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Environmental impact of nitrogen fertilization in tea eco-system

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Abstract: *To quantify the nitrogen losses through runoff, and leaching under a tea plantation in hilly soil, a field experiment was conducted from October 2001 to October 2002 at United Planters Association of Southern India (UPASI), Coonoor in Nilgiri district. Runoff water was collected in the collection tub on most rainy days but the leachate was collected in the soil water sampler when the rainfall exceeded 150 mm. Higher nitrogen fertilization levels significantly influenced the NO_3-N concentration in both the runoff and leachate and it was likely to cause adverse environmental impact at the delivery end. The NH_4-N and NO_3-N concentrations in runoff decreased with the days after fertilizer application. NH_4-N concentration reduced from 10.27 mg/l on the 9th day to 1.72 mg/l on the 34th day after fertilizer application. NO_3-N concentration reduced from 23.5 mg/l on the 9th day to 4.32 mg/l on the 34th day after fertilizer application. Nitrogen loss varied depending on the quantity of rainfall and runoff. The NO_3-N concentration in the leachate increased with increase in depth (18.06 mg/l at 22.5 cm depth to 20.98 mg/l at 45 cm depth) whereas NH_4-N concentration decreased with increase in depth (6.32 mg/l at 22.5 cm depth to 5.79 mg/l at 45 cm depth.*

Key words : *Clay loam, Runoff, Leachate, NH_4-N, NO_3-N concentration*
PDF file of full length paper is available with author

Introduction

Tea is one of the world's most important plantation crops and its production is dominated by India followed by China, Kenya and Sri Lanka. In world tea exports, India occupies the fourth place and tea exports represent 0.98% of national export and 6.83% of agricultural exports.

Success of food grain production and increase in the yield of plantation crops in developing countries hinge on the expansion of fertilizer use. Conventional tea plantations make heavy use of chemical fertilizers and pesticides (Das *et al.*, 2005). Among the chemical fertilizers, nitrogen fertilization plays an important role in a crop such as tea where the stimulation of vegetative growth is the ultimate aim of the planter. The fertilizer use efficiency of tea plants varies from 13 to 43% depending upon the type of fertilizer, reaction of the soil, rainfall, intensity of shade, stages in the pruning cycle and yield potential of the jat / clone. The low nitrogen use efficiency is due to volatilization losses after hydrolysis of ammonium forming fertilizers like urea, denitrification losses through biological and chemical mechanisms, leaching and runoff losses due to rain.

Egression of fertilizer nitrogen as gases, surface runoff and leaching is implicated in the degradation of the biosphere. Surface runoff takes nitrogen to water bodies where it accelerates the nitrate pollution and causes eutrophication in fresh water; hypoxia in seawater; methaemoglobinemia; stomach cancer; foetal malformation and illness to cattle and sheep. In 1962, U.S. Public Health Service set an upper limit on nitrate in drinking water at 10 mg N/l (USEPA, 1976 ; Fletcher, 1991).

Most of the earlier studies concentrated mainly on the effect of erosion on soil fertility and productivity. The issue of off-site damages, specifically nitrate pollution, has not been given much importance. To overcome this lacuna, the present study was conducted on the environmental impact of nitrogen fertilization in a tea eco-system.

Materials and Methods

A field experiment was conducted from October 2001 to October 2002 under a tea plantation (clone = UPASI-2) at UPASI, Coonoor in Nilgiri district to quantify the nitrogen losses through runoff and leaching.

Site characteristics of the experiment: This location is situated at 11°2' N latitude, 76°48' E longitude and at an altitude of 1760 m above MSL. It has a slope of 48%. This zone received an annual rainfall of 1532 mm in 73 rainy days and distributed over two seasons *viz.*, northeast monsoon and southwest monsoon. Of the total rainfall, 1060 mm was received during northeast monsoon period of October to December 2001 and 205.1 mm during southwest monsoon period of June to September, 2002.

The study area lies in the humid belt of western ghats. The annual mean maximum and minimum air temperatures at 08:30 hr and 14:30 hr were 24.8°C and 13.8°C and soil temperature were 20.8°C and 20.7°C, respectively. Relative humidity ranged between 80.4% and 75.7% at 8:30 hr and 14:30 hr, respectively. The mean bright sunshine hour per day was 3.2 and wind speed was 3.6 km/hr.

Table - 1: Properties of the experimental soil

	Particulars	Coonoor soil	
		0-22.5 cm	22.5-45 cm
1.	Physical properties		
a.	Particle size distribution (g kg^{-1})		
	Clay	398	362
	Silt	160	260
	Fine sand	220	169
	Coarse sand	209	191
	Texture	cl	cl
b.	Bulk density (mg m^{-3})	1.08	1.11
c.	Particle density (mg m^{-3})	2.5	2.22
d.	Pore space (%)	56.6	51.4
e.	Pore space volume (ml)	10.0	9.5
f.	Field capacity (%)	22.4	22.0
g.	Wilting point (%)	19.0	17.0
II.	Physico-chemical properties		
a.	Soil reaction (pH)	4.75	4.85
b.	Electrical conductivity (dS m^{-1})	0.51	0.16
c.	Cation exchange capacity [cmol(p^+)kg^{-1}]	12.5	11.27
III.	Chemical properties		
a.	Organic carbon (g kg^{-1})	30.8	25.9
b.	Total nitrogen (g kg^{-1})	3.20	2.10
c.	$KMnO_4$ -N (mg kg^{-1})	316.0	176.0
d.	Ammoniacal nitrogen (mg kg^{-1})	56.0	28.0
e.	Nitrate nitrogen (mg kg^{-1})	42.0	14.0
f.	Ammonium fixing capacity (cmol kg^{-1})	2.5	2.0

