ICIWRM – 2000, Proceedings of International Conference on Integrated Water Resources Management for Sustainable Development, 19 – 21 December, 2000, New Delhi, India

Studies on impact of excessive use of fertilisers in agricultural areas – a case study

SADASHIVAIAH, C
Dept. of Civil Engineering, Siddaganga Institute of Technology. Tumkur – 572 103, Karnataka, India
INAYATHULLA M, MANAMOHAN RAO M
Department of Civil Engineering, Jnanabharathi Campus, Bangalore University, Bangalore – 56, India
RANGANNA G, VENKATACHALAPPA M, PUTTASWAMY, J
UGC-DSA Centre in Fluid Mechanics, Department of Mathematics, Bangalore University, Bangalore-1, India

Abstract
Increasing population calls for producing more food from out of continuously diminishing per capita arable land. This challenge is also rightly taken and the problem is being solved but with the aid of unmindful use of fertilizers and pesticides. In the case of widely used N-fertilizers, only about 30-50% is assimilated into the edible food, while the unutilised nitrate moves along with porewater. In the unsaturated soil zone, the moisture movement (solute movement) need not be always vertically downward. In order to assess the mobility and accumulation of leached nitrates, a field-cum-laboratory investigation was carried out by the authors. Lateral movement of the pollutant is verified by a field-oriented test.

INTRODUCTION

Recently we celebrated the India's achievement in population crossing 100 crores. When population has increased 3 folds after mid-century, the food grain production increased by 4 folds. But this is no longer a happy news. The pollution of the soil, surface water sources and groundwater sources go hand in hand with the increased use of fertilizers. The fertilizers application which was mere 0.07 million tonne during 1950, has now reached around 20 million tonnes. The earlier studies have revealed that out of total nitrogen fertilizers applied 30-50% is cemented into human edible food, 20-30% entering into the atmosphere by volatilization, 10-20% towards soil immobility, and about 20-30% leaching as nitrates to water table (Rajendraprasad, 1998). The documented health risks like methaemoglobinaemia, gastric cancer, brain damages, mass fish kills and destabilising of entire eco-system are the gifts of nitrates to the living beings of our environment. Ammonia that emanates from the urea applied to agricultural fields, contributes to acid rain, while nitrates produced in soil contribute to contamination of groundwater due to leaching of nitrates, and ozone depletion due to release of nitrous oxide by denitrification process. Hence, N-fertilizers are now being treated as No. 1 enemy of sustainable agriculture. Their optimal application, however, to satisfy the nutrient deficiency in soils is necessary to fetch the desired goal of crop yield. Urea is the major nitrogen fertilizer used in the world due to its high N content, high solubility, and nonpolarity.

The nutrient fertilizers after application get dissolved with irrigated water or rain and the nutrient solution first enters the soil through surface by infiltration, then migration through the soil root zone vertically downward as well as there will be lateral spread according to soil layer arrangements (structure). Many investigators viewed these physico, chemical process phenomena as briefly discussed under –.

Infiltration studies

Infiltration is the entry of water into the soil through the soil surface. It forms one of the important factors of water loss in the hydrologic cycle. Flooding infiltrometers are usually rings or tubes inserted into the ground. Water is supplied and maintained at a constant level and observations are made for the rate of replenishment required. In the case of rainfall simulators, artificial rainfall is simulated over a small test plot and the infiltration is calculated from observations of rainfall and runoff, with consideration given to depression storage and surface retention (Ranganna et al., 1991).

Soil column studies in the laboratory

In the field of agriculture, the retention of nitrogen in surface soils is of vital concern in the application of plant fertilizers. Preul and Schroepfer (1968) have investigated the effects resulting from intimate contact between nitrogen-bearing solutions and selected soils. Column tests were devised in the laboratory keeping the following variables under control: soils, concentration and forms of influent nitrogen, rate of flow application, temperature, and soil-solution contact time. The specific purpose of the column tests were:

> to isolate the physical and chemical effects from the biological effects which result when nitrogen-bearing solutions are placed in contact with soils, and
>
> to evaluate the magnitude of their effects.

In agriculture, when fertilizers are applied, nitrogen after satisfying the crop requirement accumulates in the soil medium and changes the natural soil equilibrium. This results in the accumulation of nitrogen (i.e. NH_4^+ or NO_3^-) and behaves as a pollutant (Hajek, 1969).

