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Movement of bromide as a tracer for nitrate in an Alfisol of the Indian Semi-Arid Tropics under rainfed condition

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Abstract

The variable responses of crops to added nitrogen (N) in Alfisols of the Indian semi-arid tropics are partly due to variable rainfall and partly due to variable losses of available-N. To measure the losses of N through leaching, which can be appreciable under some circumstances, a field experiment was conducted during the rainy season (June-September) of 1992, using bromide (Br) as a tracer for NO_3^-. Bromide (as NaBr) was applied to bare fallow soil at a rate of 200 kg ha^{-1} in microplots (2 m × 2 m) and its vertical movement was monitored periodically. Data on rainfall and Br^- distribution in the soil profile on different dates of soil sampling clearly indicated that the movement of Br^- was strongly dependent on rainfall. During the first month (15 June–15 July) after Br^- application, with scattered and light rainfall about 90% of the added Br^- remained in the soil profile (0.6 m). After continuous heavy rainfall in early August more than 90% Br^- had moved beyond 0.6 m depth. This indicates a very high risk of NO_3^- leaching in this soil, and it is unavoidable without special measures to protect the applied N.

Introduction

Alfisols in the Semi-Arid Tropics (SAT) of India are well drained soils and possess poor water and nutrient storage characteristics [4,16]. Nitrogen (N) deficiency is one of the major constraints in these soils [3]. Response of crops to added N in these soils is variable, partly due to variable rainfall and partly due to variable losses of available N. While a particular agronomic yield result is frequently attributed to one or more of the soil nitrogen loss processes, almost invariably the evidence is indirect.

Because of the nature of these soils and rainfall in the SAT occurs predominantly in big storms, separated by discrete dry periods [7], leaching of N in the anionic forms (NO_3^-, NO_2^-) may be a dominant loss mechanism, causing a significant reduction in the amount of N available for crop growth. Of note, however, is the absence of data on direct field measurement of NO_3^- leaching losses from dryland agriculture in India [3,5]. Knowledge on this aspect is important to develop and perfect new technologies for increasing efficacy of fertilizer N application and minimizing the pollution of surface and subsurface streams.

Leaching of NO_3^- in soils can be measured by direct estimation. But often it is difficult to distinguish whether the NO_3^- derived from fertilizer N or any other source. Use of ^{15}N labelled fertilizer gives the most accurate answer, but the costs of such techniques generally prohibit their use in large scale field studies. In such situations a substitute tracer which is inexpensive and easy to measure can be adopted. Due to the an ionic character of NO_3^-, its movement in soils is often compared with other anions that are similarly charged, like Br^- or Cl^- [12,13,15,17]. These ions have the advantage of neither degrading nor volatilizing over time and thus are not lost from the soil profile other than by deep leaching or plant-uptake. However, Cl^- is not acceptable for use in most arid soils because of the typically high natural background levels of Cl^-

in these soils. Therefore, Br^- as a tracer was used in this study to investigate the pattern of NO_3^- movement and to estimate the potential for NO_3^- leaching losses of an Alfisol under rainfed condition. It should be mentioned, however, that Br^- being a biologically conserved tracer a complete picture of the fate of fertilizer N in a soil-plant system can not be determined. Nevertheless, it can be used to infer solute-movement patterns and present the soil potential for NO_3^- leaching losses in a worst-case scenario, that may occur in the rainfed condition of the Indian semi-arid tropics.

Materials and methods

Soil

The experiment was carried out during the rainy season of 1992 at the ICRISAT Center, which is located about 25 km north-west of Hyderabad, India (latitude 17.5 °N, longitude 78.5 °E, and altitude 545 m). The experimental soil, a 0.6 to 0.7 m deep Alfisol ('red'soil), belongs to the Patancheru series (clayey skeletal, mixed isohyperthermic Udic Rhodustalfs). Before commencing the experiment, soil samples were collected in increments of 0.1 m to a depth of 0.6 m to characterize the physical and chemical properties (Table 1). The soils were analyzed according to methods previously reported [11]

Experimental

This experiment was conducted in microplots constructed with iron barriers, of 0.3 m high and 2 m × 2 m area, inserted to a depth of 0.2 m to prevent run-off losses. In addition, each microplot was protected by a border of aluminium sheet placed at 0.5 m distance and inserted to the same depth (0.2 m).

Bromide (as NaBr, AR grade) dissolved in 1000 mL distilled water was applied uniformly with a handheld sprayer on the entire soil surface of each microplot at a rate of 200 kg ha^{-1} on 15 June 1992. At this rate 103.02 g NaBr was required for each microplot. Prior to applying Br^- solution on the experimental plots several trials were given in the neighbouring area with same amount of NaBr free water. This was done to obtain uniform distribution of Br^- on the experimental plot. Bromide was also applied at the same rate to the area between the iron barrier and the aluminium sheet to reduce the possible errors due to its lateral movement from the treated microplots. One day after application, the NaBr was lightly incorporated into the soil to a depth of 0.05 m with a small garden type hand cultivator [2]. There were three replications of the treatments. A control plot was not included in the experiment, as the background concentration of Br^- was negligible (< 1 mg kg^{-1}). The plots investigated were kept clean, weed free and without growing any crop.