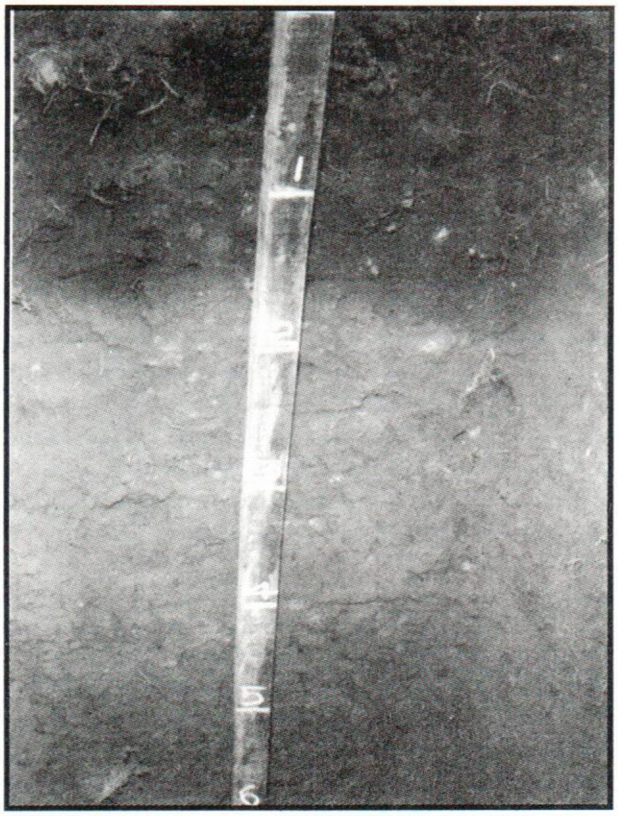

Fig. 1: Soil profile features at the field experiment site

The details of soil profile characteristics are presented in Table 1. The profile and field view are depicted in Fig. 1, 2 respectively.

Details of the experiment: In the field, nitrogen was applied at different levels *viz.*, 250, 375, 500 and 625 kg N/ha/yr in the form of urea in five splits during October, November, December months of 2001 and April and July months of 2002 by broadcasting. Each treatment was replicated five times and potassium was added at the ratio of 4:3 (N:K) in each split. Layout of the experiment is depicted in Fig. 3. Each plot consisting of 40 bushes with the spacing of 135 x 75 x 75 cm.

Collection of runoff water: Runoff water samples were collected during rainy days in the months of October and November, 2001 from each plot by using polythene sheet (Fig. 4). There was no significant rain in the remaining months. The samples were analyzed for pH by potentiometry method (Jackson, 1973), electrical conductivity by conductometry method (Jackson, 1973), NH_4-N and NO_3-N by steam distillation method (Bremner and Keeney, 1966). The analytical data were statistically analyzed by Randomized Block Design (Gomez and Gomez, 1984).

Collection of leachates: Leachate samples were collected three times during October, November and December at 0-22.5 cm and 22.5-45 cm soil depth from each plot depending on rainfall and analyzed for NH_4-N and NO_3-N contents. The leachate samples were collected

Table - 2: Changes in NH_4-N and NO_3-N concentration mgl^{-1} of leachate under two depths

Treatments	NH_4-N		NO_3-N	
	22.5 cm	45 cm	22.5 cm	45 cm
150 kg N ha^{-1}	4.92	5.03	12.07	13.58
225 kg N ha^{-1}	6.59	5.53	15.22	16.86
300 kg N ha^{-1}	6.46	5.64	18.14	23.18
375 kg N ha^{-1}	7.31	6.95	26.79	30.32
Mean	6.32	5.79	18.06	20.98
CD ($p \leq 0.05$)	0.465		1.048	