Basak and Murthy (1979) have attempted to provide a useful and unique method for quick and exact determination of the hydrodynamic dispersion coefficients from soil column experimental data. The determination of the numerical value of the dispersion coefficient is fundamental to all problems of solute transport in porous media. The determination of the longitudinal dispersion coefficient in the laboratory is normally done by using the analytical solution to the one-dimensional dispersion equation (Fried and Combarnous, 1971). The solution for the dispersion equation (1)

$$\frac{\partial C}{\partial t} = D_L \frac{\partial^2 C}{\partial x^2} - u \frac{\partial C}{\partial x} \quad (1)$$

is given by -

$$\frac{C}{C_0} = \frac{1}{2}\left[erfc\left(\frac{x - ut}{2\sqrt{D_L\, t}} \right) + \exp\left(\frac{ux}{D_L} \right) erfc\left(\frac{x + ut}{2\sqrt{D_L\, t}} \right) \right] \quad (2)$$

From the above equation (2) it is difficult to obtain an explicit expression for D_L, and indirect methods for D_L are in vogue i.e., through experimental data.

In the method proposed by Fried and Combarnous (1971), the second term in above eqn is neglected and the following expression for D_L, is obtained using the property of a normal distribution function.

$$D_L = \frac{1}{8}\left(\frac{x - ut_{0.16}}{\sqrt{t_{0.16}}} - \frac{x - ut_{0.84}}{\sqrt{t_{0.84}}} \right)^2 \tag{3}$$

where $t_{0.16}$ and $t_{0.84}$ are the times required for the concentration ratios $C/C_0 = 0.16$ and $C/C_0 = 0.84$ to reach a particular distance x.

Recent field studies show that colloids, which may migrate at velocities similar to the velocity of the groundwater flow, can sorb the contaminants and therefore act as carrier (Luhramann et all., 1998). This can cause travel distances of contaminants far greater than those predicted by retardation factors measured in the laboratory.

Sadashivaiah et al (2000) have assessed the values of hydrodynamic dispersion D, based on experiments carried out on soil columns of the study site using artificial nitrate solution and tritium as tracers.

Among several unstable radioactive isotopes, tritium is considered to be an ideal tracer in many hydrological investigations. Tritium being a nonabsorbing tracer, is widely adopted in predicting the migration mechanics of the pollutants in natural soil.

Tritiated water (HTO) is an important tracer which belongs to the group of conservative tracers under artificial isotopic water tracers, having a half life of 12.43 years and emits low energy β - radiation (E_{max} = 17.6 kev) (Vasu and Hameed, 1998).

Field study relating to point source pollution and lateral travel of contaminants

In nature when liquid wastes are spread over the ground surface, it is but natural for it to travel in all the three directions X, Y and Z. Broadly applicable, theoretical studies of transient water transfer in unsaturated or in partly unsaturated soils ordinarily are based on Darcian approach (Rubin, 1968). In the past, such studies were concerned primarily with unidirectional flow. The more general, multidimentional flow problems are of considerable importance in hydrology, agriculture and engineering. In many cases, the published work involving time-dependent water transfer, in addition to the usual Darcian coverage, one or more assumptions made grossly oversimplified the actual conditions.

However, here, an attempt is made to carry out field tests in two and three dimensions for studying the phenomena of solute travel in porous media, i.e., natural soils of the vadose zone.

STUDY AREA

The study site is selected in the coconut garden belonging to M/s Mahaveer Coconut Industry, situated along Tumkur - Gubbi road (Bangalore - Honnavar highway) at the 10^{th} km from Tumkur town. It lies between the latitudes 13^0 0' and 13^0 30' North and the longitudes 77^0 0' and 77^0 15' East (Fig 1). The Geology area is formed predominately with peninsular gneisses which are highly migmatitic in nature. Groundwater occurs under water table conditions in the weathered and fractured granite gneisses and schists. Depth of weathering varies from 10 to 15 m followed by fractures. The study area enjoys an overall agreeable climate. The month of April is the hottest with the maximum temperature rising upto 39^0C and the minimum temperature is about 10^0C. The annual average rainfall over the area is 689 mm and the maximum is 820 mm. Red soils followed by gravelly soils, sandy soils, loamy soils and small pockets of clayey soils are existing in the study area. The traditional dry crops like ragi, mixed crops, jowar, cotton and vegetables are grown. In the valleys paddy, coconut and arecanut are cultivated. The fertilizers like complex, DAP, potash and animal wastes are usually applied.

