occurred during fall of the second year (week 67) for Hubbard loamy sand and during fall of the first year (week 14) for Waukegan silt loam, whereas Lester clay loam concentrations maintained relatively constant levels after septage application until the fall of the third year.

Phosphorus and Salts in the Soil Profile

Analysis of variance indicates that application rates significantly affected only phosphorus and sodium concentrations in the soil profile taken from soil samples upon completion of the three-year study at an alpha level of 0.01.

Phosphorus applied in septage remained in the upper 15 cm of the soil profile (Fig. 5). The largest increase of phosphorus occurred in Lester clay loam where 1120 and 1500 kg/ha application rates increased phosphorus concentrations by 2.6- and 1.7-fold (29 and 19 mg/kg), respectively.

Sodium concentrations were greater in Lester clay loam and Waukegan silt loam, possibly due to the increased cation exchange capacity of these two soils. On the average, 1120 and 1500 kg/ha application rates increased sodium concentration 5.4-fold (143 mg/kg) over the top 40 cm of the profile. For Hubbard loamy sand, the relatively small increase due to the septage application could indicate that by the end of this three-year study, most of the sodium had leached below the sampling depth.

CONCLUSIONS

Even though 225 kg/ha nitrogen applied in septage to a loamy sand soil increased nitrate concentrations in the upper 60 cm of the soil profile, the nitrate concentrations below this point were similar to background concentrations. This indicates that for this soil type, the 225 kg/ha application rate may be considered acceptable.

The nitrogen application rate of 1120 kg/ha would exceed the nitrogen storage capabilities of silt loam and clay loam soils because nitrate concentrations increased below the 105-cm depth, where crop nutrient uptake is reduced. Since nitrate concentrations from the 225 kg/ha application rate were less than or similar to background levels, the acceptable application would be between these two rates.

Application of septage did not affect concentrations of fecal streptococcus and fecal coliforms in soil water.

Septage application resulted in a statistically significant increase in the concentration of soil water potassium, sodium, calcium and magnesium.

Application of septage produced an increase in the phosphorus and sodium concentrations in the soil profile at the completion of this project.

REFERENCES

American Public Health Association. 1975. Standard methods of the examination of waste and wastewater. 14th Ed. Washington, D.C. 1193p.

Linden, D. R. 1977. Design, installation, and use of porous ceramic samplers for monitoring soil-water quality. ARS-USDA. Tech. Bull. 1562. 16p.

Soil Survey Staff. 1951. Soil survey manual. USDA Handbook No. 18.

Soil Survey Staff. 1975. Soil taxonomy. USDA Handbook No. 436. 743 p.

