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Leaching Of Nitrate Through Loamy Soil: A Column Study

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ABSTRACT

The contamination of groundwater by nitrate is a worldwide problem because of its health affects. The leaching behavior of nitrate was carried out under unsaturated and saturated conditions using loamy soil. The affect of concentration of nitrate, pH, column length and flow rate was studied. High concentration of nitrate, high flow rate, low pH and low column length are responsible for the high rate of percolation. The maximum amounts of nitrate leached were 208.0 mg (using nitrate solutions of 250 mg/25 mL), 142.3 mg (pH 2.0) and 139.1 mg (5 cm column lengths) respectively. It has been observed that the uniform distribution of nitrate in saturated condition was after 162 hrs. Suggestions were made to use the nitrogen based fertilizers.

KEYWORDS

Leaching;
Groundwater;
Nitrate;
Column;
Unsatrurated and saturated condition.

INTRODUCTION

Nowadays, ground water contamination is one of most pressing problems worldwide. Among various pollutants the contamination due to nitrate is very serious due to its health hazards. High concentrations of nitrate can cause methaemoglobenamea, intestinal cancer, goiter, birth defects, anoxia, dipsnia, anemia, cardiovascular diseases, eutrophication etc. problems. The main source of nitrate contamination is the use of nitrogen based fertilizers in agriculture and forestry activities[1,9,6,11,12]. Ground water pollution due to nitrate has been recognized world wide including European, USA, Chile, India and many other countries and has been reviewed in recent years [2,4,8,10,13,14,16,17]. Nitrate from fertilizers is leaching into groundwater during rainy season and irrigation processes. The leaching of nitrate is controlled by many factors such as the frequency of rain and irrigation, pH of water, presence of other constituents into water, type of soils, adviction, dispersion, diffusion and dissolution processes. It is apparent that the ground water is the main source of water supply in many parts of the world. Therefore, the monitoring and the maintenance of the ground water quality; by nitrate point of view; are very important and necessary aspects of hydrology. Due to the importance of groundwater and the dangerous nature of nitrate, the scientists have been attracted towards the monitoring of nitrate in ground water. Although the overall adverse impact of fertilization have been recognized widely but unfortunately, this issue has not been considered quantitatively which describes the mechanisms of the groundwater contamination by nitrate. In view of these points, attempts have been made to describe the mechanism of nitrate transportation in soil. For this purpose, column experiments were carried out using loamy soil under unsaturated and saturated conditions. The results of these findings are given herein.

EXPERIMENTAL

Materials and methods

Chemicals and reagents

All the chemicals and reagents used were of analytical grade. Sodium nitrate was purchased from Samir Technology Chemicals, Vadodra, India. The standard solutions of nitrate (50.0 to 250 mg/25 mL) were prepared in double distilled water. The quantitative analysis of nitrate was carried out by the well known spectrometric methods[5]. Spectronic 21D UV/Visible spectrometer (Milton Roy, USA) was used for the analysis of nitrate. The samples of loamy soil were collected from agricultural fields; with the help of soil sampler; up to a depth of 25 cm, pretreated and then packed in different columns.

Analysis of soil sample

The collected soil samples were washed with distilled water (5 g in 25 mL) until there was no nitrate. The physical characteristics of the soil samples were determined as per the standard methods[3,5,7,15]. The various physical parameters determined include pH, density, porosity, content of gravel, sand, clay and silt. The chemical parameters ascertained were sodium, potassium, calcium, magnesium, iron, nitrate, sulphate, chloride, alkalinity, hardness and total organic carbon.The physico-chemical properties of soil samples are given in TABLE 1.

For pH measurement, soil sample (5.0 g) was shacked with 25 mL distilled water (pH 6.0) for 60 minutes on mechanical shaker and the sample was filtered by Whatman 24 filter papers. pH of the filtrate was determined by standard methods. The density and porosity of the soil samples were determined with the help of Multi Volume Pycnometer (model 1305, USA) and Geo Pycnometer (model 1360, USA) respectively. The percentage of gravel, sand, clay and silt were determined by sieve analysis and Master Sizer E-System (model MAE 5000, UK).