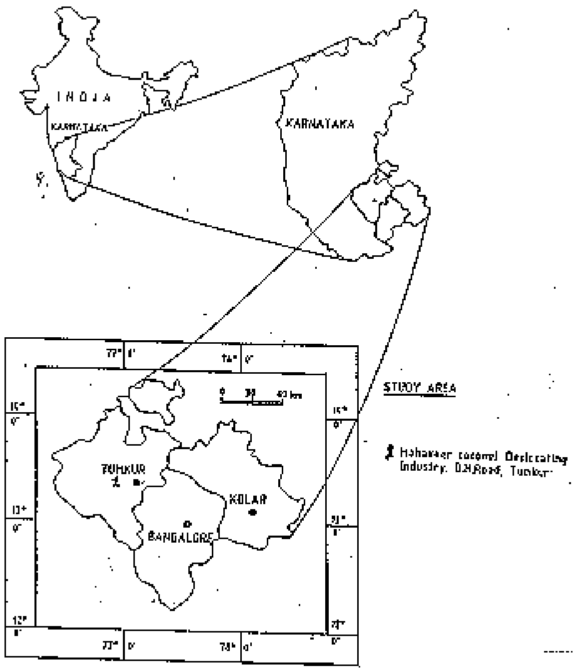


Figure 1. Location map of the study area.

METHODOLOGY OF INVESTIGATION

Before any specific experiment, the soils from the study sites were sampled and subjected to essential physical and chemical tests using standard test procedures (Jackson, 1958). The results of analysis are presented in Table 1& 2. The water samples from the nearby field wells were sampled and tested for important chemical parameters as per the standard procedures (Eaton 1995). The results of analyses are tabulated in Table 3.

Table 1. Physical parameters of the soil.

Parameters	Mallasandra, Tumkur			
	I	II	III	Average
Specific Gravity	2.54	2.64	2.53	2.57
Moisture Content (%)	18.36	10.93	8.01	12.43
Bulk Density (gm/cc)	1.95	1.8	1.93	1.86
Dry Density (gm/cc)	1.647	1.62	1.83	1.7
Void Ratio	0.54	0.62	0.355	0.505
Degree of Saturation (%)	86	46.1	57.33	63.14
Porosity (n%)	35	38.49	26.1	33.19
Permeability (cm/day)	1.48	5.99	3.45	3.64
	Uniformly graded sandy soil			

Note : The soil samples were analysed during successive seasons of the year

Table 2. Chemical properties of soil of Mallasandra site.

Sl. No.	Depthwise (cm)	pH	EC mS/cm	OC (%)	P_2O_5 kg/ha	K_2O kg/ha	Zn mg/l	Fe Mg/l
1	0	8.3	0.05	0.23	5	675	0.64	2.2
2	30	8.5	0.07	0.23	5	>1000	0.37	12.8
3	60	8.6	0.04	0.19	5	>1000	0.15	3.8
4	90	8.5	0.05	0.15	5	>1000	0.14	4.7

The field and laboratory tests carried out are categorized as:

Field infiltration tests.

Soil column studies in the laboratory.

Field study relating to point source pollution and lateral travel of contaminants.

Table 3. Chemical Analysis of water samples.

Study site	pH	EC µmho/cm	Total Hardness mg/l as $CaCO_3^-$	Cl^- mg/l as Ca-CO_3	SO_4^{2-} Mg/l	K mg/l	PO_4^{2-} mg/l	Na^+ mg/l	NO_3 mg/l
Mallasandra	7.1	580	190	110	23.8	10.13	0.21	47.5	2.78

Field infiltration tests

In the study site viz., Mallasandra village a double-ring infiltrometer unit was used to assess the infiltration rates. The unit consists of an outer ring of 45 cm diameter and an inner ring of 25 cm diameter, with a provision to measure the water level during the course of experiment i.e., by a point gauge.

The field data procured during tests are deduced for infiltration rates using Horton's (1933) approach, namely

$$f_p = f_c + (f_o - f_c)e^{-kt}. \qquad (4)$$

where, f_o is the infiltration rate at the beginning of the storm f_c is the ultimate or final infiltration capacity attained when the soil profile becomes saturated, f_p is the infiltration capacity at time, t, k is the Horton's constant which depends both upon the basin and rainfall characteristics.