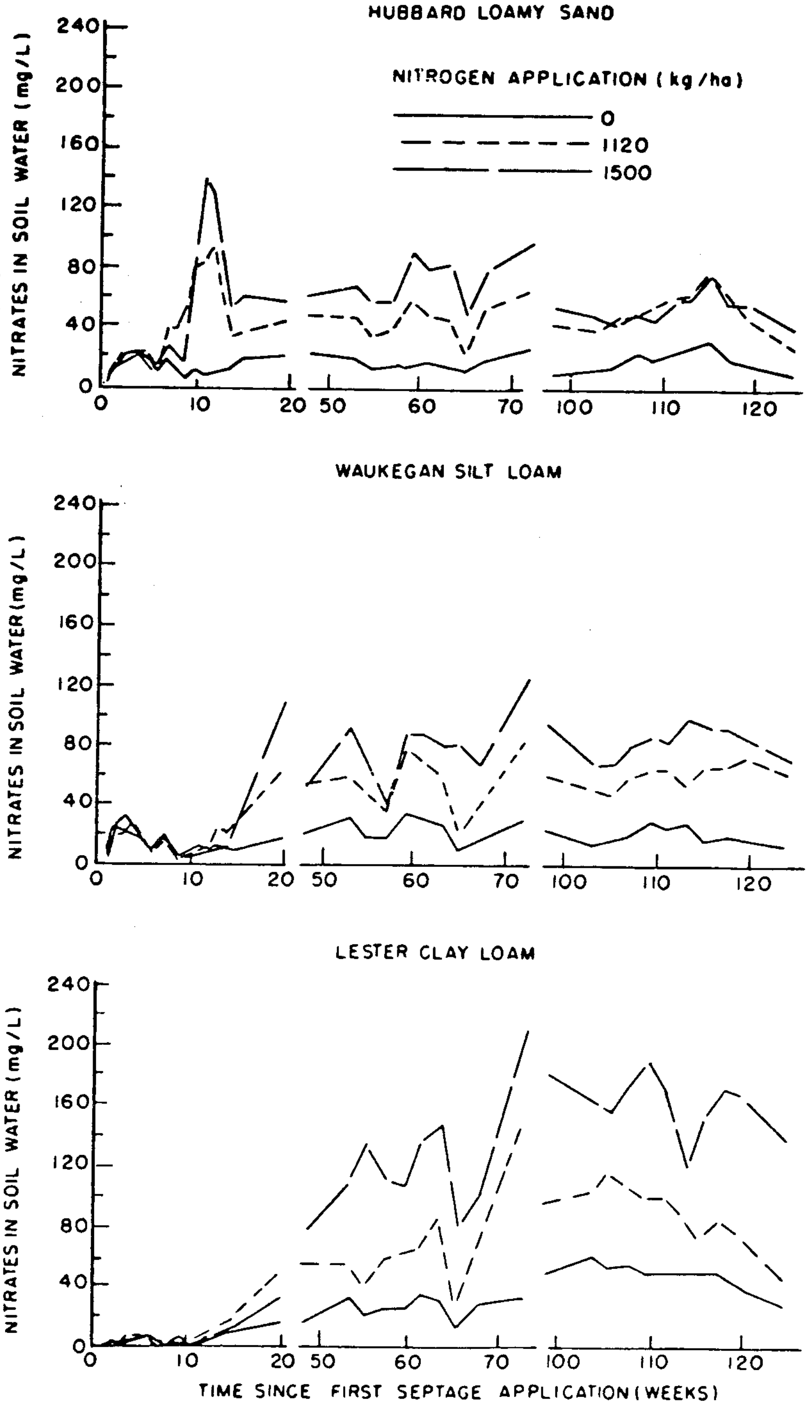

Fig. 1 Comparison of nitrates in soil water for the 1120 and 1500 kg/ha nitrogen application rates averaged over the five depths