TABLE 1: Physico-chemical properties of loamy soil

S.No.	Parameters	Values
1.	pH	7.0
2.	Density (g/cm^3)	2.58
3.	Porosity (%)	30.8
4.	Gravel(%)	0.1
5.	Sand (%)	38.0
6.	Clay (%)	5.3
7.	Silt (%)	56.9
8.	Alkalinity	59.0
9.	Sodium	30.0
10.	Potassium	9.0
11.	Calcium	18.0
12.	Magnesium	3.5
13.	Iron	1.2
14.	Nitrate	2.0
15.	Sulphate	5.0
16.	Phosphate	0.6
17.	Chloride	30.0
18.	TOC	3.5

50.0 g sample of soil was mixed with 250 mL of distilled water and shacked for 60 minutes on mechanical shaker and the samples were filtered by Whatman 24 filter papers. The residues of soil samples were further shacked with 250 mL distilled water in the similar way and filtered. Two filtrates were mixed together to make the total volume of 500 mL of filtrate. The above cited chemical parameters were determined in this 500 mL filtrate. The standard methods of water analysis were followed for the purpose.

Column experiments

Two types of glass columns were used and they are shown in figure 1. The first type of glass columns, comparable to unsaturated zone, were simple of the size of 30 cm x 2cm while the second type of glass columns (20 cm x 2 cm), comparable to saturated zone, were with outlets at 5.0 cm distances each. These columns were packed with the above mentioned soil separately. For packing the column, the supporting media i.e. glass wool was packed by hydraulic filling. The slurry of the weighed soil sample was prepared in distilled water and then it was used to pack the column. The column was kept undisturbed for over night for its full settlement and saturation. The flow of the column was controlled by the stopper point at the lower end of the column. Nitrate solutions of different concentrations were loaded on to the column and the fractions of 25 mL were collected. The affect of nitrate concentrations, pH of the percolating water, soil column length and flow rate of percolating water was studied. The concentration of nitrate was varied 50 to 250 mg/25 ml. The flow rate ranged from 1.0 to 5.00 mL/min. Furthermore, the column study was also carried out using percolating water of different pH ranging from 2.0 to 10.0. The fractions collected from each column were of 25.0 mL. To find out the diffusion and distribution of nitrate in saturated zone of the soils, second types of glass columns were also packed with the soil as cited above. The effluent flow rate of