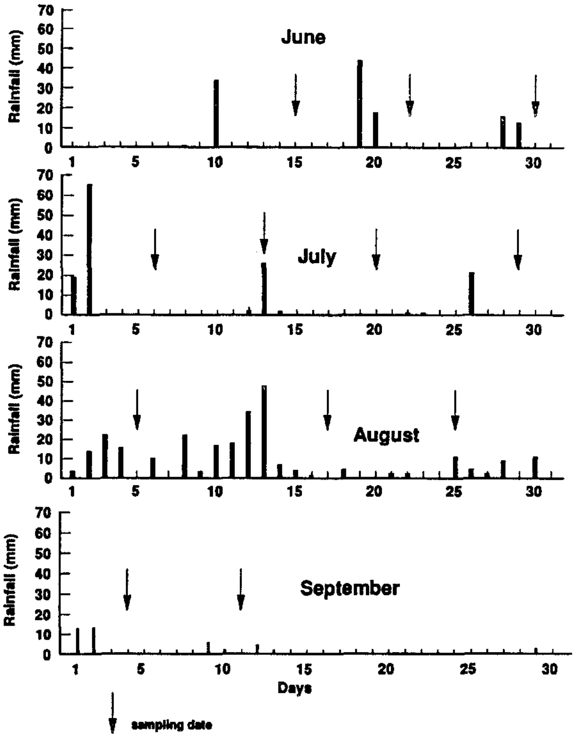

Figure 1. Rainfall distribution (June - September) during 1992 at ICRISAT, Hyderabad, India. The inverted arrow (↓) indicates soil sampling dates for moisture and bromide estimation

Soil samples were taken at different dates after Br^- application in increments of 0.1 m to 0.6 m. To prevent free water movement, each sample hole was refilled with soil of the same depth from an adjacent area. Soil samples, collected from the microplot, were analyzed for moisture (v/v) and Br^- contents. Bromide in soil was measured by the method of Abdalla and Lear [1], with some modifications for most precise and near 100% accuracy of the measurement of Br^- recovery from the soil [10], using an ion-specific electrode (model PHM 85 precision pH meter, Radiometer, Copenhagen, Denmark). The Br^- recovery per unit volume of soil was determined by multiplying the measured concentration by the corresponding bulk density for each 0.1 m incremental depth. Soil sampling dates

Table 1. Some properties of the soil at different depths before commencing the experiment

	Depth(cm)					
Property	0–10	10–20	20–30	30–40	40–50	50–60
pH (1:2 soil to water ratio)	6.50	5.99	5.95	6.16	6.35	6.39
CEC (c mol(+) kg^{-1})	6.90	8.90	15.50	17.10	20.80	19.00
NH_4^+-N (mg kg^{-1})	2.10	2.60	2.40	2.30	2.10	2.10
NO_3^--N (mg kg^{-1})	2.10	1.50	1.50	1.80	2.30	1.40
Organic-C (%)	0.77	1.31	1.38	1.42	1.42	1.48
Total-N (mg kg^{-1})	619	640	758	746	869	782
Sand (%)	79	74	64	52	47	50
Silt (%)	6	8	6	10	11	11
Clay (%)	15	18	30	38	42	39
Bulk density (Mg m^{-3})	14.1	16.2	14.8	14.8	17.9	18.1

and data on rainfall distribution during the experimental period are presented in Figure 1. Total precipitation (597 mm) during June to October of 1992 was slightly higher than the 30-year average(1931–60) of 582 mm for the Hyderabad region [8].

Results and discussion

Soil moisture

Soil moisture changes (Figure 2) at depths up to 0.6 m in the Alfisol revealed the dynamic changes in profile water recharge and depletion during the wet season of 1992. In the surface layers up to 0.2 m depth, water content was in the range of 10–15%, and increased progressively with increasing depth, reaching a maximum at 0.4–0.5 m (30–38%) and then decreased. It has been noticed that, although the amount of rainfall varied largely from traces to more than 60 mm day^{-1}, the water contents in the different soil layers on different sampling dates were rather similar. Thus, it is clear that moisture storage ability at different depths is more influenced by soil factors than the amount of rainfall. Soil properties like particle size distribution and mineralogical composition are important characteristics associated with water storage ability [4]. This was also reflected in this study from the observation of increasing amount of moisture retention (Figure 2) and the amount of clay content with increasing depth (Table 1). However, at the event of large rainfall, Alfisols with a shallow depth (such as this one), and poor water storage capacity, are expected to be saturated early, and the excess water is lost rapidly through percolation [9]. Also, with the volume of percolating water a greater proportion of the resident nutrient elements, particularly the anions such as NO_3^-, NO_2^-, etc., undoubtedly find their way to the ground water or sub-surface streams.