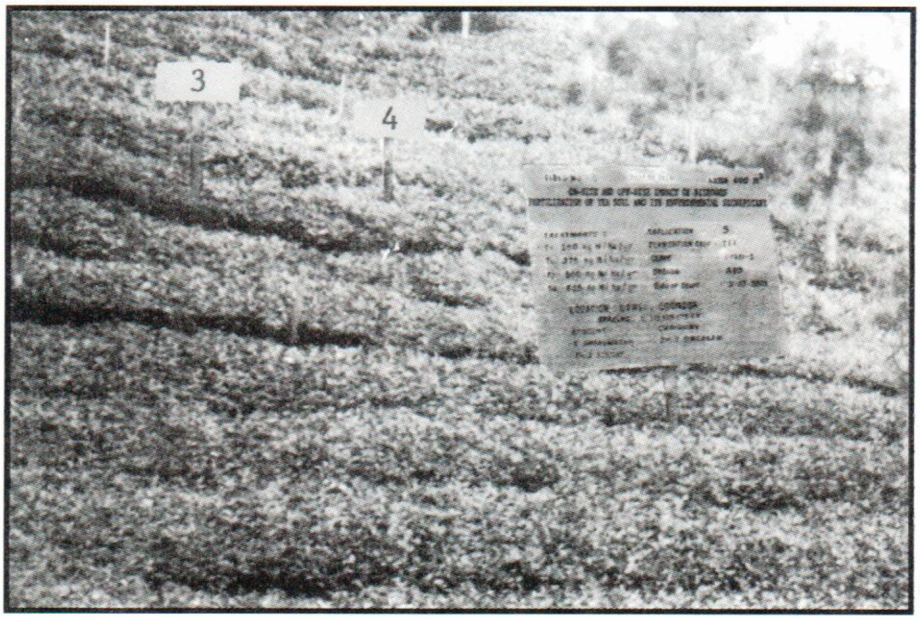

Fig. 2: View of the field experiment site

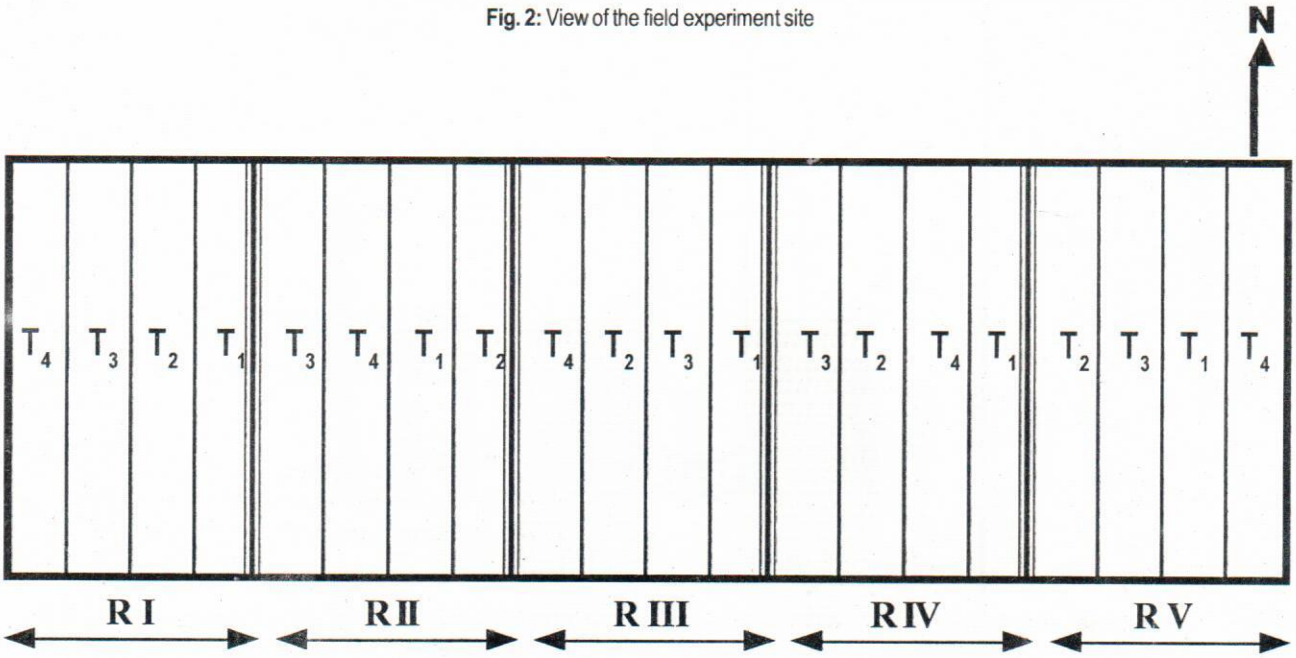

Fig. 3: Field layout plan

Fig. 4: Arrangement for run off water collection at the experiment site

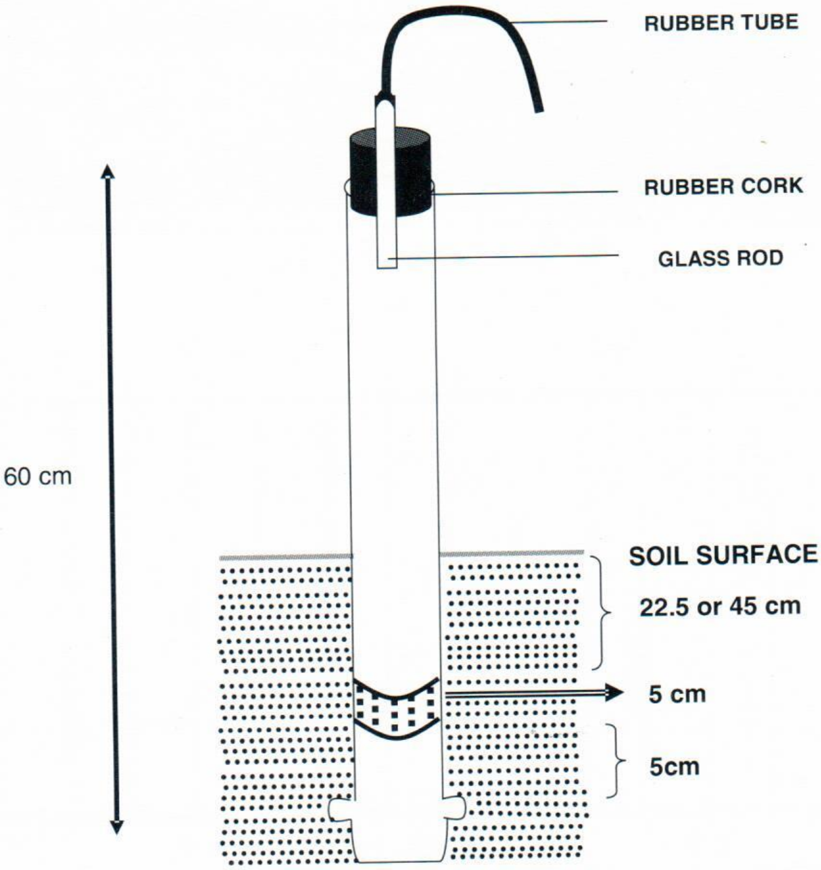

Fig. 5: Fabricated soil water sampler

by using fabricated soil water sampler which consists of a hard PVC tube of 60 cm length and 5 cm diameter, fitted with an end cap at the bottom and glued with araldite. Small holes were made over a 5 cm length in each PVC tube by using needle. The first row of holes started at 5 cm height from end cap. These holes were covered by netlon with the help of araldite. The upper portion of the pipe was covered with a polyethylene cover (Fig. 5).