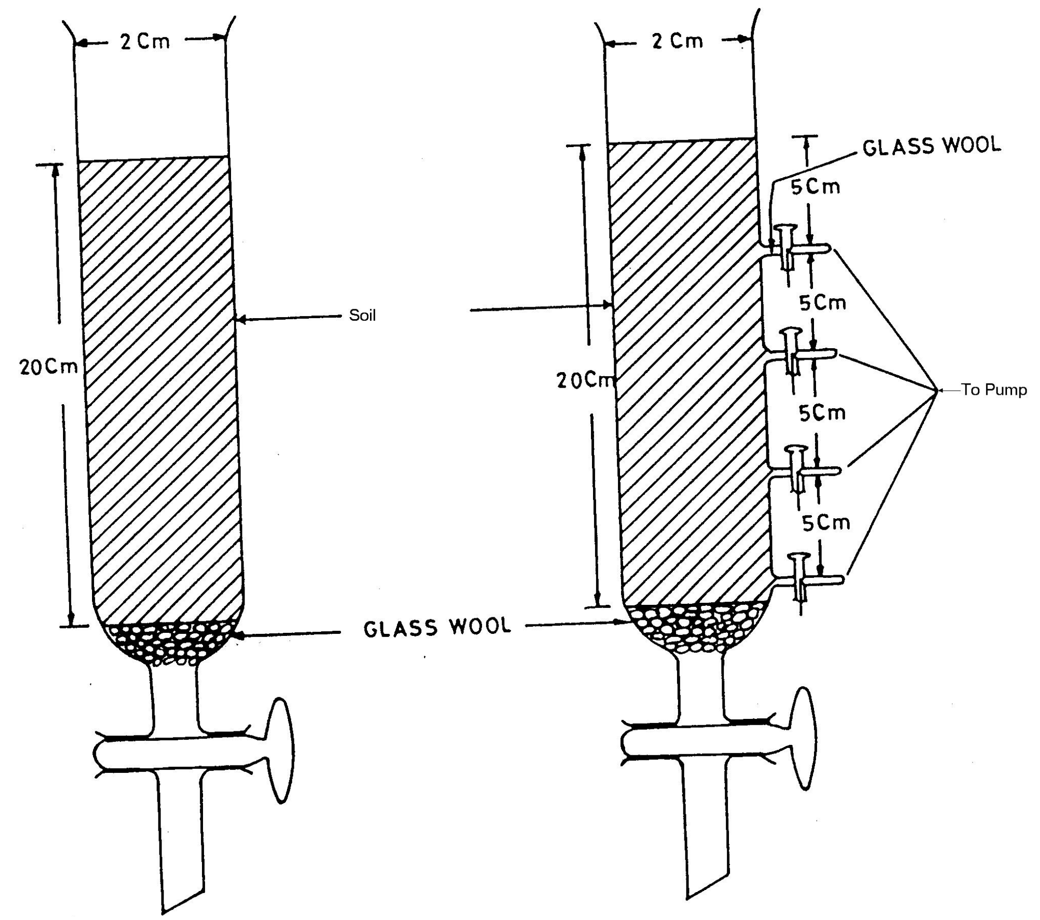

Figure 1: Vertical view of soil columns, A: Saturated and B: Unsaturated conditions

these columns was set to zero. 50 mL of nitrate (200 mg/25 mL) solution was loaded on this column. Water samples were collected from each outlet with the help of vacuum pump and the concentrations of nitrate were determined by spectrometric methods. To find out the affect of distribution time of nitrate in this column, water samples were collected from each outlet at different times of intervals. Water samples collected from both columns were filtered through Whatman filter paper (number 24) and then used for the analysis of nitrate.

To find out the transportation behavior of nitrate in loamy soil, the adsorption and desorption experiments were also carried out. The adsorption experiments were carried out by the batch technique using a series of Erlenmeyer flask of 50 mL capacity covered with teflon sheets to prevent the introduction of any foreign particle contamination. The affect of pH, concentration, dose, temperature and shaking time was studied. Isotherms were run by taking different concentrations of nitrate at desired temperature and pH. These concentrations were decided after a good deal of preliminary investigations. After the required experimentation was over, the solutions were centrifuged and the concentrations of nitrate were determined in supernatant using UV/ Visible spectroscopic methods.

RESULTS AND DISCUSSION

Loamy soil samples were analyzed for physico-chemical parameters. The values of physico-chemical parameters are given in TABLE 1. It is clear from this TABLE that the aqueous loamy soil is alkaline in nature. The density and porosity of loamy soil were 2.58 g/cm^3 and 30.8 fractions respectively. The percentages of gravel, sand, clay and silt for loamy soil were 0.1, 38.0, 5.3 and 56.9 respectively. The concentrations of alkalinity, sodium, potassium, calcium, magnesium, nitrate, sulphate, potassium, chloride and total organic carbon were 59.0, 30.0, 9.0, 18.0 3.5, 2.0, 5.0, 0.6, 30.0 and 3.5 mg/kg respectively. Among the various factors responsible for nitrate leaching, adsorption/desorption and the amount of organic matters are very important. The transportation behavior of nitrate was studied in loamy soil. The affect of adsorption, concentrations of nitrate, pH of percolating water, flow rate of percolating water and soil column lengths on nitrate transportation was carried out under unsaturated conditions. Besides, the distribution of nitrate in loamy soil was also studied under the saturated soil condition.