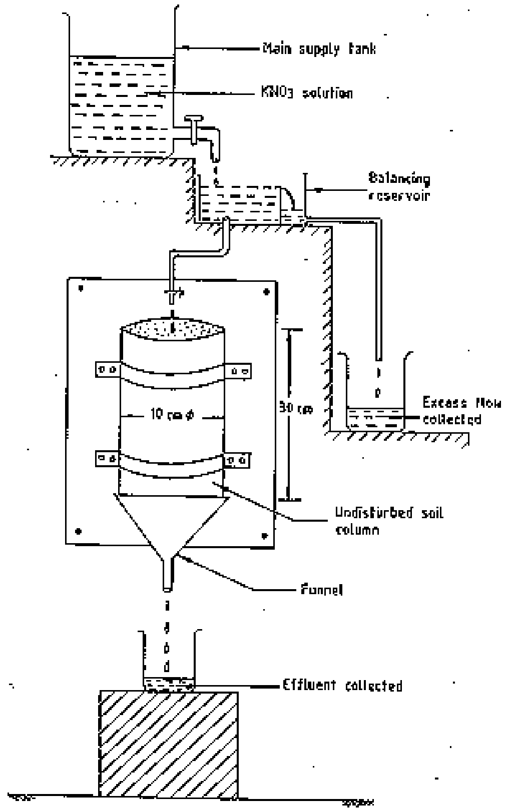


Figure 2. Schematic view of vertical soil column experimental set up.

Soil Column studies in the Laboratory

The experimental investigation was carried out on the undisturbed soil column extracted from the study site by the help of a specially devised core attached with a mild steel shoe.

The soil columns were of 30 cm height and 10 cm diameter, and extracted from the un-saturated zones, by piercing a rigid PVC pipe of 10 cm internal diameter, with the shoe. Three such columns were extracted from the site.

The objectives of the experiments are:

- to predict the hydrodynamic dispersion co-efficient, and
- to study the behavioural characteristics of the pollutants during their travel through soils, vis-à-vis soils themselves.

The columns were mounted on to a plywood stand fabricated for the purpose (Fig. 2)
The tracer solutions employed were – deionized water, aqueous potassium nitrate and tritium (tritiated water) and used separately for three different columns obtained from each site. The potassium nitrate influent solution was prepared by dissolving dry KNO_3 chemical in deionized water to obtain a concentration of 25 mg/l as NO_3. Initially the tritium counts were 3290 per minute in the tritiated water (tracer) prepared for experimentation on soil column.

Methodology for experimentation

The deionized water was allowed to flow through the soil column to study the leaching level of NO_3^- and timely variations in the soil water interactions appearing as leachates. Different cations and anions, pH, EC, metals etc., were analysed adhering to standard procedures (Eaton, 1995). The results of variations of important parameters, viz., nitrate, chloride and pH are presented in Fig 3 for the study site.

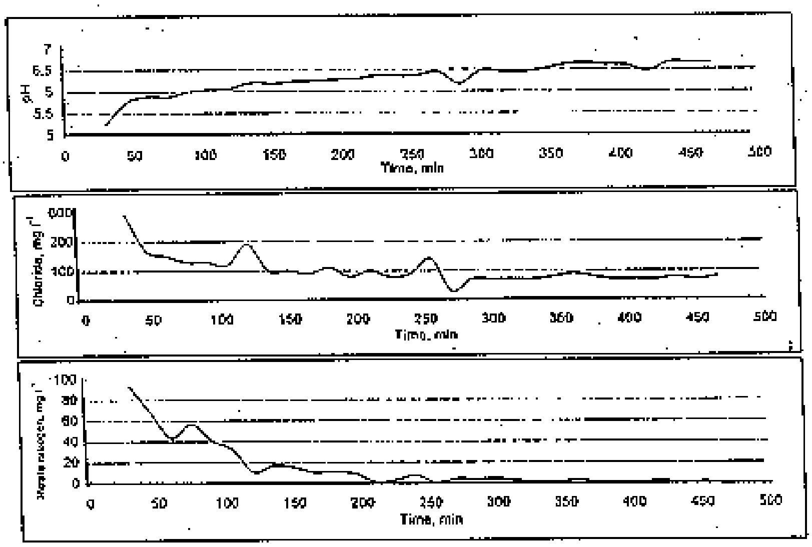


Figure 3. Parameters pertaining to analysis of deionized water leachate passing through undisturbed soil column, site : Tumkur.