Two soil water samplers were installed in the middle of each plot and between the rows of tea bushes before the starting of the experiment by boring holes with a soil auger such that the holes in PVC pipe were at two different soil depths *viz.*, 22.5 cm and 45 cm depth from the surface of soil. Leachate samples were collected from the soil water samplers by using a hand suction pump and placed in polyethylene bottles containing a few drops of phenyl mercuric acetate (PMA).

Results and Discussion

When the nitrogenous fertilizers were applied to the steep slope under high precipitation conditions, only 20-25 percent of applied fertilizer nitrogen was used by the plants and the remaining nitrogen is lost through runoff and percolation in different forms (NH_4-N and NO_3-N). The concentration and loss of two forms of nitrogen through runoff and leachate were quantified for two months during rainy days only. Two splits of nitrogen were applied during October and November months. Graphs were drawn between cumulative effect of applied nitrogen in different treatments (250/5 + 375/5 + 500/5 + 625/5 = 350 kg N/ha/split) and the number of days after fertilizer application and the results are discussed below.

Runoff losses:

pH in runoff water: The pH value of runoff water collected at 9th day after fertilizer application (first time after fertilizer application) was low and then increased with time up to the 34th day and thereafter it reduced from 8.22 to 7.44 (Fig. 6). The significant decrease might be due to the 2nd split of fertilizer application at 35th day. Low pH value at 9th day after fertilizer application explained the combined effect of carbonic acid produced due to the decomposition of urea and the organic acids released due to the decomposition of organic matter. The priming effect of urea on organic matter decomposition