Adsorption

To optimize the experimental conditions for column experiments, the adsorption behavior of nitrate was carried out on loamy soil. The adsorption experiments of nitrate were carried out under the varied conditions of pH, concentrations of nitrate, contact time and dose. After extensive experimentation, it was found that the maximum uptake of nitrate took place at pH 7.0 with 2 h of contact time at 30^{o}C. The adsorption capacity of nitrate on the soil was found to be 0.25 mg/g. The desorption experiment of nitrate from the soil were also tried with distilled water of different pHs. It was found that maximum desorption is occurred at 2.0 pH. These findings were used to design the column experiments.

Leaching of nitrate under unsaturated conditions

To study the leaching behavior of nitrate, glass columns of different sizes were packed with loamy soil. The effluent fractions of 25 mL each were collected and analyzed as described above. The affect of nitrate concentrations, pH of percolating water, soil column lengths and flow rate was studied on the transportation behavior of nitrate in soil columns.

Affect of concentrations

pH of the aqueous solution of loamy soil was found to be 7.0 (TABLE 1) and, therefore, all the column experiments with different concentrations were carried out at pH 7.0. The different concentrations of nitrate loaded on the packed column (20 cm x 2 cm) were 100.0 – 250 mg/25 mL. The flow of the column was allowed under natural condition and 25 mL fractions were collected. The column flow was maintained till no nitrate was detected in effluent samples. The results obtained for the concentration affect of nitrate are given in figure 2. It is clear from this figure that nitrate was absent in the initial

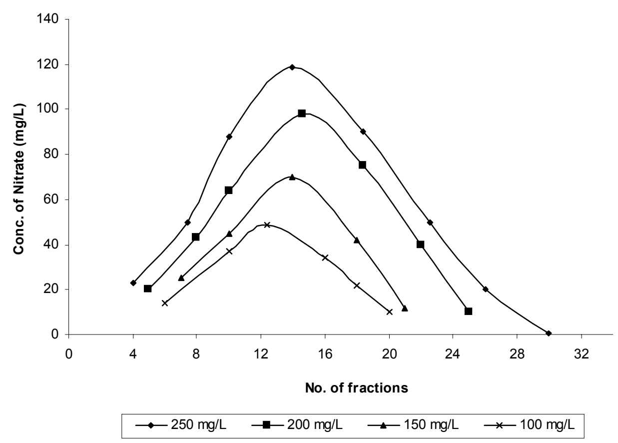

Figure 2: Affect of different concentrations of nitrate

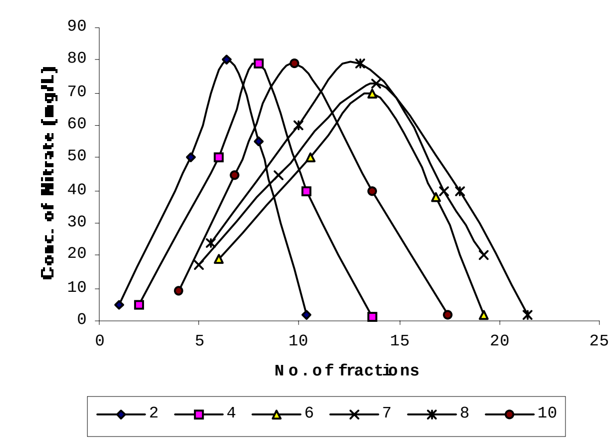

Figure 3: Affect of pH on nitrate leaching

effluents which is due to its adsorption on to soil. The nitrate was absent in initial 50, 75, 100 and 125 mL effluents when using 250, 200, 150 and 100 mg/25 mL concentrations respectively. The maximum concentration of nitrate was observed at 350 mL effluent (fraction number 14) in all the concentrations except in the case of 100 mg/25 mL concentration where it was observed in 300 mL effluent (fraction number 12). The values of nitrate in each fraction of different concentration solutions were computed and subtracted from the initial loaded amount. The net (subtracted) values were in good agreement with the amount adsorbed by the loamy soil column. These studies clearly indicate that high concentrations of nitrate were migrated fast and eluted lately. It may be concluded from these studies that higher concentrations of nitrate are contaminating ground and surface water increasingly.