The input to the soil columns is drawn from the constant level tank containing the tracer and allowed over the column drop by drop to avoid ponding of the tracer on the column.

The tritium tracer was allowed to pass through the third soil column at a uniform velocity. The activity in the leachate samples were assessed by injecting a volume of 1 ml of sample diluted to 3 ml of distilled water and 6 ml of diaxane cocktail. The mixture in 20 ml vials were cherned vigorously. The vials were then arranged in liquid scintillation machine and the activity counts were obtained.

The Break-Through-Curves (BTC) were constructed for artificial nitrate tracer (Fig 4) and for tritium tracer (Fig 5).

Sl. No.	Time (min)	C/Co
1	20	0.03
2	30	0.06
3	40	0.1
4	50	0.15
5	60	0.2
6	70	0.22
7	80	0.3
8	90	0.35
9	100	0.45
10	110	0.53
11	120	0.6
12	130	0.60
13	140	0.69
14	150	0.72
15	160	0.76
16	170	0.79
17	180	0.84
18	190	0.88
19	200	0.89
20	210	0.87
21	220	0.86
22	230	0.87
23	240	0.88
24	260	0.89
25	280	0.89
26	270	0.8

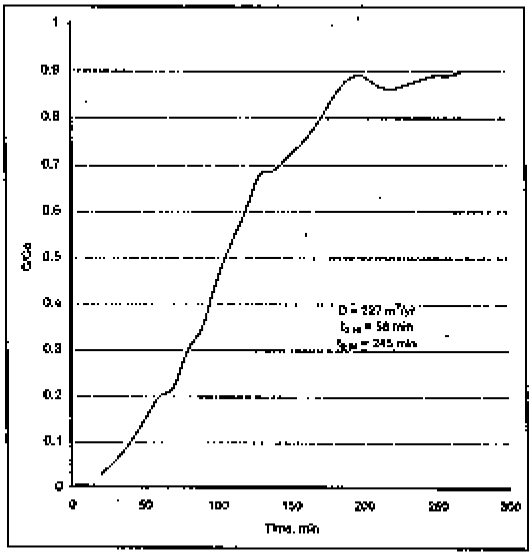


Figure 4. Break through curve for artificial nitrate (KNO_3) solution as tracer when passing through soil column. Site – Mallasandra, Tumkur.

Sl. No.	Time (min)	C/Co
1	0	0
2	30	0.08
3	45	0.148
4	55	0.255
5	60	0.409
6	65	0.438
7	70	0.458
8	75	0.503
9	80	0.57
10	85	0.577
11	90	0.623
12	85	0.637
13	100	0.633
14	105	0.7
15	110	0.71
16	115	0.72
17	135	0.752
18	145	0.787
19	155	0.777
20	165	0.84
21	205	0.85
22	225	0.852
23	235	0.918
24	240	0.925
25	275	0.911
26	306	0.939