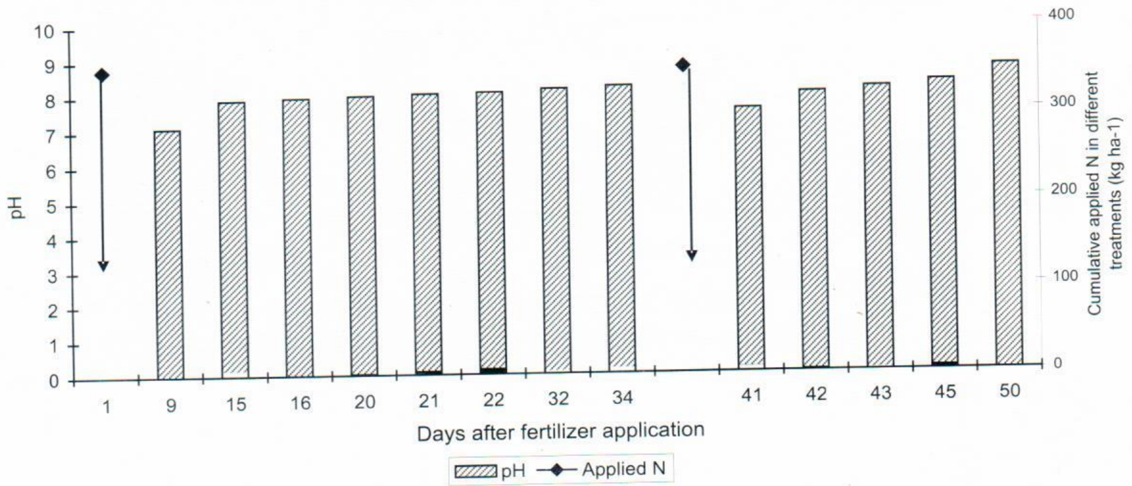

Fig. 6: Changes in pH of runoff water under clay loam soil

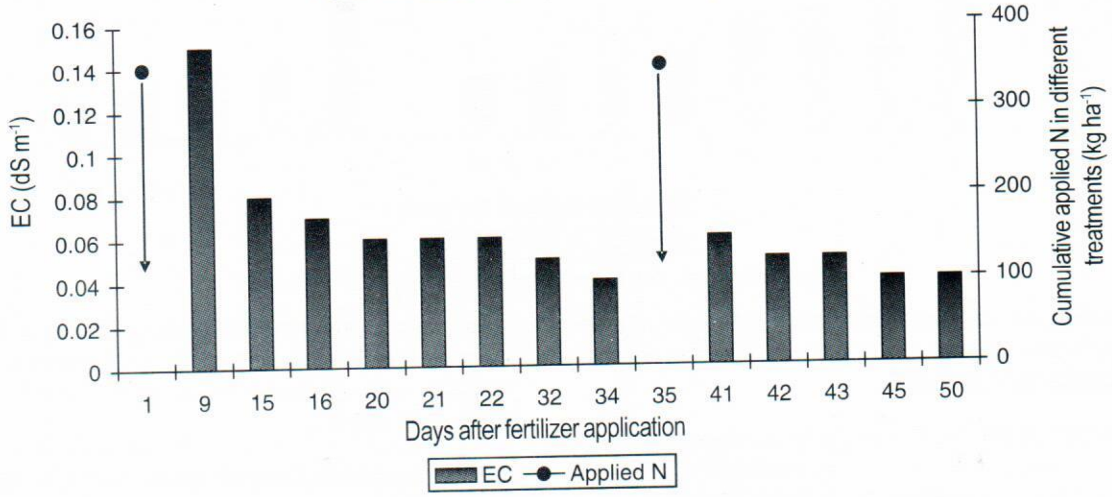

Fig. 7: Changes in EC of runoff water under clay loam soil

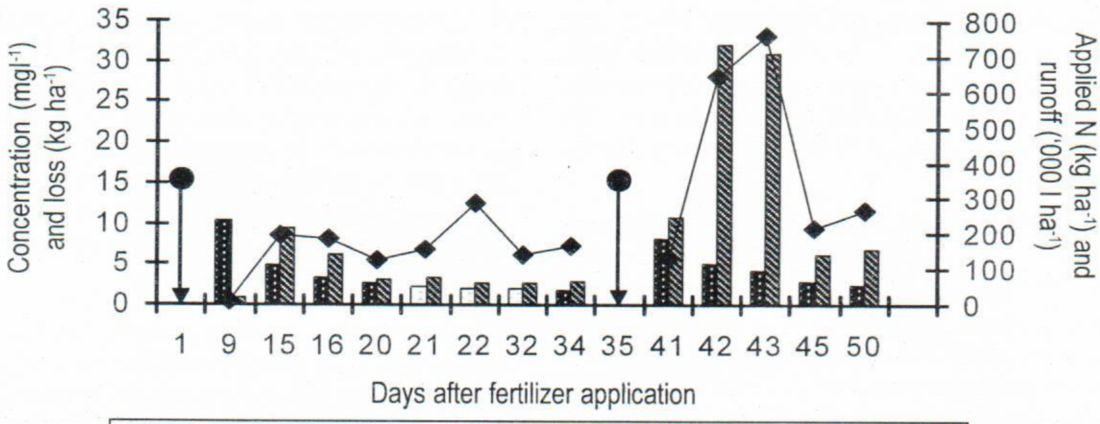

Fig. 8: Changes in NH_4-N concentration and loss of runoff under clay loam soil

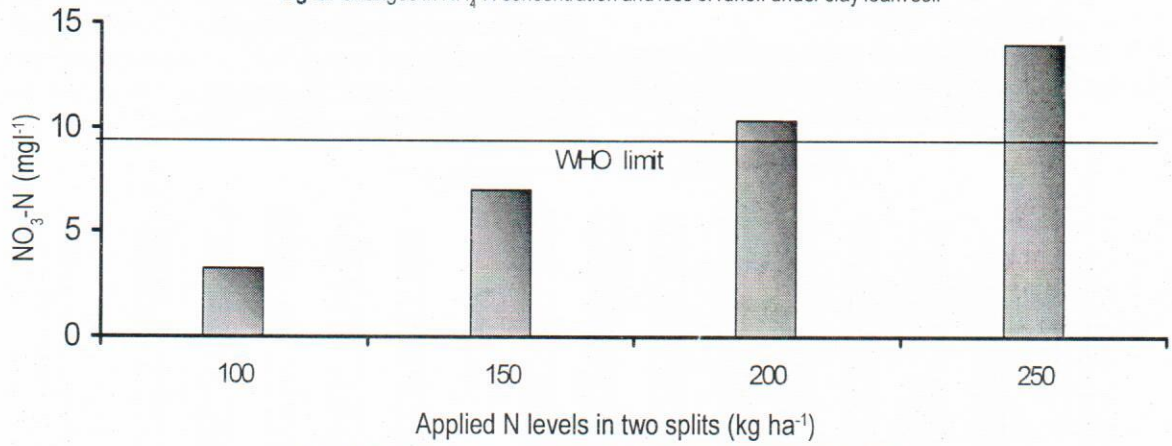

Fig. 9: Changes in NO_3-N concentration of runoff under different N levels

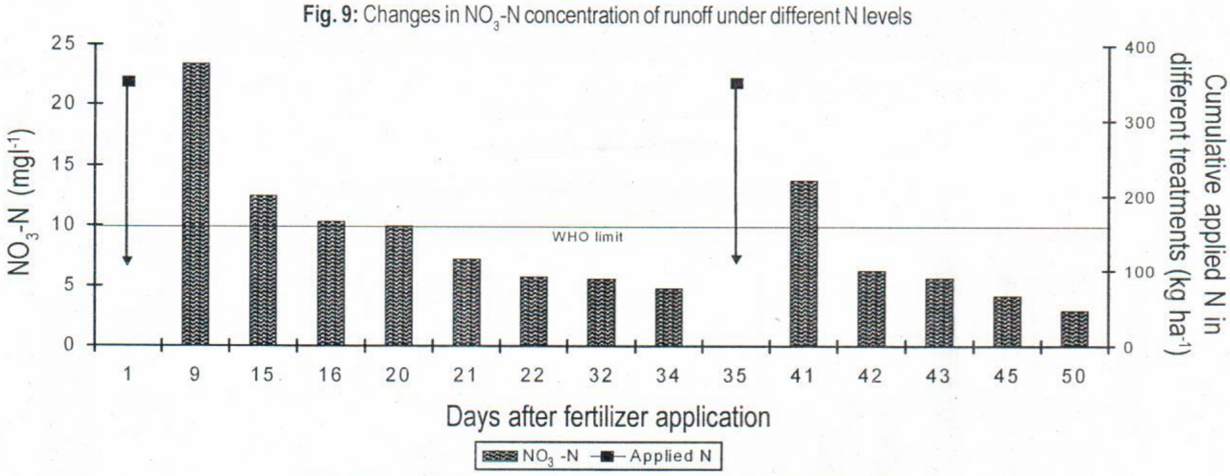

Fig. 10: Changes in NO_3-N concentration of runoff under different days

was very short as evidenced by increase in pH from 15th day after fertilizer application onwards. Similar trend was also observed during the 2nd split of fertilizer application.