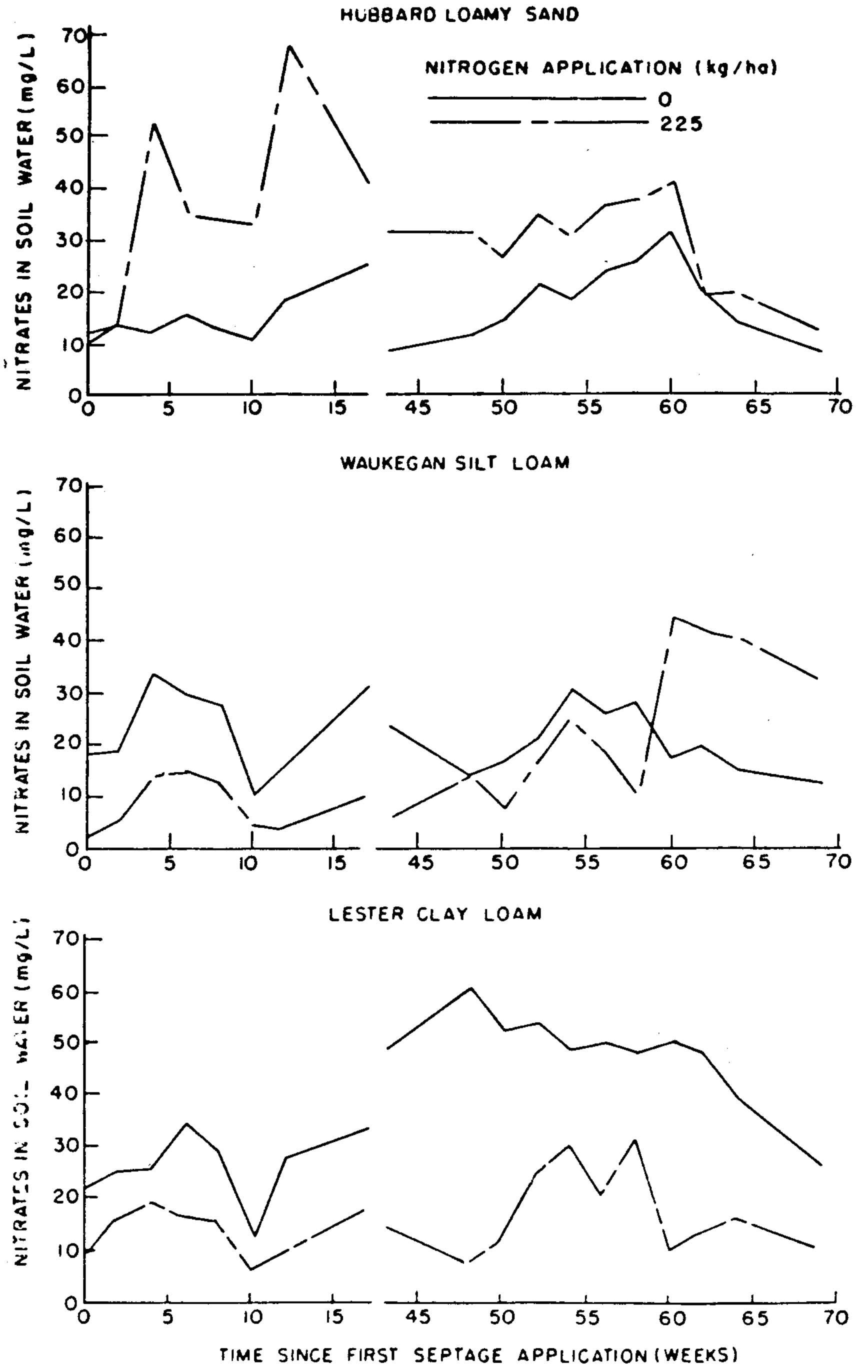

Fig. 2 Comparison of nitrates in soil water for the 225 kg/ha nitrogen application rates averaged over the five depths