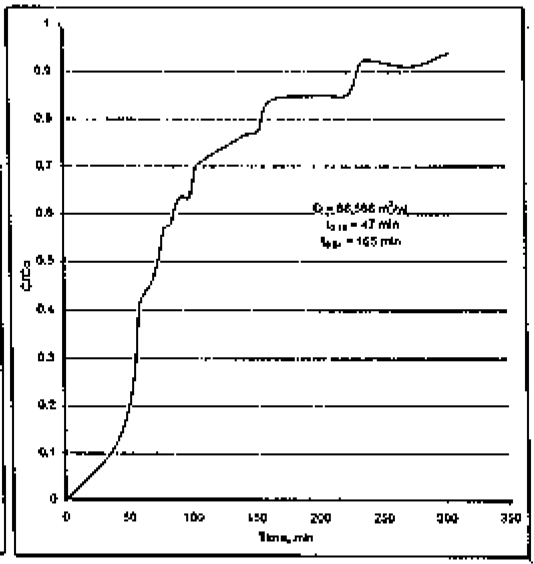


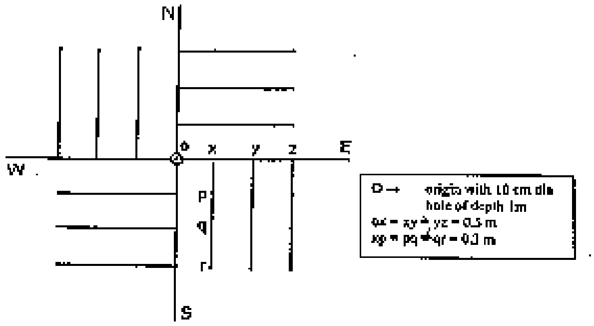
Figure 5. Break through curve for tritium solution as tracer when passing through soil column. Site – Mallasandra, Tumkur.

Making use of the experimental data related to soil columns with NO_3 and tritium tracers, the dispersion coefficient values were computed using Fried and Cumbarnous (1971) equation, (3).

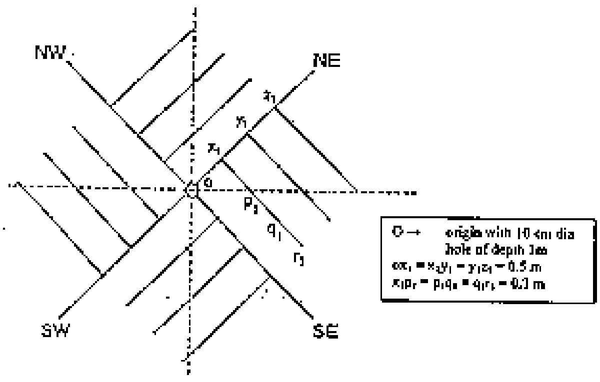
The KNO_3 solution was eluted through the soil column and nitrates washed out during its travel through the soil column were analysed using cadmium reduction method and the concentration was determined using a UV-VIS spectrophotometer. The leaching of NO_3^- depends on the texture of the soil media.

The purpose of the field work envisaged now in this investigation is to study the behavioural pattern of nitrate travel in the unsaturated zone considering point-source application of N-contaminant. This is an assumption made to use the computer program already in use here in the UGC-DSA Centre, Dept. of Mathematics, Bangalore University.

The horizontal and vertical migration and accumulation of nitrogen based fertilizers residues in the unsaturated zone of the soil profile in Mallasandra (Tumkur) has been investigated. Vertical movement of contaminants has been verified through disturbed soil column experiments., The horizontal migration of nitrate is verified in the field adopting a novel method. The soil samples in the selected spot were extracted by an auger in four directions (North, East, South, West) from a central origin 'O' equidistant at 0.5 m interval X, Y, Z towards East; (Fig. 6). Three bores in each directions were augured and four soil samples from each bored hole, viz., at 0 m, 0.3 m, 0.6 m and 0.9 m depths were collected.



a. Before KNO_3 solution injection into the hole O

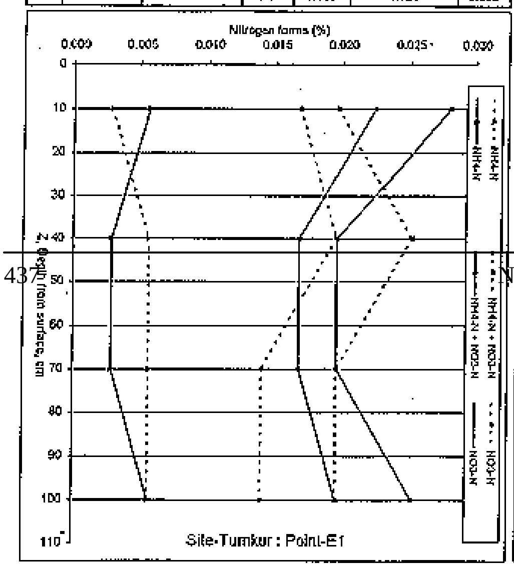


b. After KNO_3 solution injection into the hole O

Figure 6. Layout for soil samples extraction at x, y and z and depthwise at p,q and r.

The central hole 'O' of 10 cm dia and 1 m depth is then filled with nitrate solution (250 mg/l as NO_3) by repeated pourings totalling to 42 litres. To the bottom of the feed hole a PVC plate of 10 cm diameter was placed to prevent the vertical travel of pollutant poured into it. After four weeks, soil sample extraction process was repeated along NE, SE, NW and SW directions. The soil samples so extracted were analysed for combined NH_4^+-N and NO_3^--N by Devardas alloy method. The concentrations before injecting the nitrate solution along NE, SE, NW and SW directions were obtained by the average values of North and East, South and East and the like.