EC in runoff water: Runoff water collected after the fertilizer application recorded relatively high value of EC (0.15 dS/m) that reduced with the passage of time (Fig. 7). Probable reason might be that during the first rainfall, maximum amount of salts might have been transferred to runoff flow in solution form by rainwater mixing with the soil solution, dissolution of chemicals partly present in solid form, desorption of the adsorbed chemical from the soil and crop residue (Bailey *et al.*, 1974).

NH_4-N concentration in runoff water: The NH_4-N concentration in the runoff water decreased with the days after fertilizer application and there was a sharp increase at 41st day after fertilizer application due to second split of fertilizer application at 35th day. The maximum NH_4-N concentration was obtained at 9th day after fertilizer application and it was 53 percent higher than that of 15th day after fertilizer application. However, NH_4-N loss was very low (0.82 kg/ha) at 9th day after fertilizer application (Fig. 8). It might be attributed to low rainfall (14,000 l/ha) that led to low runoff (7980 l/ha) when compared to other days. It confirmed the results of Padmaja and Koshy (1978) who indicated that the nutrient loss through runoff could be as high as 70 percent if heavy rainfall occurs on the day of fertilizer application and the magnitude of loss decreased with the delay in rainfall. Hubbard *et al.* (1989) confirmed that percent of applied water lost as surface runoff increased with increasing rainfall intensity.

NO_3-N concentration in runoff water: Fertilizer application greatly influenced the NO_3-N concentration and the loss through runoff. The NO_3-N concentration increased with the fertilizer level and at 200 and 250 kg N/ha, the concentration increased beyond the WHO limit of 10 mg/l (Fig. 9). It is due to quantity of rainfall, intensity of rainfall, slope, infiltration besides fertilizer mineralization and priming effect.

Nitrate-N concentration was high in the runoff collected at 9th day after fertilizer application (first time after fertilizer application) (23.5 mg/l) and it decreased with time (Fig. 10). It was supported by the results of incubation study, which revealed that the highest concentration of NO_3-N in the early stages by hydrolysis of nitrogen fertilizer. Runoff collected at 41st day after fertilizer application increased the NO_3-N concentration by 185 percent when compared to 34th day runoff concentration, which could be attributed to 2nd split of fertilizer application. The NO_3-N concentration at 9th day, 15th day, 16th day and 41st day is higher than the WHO limit of 10 mg/l. This high concentration is likely to cause eutrophication in the receiving end depending on the volume of water in the receiving body and the distance between the fertilizer application spot and the delivery end. It is in consonance with the findings of Blevins *et al.* (1996).

In the present study, urea was broadcasted at or near the soil surface and this would have resulted in localized changes in pH and subsequent rapid transformation and these were intensified by the rate of urea and precipitation of rainfall. Another possible reason could be the presence of fertilizer granules at or near the surface,