Affect of pH

To study pH affect, the glass column (20 cm x 2 cm) was packed by loamy soil and 150 mg/25 mL solution of nitrate was loaded. The column was allowed to run using distilled water of different pHs i.e. 2, 4, 6, 7, 8 and 10. The results of these experiments are plotted in figure 3. This figure clearly indicates that faster migration of nitrate occurred at 2, 4 and 10 pHs while the leaching of nitrate was slow at 6, 7 and 8 pHs. Nitrate was observed in 1, 2, 4 and 5 fractions by using pH 2, 4, 10, 8 and 7 respectively. More precisely the leaching of nitrate was in the order of 2 > 4 > 10 > 8 > 6 > 7 pHs. The amount of nitrate recovered was lower when using pH 7.0, which may be due to higher uptake of nitrate at this pH. These studies clearly indicated that the leaching of nitrate is higher at low and high pHs. The mass balance of nitrate was calculated by computing the amount of nitrate in effluent fractions and adsorption processes and it was conserved. Fortunately, pH of the natural surface water is in the range of 6.5-8.5 and under this condition the leaching of nitrate is not high which is a self-purification capacity of the nature to save our ground water.

Affect of column length

Affect of column length was studied by using 5, 10, 15, 20 and 25 cm as column lengths. A nitrate solution (150 mg/25 mL) of pH 7.0 was used in all column lengths. Again 25 mL fractions of the percolated water were collected and the results obtained for the affect of column lengths on the migration of nitrate are shown in figure 4. It may be seen from this figure that the migration of nitrate is higher at low column lengths. Precisely the order of migration was 5 > 10 > 15 > 20 cm. The maximum concentration of nitrate was observed in fraction number 4, 10, 12 and 14 using 5, 10, 15 and 20 cm column lengths. These studies indicate that the higher soil column length retards the movement of nitrate.

Affect of flow rate

The flow of water percolation through loamy soils column (20 x 2 cm) under the natural conditions was

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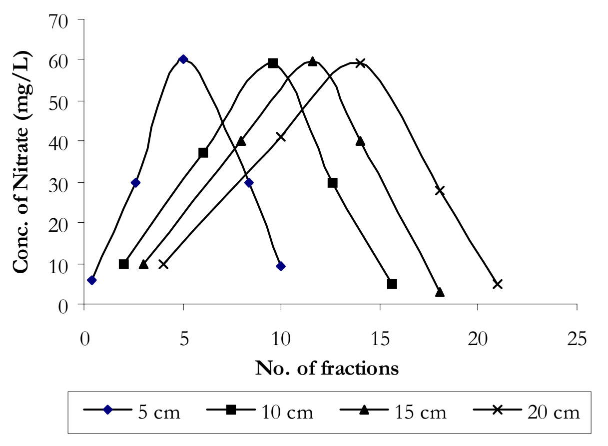

Figure 4: Affect of column lengths on nitrate leaching

2.5 mL/h. The flow rate was varied from 0.5 to 2.5 mL per hour but there was no affect on the leaching of nitrate. It may be due to the fact that 25.0 mL column fraction required 10 h (with a maximum 2.5 mL/h flow rate) and the loamy soil takes 2 h for the maximum adsorption of nitrate at room temperature (30°C). Therefore, it may be concluded that there was no affect of flow rate on the transportation of nitrate on loamy soil due to 2 h as the adsorption time, which is sufficient time required for the maximum uptake of nitrate by the loamy soil. The amount of nitrate leached under varied experimental conditions were calculated and are given in TABLE 2. It is clear from this TABLE that the maximum amounts of nitrate leached were 208.0 mg (using nitrate solutions of 250 mg/25 mL), 142.3 mg (pH 2.0) and 139.1 mg (5 cm column lengths) respectively.