Z	Before Injecting KNO_3 (%)			After Injecting KNO_3		
(cm)	NH_4-N	NH_4-N + NO_3-N	NO_3-N	NH_4-N	NH_4-N + NO_3-N	NO_3-N
10	0.003	0.020	0.017	0.006	0.028	0.022
40	0.005	0.025	0.020	0.003	0.020	0.017
70	0.008	0.020	0.014	0.003	0.020	0.017
100	0.006	0.020	0.014	0.006	0.025	0.020



Z	Before Injecting KNO_3 (%)			After Injecting KNO_3 (%)		
(cm)	NH_4-N	NH_4-N + NO_3-N	NO_3-N	NH_4-N	NH_4-N + NO_3-N	NO_3-N
10	0.003	0.028	0.025	0.006	0.034	0.028
40	0.005	0.026	0.022	0.006	0.028	0.022
70	0.003	0.020	0.017	0.006	0.031	0.025
100	0.003	0.022	0.020	0.005	0.028	0.022

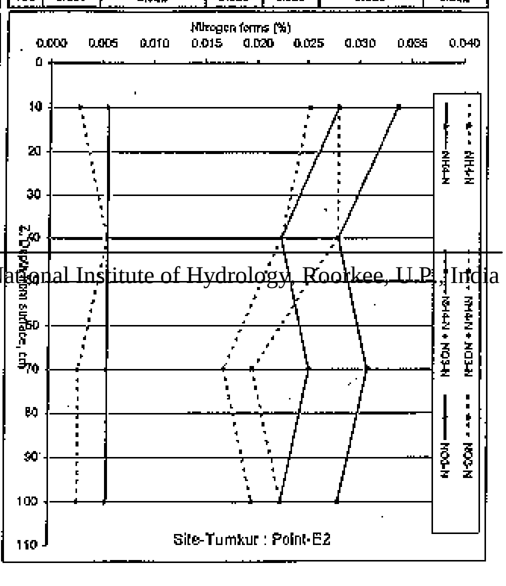


Figure 7. Variations in nitrogen forms in soils before and after injecting KNO_3 solution.

The variations of nitrate levels in the soil horizon at different positions depthwise as well as in the lateral directions are determined for the soil samples extracted using distillation method. The results of analysis are presented in Fig. 7. Thus the nitrate status of the soil can be assessed. Also, equal levels of nitrate content (isopleths) in soils (spread as well as depthwise) are presented in the form of contours in Fig 8 for illustration.

DISCUSSION OF RESULTS

The field infiltration test conducted revealed that there was a high initial infiltration rate of 19.5cm/hour and attained a uniform final value of 1.88cm/hour after a time lapse of 150 minutes.

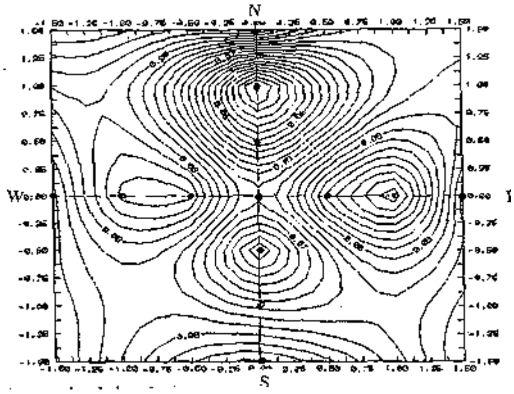


Figure 8a. Isotopes of nitrate content at 0.4 m depth before KNO3 solution injected – Mallasandra.

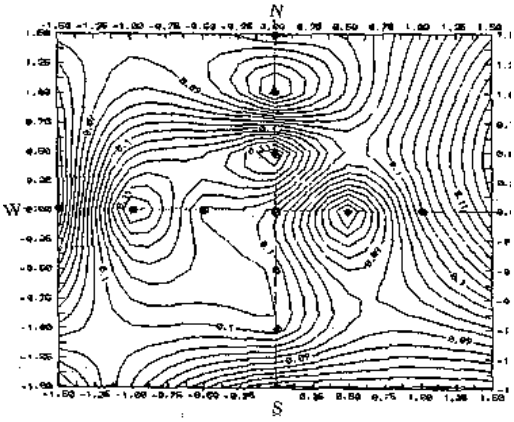


Figure 8b. Isotopes of nitrate content at 0.4 m depth after KNO3 solution injected – Mallasandra.