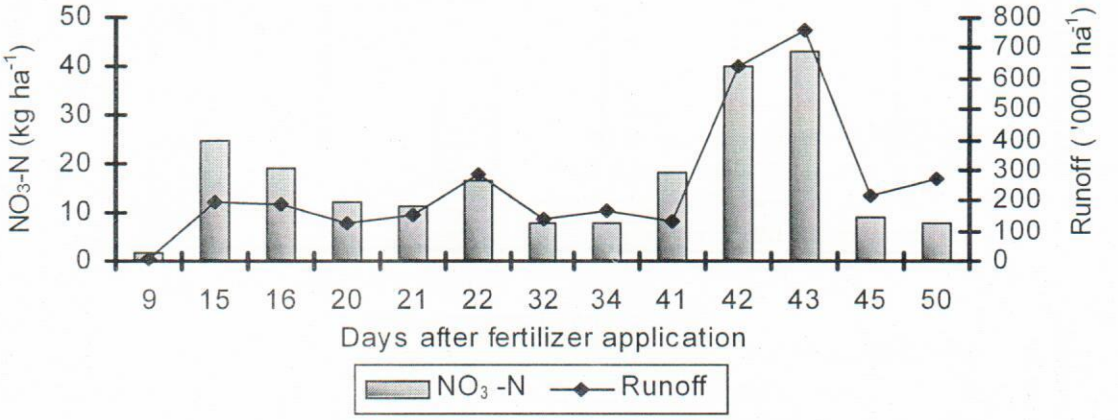

Fig. 11: Changes in NO_3-N loss of runoff under different days

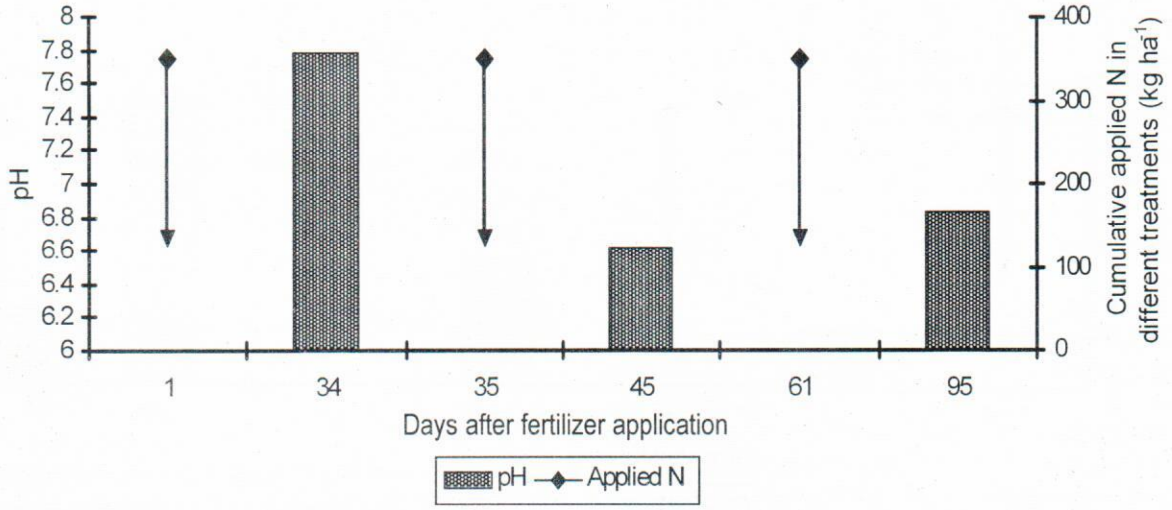

Fig. 12: Changes in pH of leachate at field condition

which are more susceptible to movement in runoff than liquid urea application (Gascho *et al.*, 1998). All these led to increase in NO_3-N content of first runoff collected at 9th day after fertilizer application and then reduced. The same trend was observed during 2nd split of fertilizer application. The possible reasons for the loss of NO_3-N in the runoff from fields are the nitrogen rates, sources, placement and time of application related to the occurrence of runoff (Barrows *et al.*, 1967).

Experimental results showed that there was no correlation between NO_3-N concentration and NO_3-N loss through runoff. The data (Fig. 10) showed that NO_3-N concentration was maximum (23.5 mg/l) at 9th day after fertilizer application but the NO_3-N loss (Fig. 11) was minimum (1.83 kg/ha) in the runoff collected on the same day. It confirmed that NO_3-N loss could be closely related to rainfall and runoff (Bedell *et al.*, 1946).

Leaching loss: Leaching loss of nitrogen from the soil is a loss from soil-plant system and reduces efficiency of applied nitrogen. It can be lost due to leaching either as NO_3^- or NH_4^+. Of the total leaching loss, 76.3 percent was in the form of NO_3^-, since anion exchange capacity (AEC) of the soil is insignificant. Therefore, its movement is related to the movement of water in the soil.

In the field experiment, leachate was collected only three times whereas runoff water was collected 13 times during a three months period. It represented that the loss of NO_3-N concentration through runoff was high due to high slope per cent, precipitation and no till. The leachate water collection confirmed that under clay loam soil, water was collected through percolation only when it received a rainfall more than 150 mm.

pH in leachate: Leachate collected at first time after fertilizer application recorded the highest pH value of 7.78 which was reduced