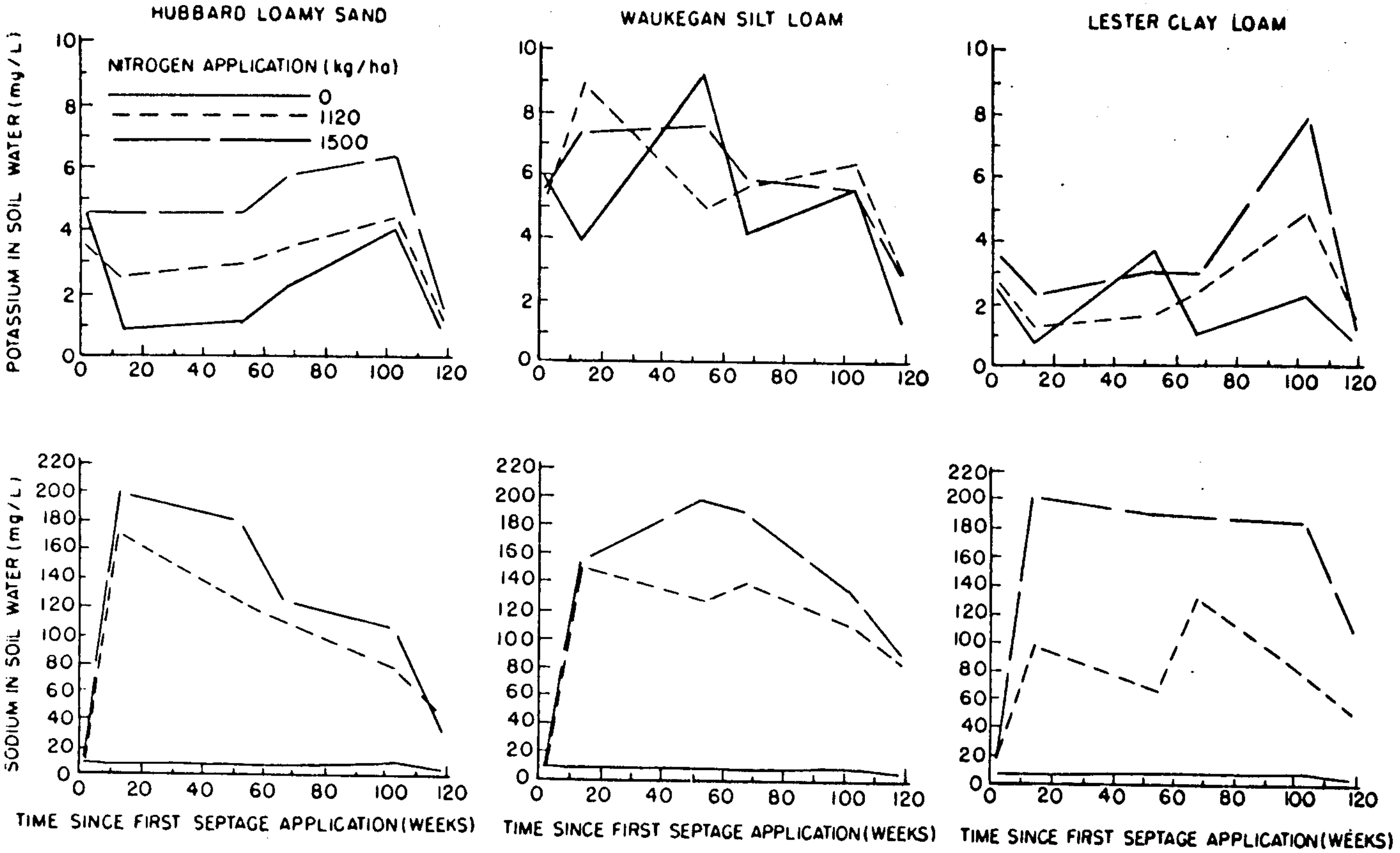

Fig. 3 Comparison of soil water potassium and sodium averaged over five depths

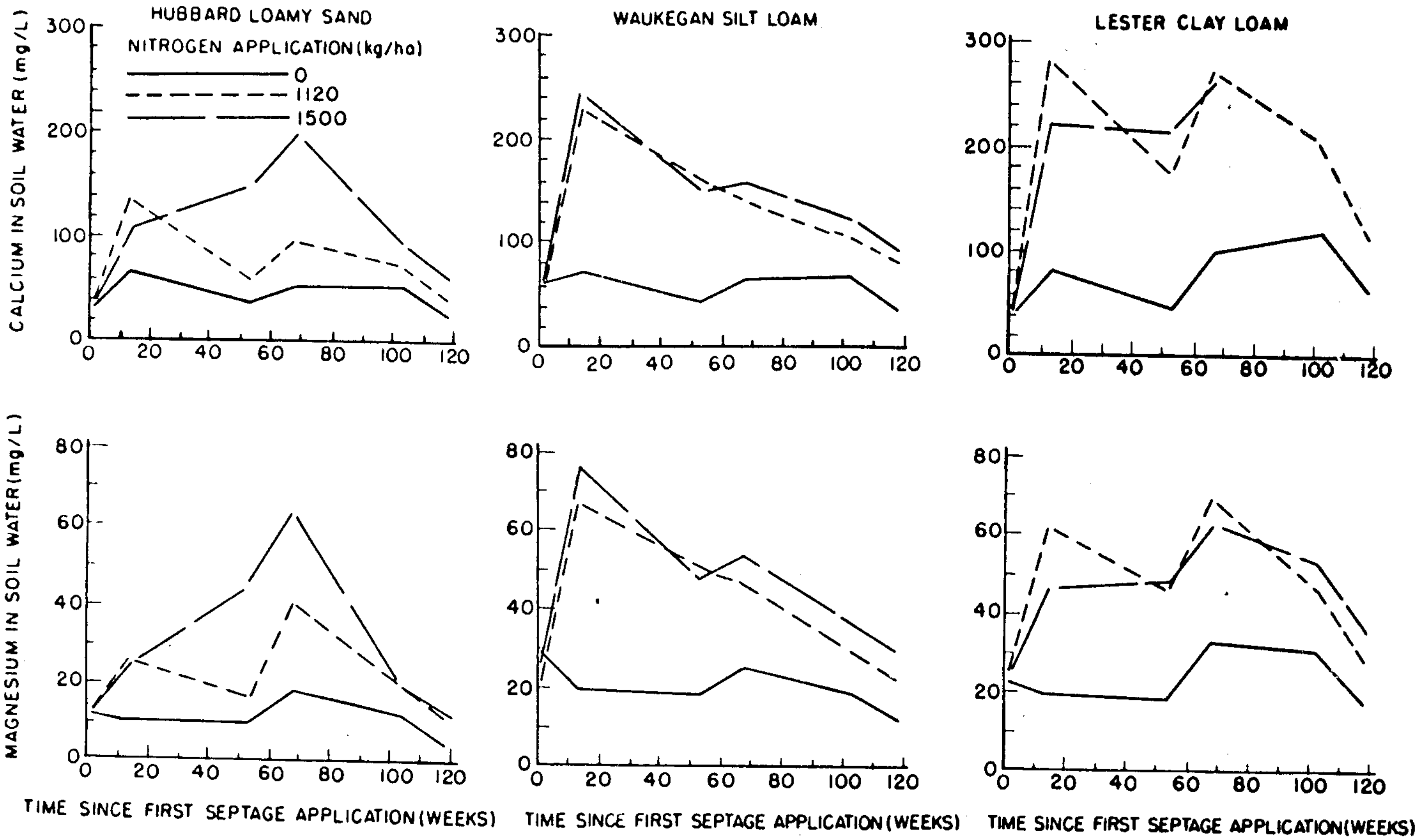