TABLE 2: Amount of nitrate (mg) leached under varied experimental conditions

Sl.No.	Experimental Conditions	Nitrate
Concentrations Used#		
1.	100 mg of NO_3	59.0
2.	150 mg of NO_3	107.8
3.	200 mg of NO_3	158.6
4.	250 mg of NO_3	208.0
pH*		
1.	2	142.2
2.	4	131.2
3.	6	125.6
4.	7	106.5
5.	8	111.5
6.	10	138.2
Column Lengths*#		
1.	5 cm	139.1
2.	10 cm	129.6
3.	15 cm	118.3
4.	20 cm	105.9

*: Amount loaded of nitrate: 150 mg. #: pH: 7.0

Distribution of nitrate under saturated conditions

To study the distribution of nitrate in saturated zone conditions, the glass columns (20 x 2 cm) with four outlets at 5.0, 10.0, 15.0 and 20.0 cm distances (Figure 1) were fabricated. These outlets were connected to the vacuum pump for water sample collection at the required time intervals. All the experiments in loamy soils were carried out at pH 7.0. A solution of nitrate (100 mg/50 mL) was loaded on the column. The time intervals for the collection of water samples from the different out lets were decided after an extensive experimentation. Water samples were taken from 5.0, 10.0, 15.0 and 20.0 cm distances after 1 to 200 hrs. The results are given in figure 5 and it is clear from this figure that nitrate was detected after 10, 25, 50 and 75 hrs at 5.0, 10.0, 15.0 and 20.0 cm distances respectively. The uniform distribution of nitrate was observed at 62, 100, 137 and 162 hrs at 5.0, 10.0, 15.0 and 20.0 cm distances respectively. It is also clear from this figure 4 that the complete saturation of the column was achieved after 162 hrs. Under natural conditions the flow of the ground water also contribute towards the distribution of nitrate. Therefore, the flow of ground water, discharge and recharge; if any; should

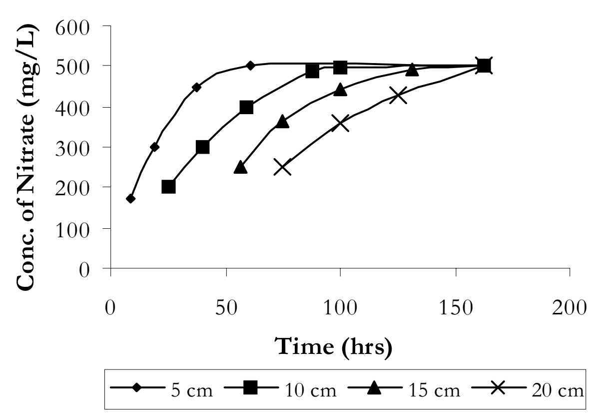

Figure 5: Distribution of nitrate at different column depth under saturated condition

be considered for the distribution of nitrate.

CONCLUSION

The leaching of nitrate was carried out under unsaturated and saturated conditions using loamy soil. The affect of concentrations of nitrate, pH, column length and flow rate was studied. The higher concentration of nitrate, lower pH, high flow rate and low column length are responsible for the high rate of leaching. The distribution of nitrate was also studied under saturated zone conditions. It has been observed that the uniform distribution of nitrate was occurred after 162 and 300 hrs respectively. The leaching of nitrate into ground water under natural condition is different and complex phenomenon. There are many types of soil strata from ground surface to the water table and, hence, all these types of soils should be considered into account. The presence of various chemical constituents into the soil strata is also a controlling factor for nitrate leaching. Moreover, adsorption-desorption, adviction, dispersion, diffusion and dissolution into ground water are very important processes, which govern the distribution of nitrate. Briefly, these results are useful to predict the transportation of nitrate into ground water. This work may be used to design the type and dose of the fertilizers used into agriculture fields by farmers. Farmers should avoid the excessive use of these types of fertilizers.

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