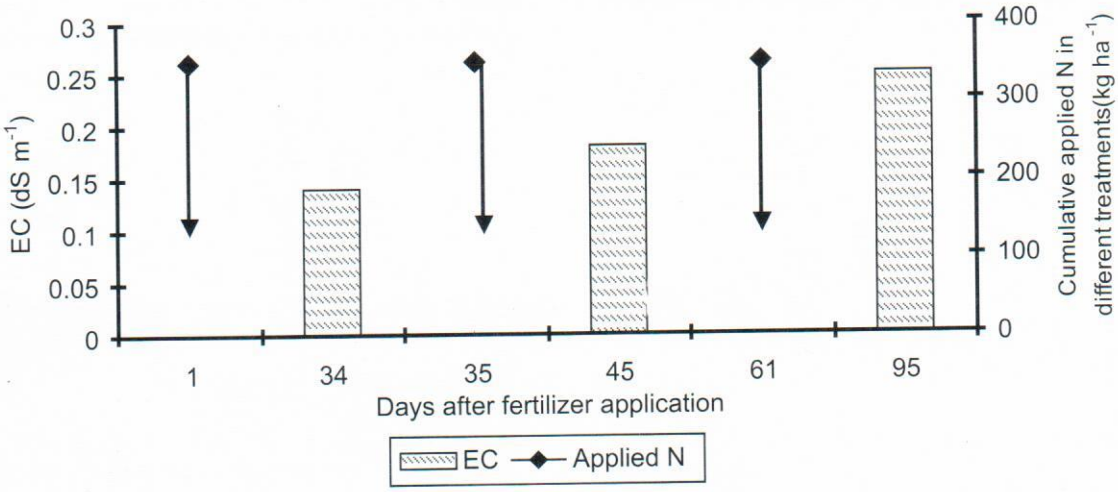

Fig. 13: Changes in EC of leachate at field condition

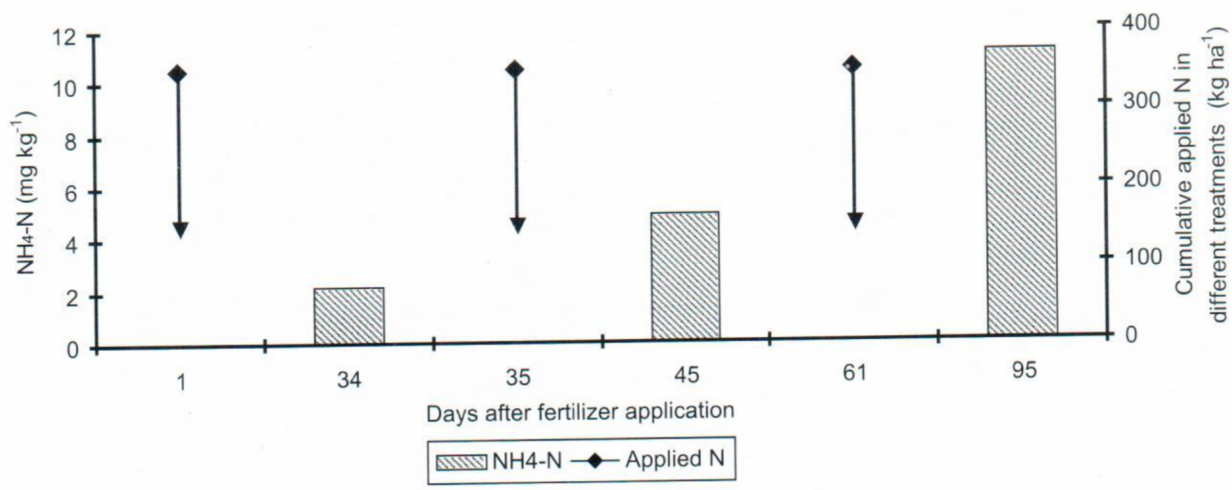

Fig. 14: NH_4-N concentration of leachate at field condition

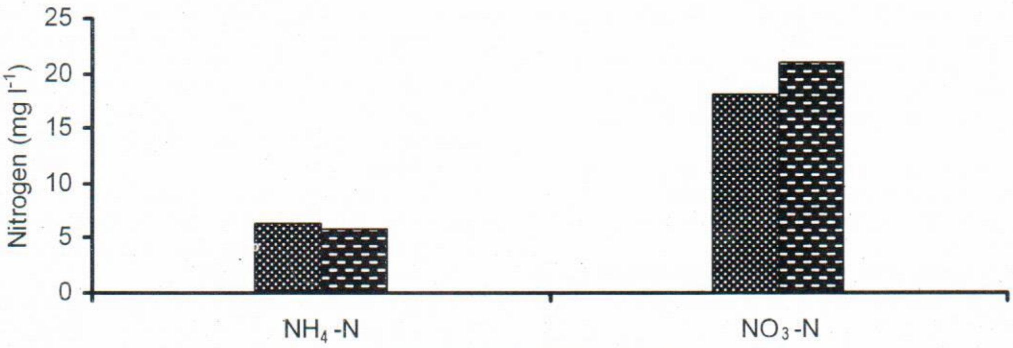

Fig. 15: Changes in NH_4-N and NO_3-N concentration of leachate under two depths at field condition

slightly afterwards (Fig. 12). The higher value might be due to the mineralization of fertilizer, its transformation and the interval between the two rainfalls. It was supported by the results of the column study under laboratory conditions (Saraswathy and Singaram, 2005).

EC in leachate: Electrical conductivity of leachate increased with days after fertilizer application. The increase was 29 percent at 45th day and 79 percent at 95th day leachate collection over 1st time of collection (Fig. 13). The increase in EC could be attributed to split application of fertilizer before each time of leachate collected and the fertilizer increased the solubility of salts.

NH_4-N concentration in leachate: The loss of NH_4-N was relatively lower than nitrate as clay colloids can retain them to considerable extent (Ranganathan, 1969). The concentration in leachate increased with the nitrogen levels and confirmed the urea hydrolysis and continuous mineralization of organic matter.

The depth of soil slightly affected the concentration of NH_4-N (Table 2). The experimental data showed that the NH_4-N concentration decreased 8.4% in the leachate collected at 45 cm depth when compared to 22.5 cm depth. It might be due to the exchangeable reaction and subsequently NH_4^+ fixation as well as increase in the nitrification rate. The increase in nitrification was confirmed by increase in NO_3-N concentration (16.2%) of the leachate collected at 45 cm depth when compared to 22.5 cm depth.

NO_3-N concentration in leachate: Generally, the chemicals move to surface and groundwater by mass flow and/or diffusion process. Nitrate leaching depends on the rate of surface runoff (Jaakkola, 1984) and the mean movement of anion was 1.075 inches for each inch of rainfall (Wetselaar, 1962). The vertical transport rate of NO_3-N was ~76 cm/yr (Bobier *et al.,* 1993).

Application of nitrogen significantly increased the NO_3-N concentration of leachate and it was 16 percent higher in the leachate collected at the subsurface region (45 cm depth) than shallow sub surface region (22.5 cm) (Table 2). It was similar with the findings of Kalita and Kanwar (1993). The reasons for the above observations are:

i. Timing and intensity of rainfall events. Once the NO_3-N is flushed beyond the rooting zone, it becomes prone to permanent loss (Power, 1970).

ii. Most of the NO_3-N losses through runoff were from shallow subsurface flow rather than surface flow (Wallach *et al.,* 1988).

iii. Subsurface flow accounted for 80 percent of the total runoff when compared to the surface flow (Jackson, 1973).

Thus the nitrogen application under tea cultivation in hilly soil undergoes many transformation reactions due to soil and land characteristics, type of fertilizer applied, meteorological parameters, genetic characters of crop *etc.*, and it leads to adverse impact on environment.

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