Fig. 4 Comparison of soil water calcium and magnesium averaged over five depths

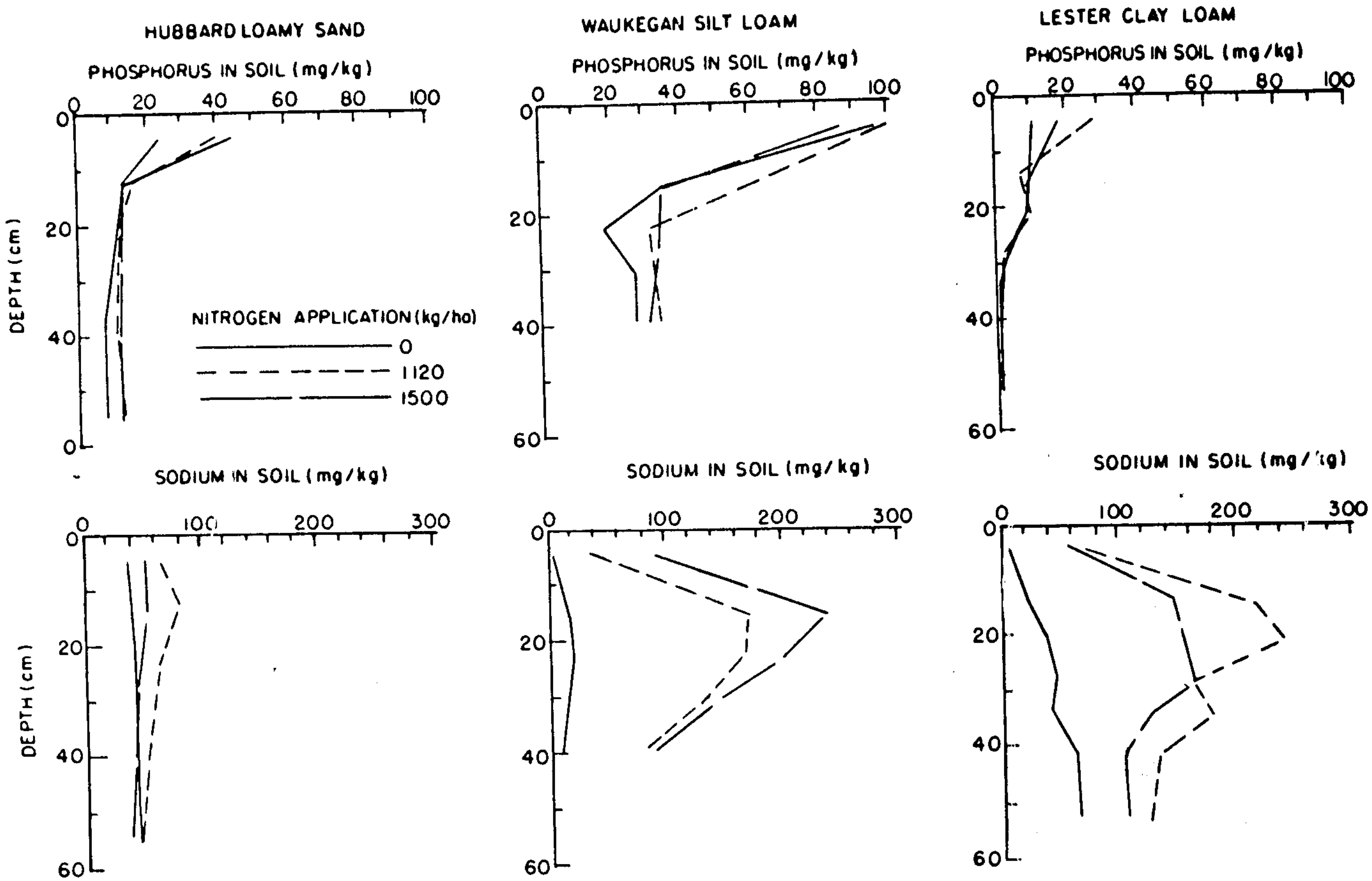

Fig. 5 Comparison of soil phosphorus and sodium with depth