The hydrodynamic dispersion which is a measure of pollutant spread yielded a value of 227 sq.m/year for nitrate tracer and 66.5 sq.m/year for tritium tracer. This indicates that there will be substantial spread of the pollutant in the soil horizon.

The field oriented pollutant injection test performed showed that the moisture(solute) movement and accumulation chiefly depends on the soil texture & structure.

The isopleths are drawn using the software 'SURFER' to obtain the concentration distributions of nitrate in the unsaturated zone at 0.1m, 0.4m, 0.7m, and 1.0m depth below the ground surface. By analysing the isopleths, it is observed that the nitrate mobility differs from place to place both in spread as well as depthwise. From the isopleths of Mallasandra study site (Fig.8), it can be manifested that there is a uniform increase of nitrate concentration at all positions depthwise. This is due to lower drainage characteristics of clayey structure of the study site. Therefore, soil physical properties play a significant role in conserving and supplementing the applied nutrients to the plant growth along with other influencing factors. The investigation, therefore, suggests the necessity of the officials of agricultural department imposing soil tests before fixing the type and dosage of chemical fertilizers. This helps in the application of optimal fertilizers thereby abating soil and groundwater pollution.

Acknowledgement

The authors are grateful to University Grant Commission, New Delhi, for financial support.

References

Basak, P., and V.V.N. Murthy (1979): Determination of hydrodynamic dispersion coefficients using 'inverfc'. Journal of hydrology. Vol. 41, pp. 43-48.

Eaton, A.D., Cleseeri, L.S., and A.E. Greenberg (1995) : Standard Methods. 19th Edition, APHD, AWWA and WEF, USA.

Fried, J.J., and M.A. Combarnous (1971): Dispersion in porous media. Advances in Hydroscience (edt: V.T. Chow). No. 7, pp. 170-282.

Hajek, B.F. (1969): Chemical interactions of wastewater in a soil environment. Jnl. WPCF., October. pp. 1775-1786.

Horton, R.E. (1933): The role of infiltration in the hydrologic cycle. Ame. Geophys. Union Trans., 14, pp. 446-460.

Jackson, M.L. (1958): Soil Chemical Analysis. Constable, London.

Luhrmann, L., Noseck, W., and C. Tix (1998): Model of contaminant transport in porous media in the presence of colloids applied to actinide migration of column experiments. Water Resources Research. Vol. 34, No. 3. March. pp. 421-426.

Preul, H.C., and G.J. Schroepfer (1968): Travel of nitrogen in soils. Journal WPCF. Vol. 40, No. 1, January, pp. 30-40.

Rajendra Prasad (1998): Fertilizer urea, food security, health and the environment. Current Science, Vol. 75, No. 7, October. pp. 677-683.

Ranganna, G., Lokesh, K.N., Gajendragad, M.R., Chandrakanth, G., Harshendra, K., Ars, A.K., and M.M. Kori (1991): Studies on infiltration characteristics in soils of Pavanje River basin of D.K. District. Hydrology Jnl. of IAH, Vol. XIV, No. 1, pp. 33-40.

Rubin, J. (1968): Theoretical analysis of two-dimensional, transient flow of water in unsaturated and partly unsaturated soils. Soil Sci. Soc. Amc. Proc., Soil Physics S-1, Sept-Oct., Vol. 32, No. 5, pp. 607-615.

Sadashivaiah, C., Ramaraju, H.K., Ranganna, G., Rao, N.M., Venkatachalappa, M., Vasu, K., Shahul Hameed, and K.T. Velayudhan (2000): Tracer techniques for predicting movement and fate of pollutants in the unsaturated soil zone through soil column experiments. Jnl. Ind. Geophys. Union. Vol. 4. No. 1, pp. 31-39.

Vasu, K., and Hameed, S. (1998): Introduction to nuclear techniques in hydrology and isotopes - classification, product and applications. Proc. Short Term Training on Nuclear Techniques in Hydrology. Nuclear Hydrology Divn., CWRDM., Calicut. pp. 49-59.