Bromide movement

Data on percent Br^- recovery in different layers of the soil at different dates after its application indicate a strong influence of rainfall on the behaviour of Br^- in this soil (Figure 3). On 22 June, i.e. one week after Br^- application and after 60 mm rainfall, Br^- was distributed throughout the soil profile. However, maximum Br^- was retained in the surface layer of 0.1 m followed by 0.1–0.2 m. Beyond 0.2 m depth, 20% of the applied Br^- was observed in decreasing order with depth.

On 6 July, after heavy rainfall events on 1 July (20 mm) and the largest (68 mm) of the year on 2 July (Figure 1), downward movement of readily available Br^- was greatly enhanced. In fact, there was a very small amount ($<$ 5%) of Br^- present in the top 0–0.2 m, and an almost equal amount was found in the layer 0.3–0.6 m. The data indicate that even some portion of the Br^- moved beyond 0.6 m depth.

The distribution pattern of Br^- in the profile on 20 July was rather similar to 6 July, but the amount of Br^- in each layer was comparatively higher. This suggests that Br^- had accumulated beyond 0.6 m depth and due to a dry period of one week before sampling on 6 July it had moved upward under the influence of evaporation

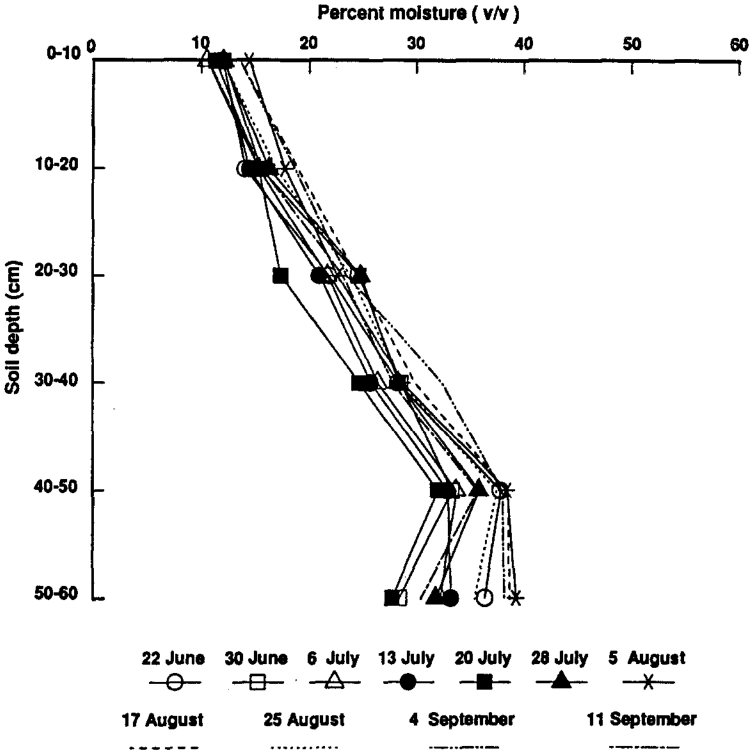

Figure 2. Moisture content (v/v) in an Alfisol (0–0.6 m) sampled at different dates; water content (v/v) = gravimetric water content (w/w) × bulk density

Table 2. Precipitation, evaporation, and percentage of applied bromide recovery from the profile of an Alfisol on different dates after NaBr application

Sampling dates 1992	Total precipitation after preceeding sampling (mm)	Total evaporation after preceeding sampling (mm)	Cumulative precipitation (mm)	Cumulative evaporation (mm)	Percentage of applied Br$^-$ recovered from the profile (0–0 .6 m)
15 June	-	-	-	-	98.5
22 June	61.4	61.7	61.4	61.7	93.7
30 June	31.8	47.6	93.2	109.3	95.8
06 July	84.6	33.8	177.8	143.1	58.1
13 July	27.2	48.4	205.0	191.5	93.5
20 July	3.8	43.7	208.8	235.2	85.8
28 July	23.4	45.6	232.2	280.8	78.2
05 Aug	53.0	40.3	285.2	321.1	80.5
17 Aug	164.8	45.2	450.0	366.3	4.2
25 Aug	17.4	34.3	467.4	400.6	3.8
04 Sept	49.5	35.7	516.9	436.3	2.3
11 Sept	8.0	25.7	524.9	462.0	4.0

Note: Bromide as NaBr was applied on 15 June 1992 at 200 kg ha^{-1}

from the soil surface and distributed over the upper layers. However, this was not of significant magnitude to reveal a measurable compensation of the downward movement of Br^- in the subsequent sampling days.

The observation made on 17 August (Table 2) was of greater significance in the context of NO_3^- leaching. Excessive rainfall during the first fortnight of August caused a lot of water to infiltrate, resulting into washing down of all Br^- which had previously accumulated in the layer of 0.4–0.6 m depth. Similar observations were also made in the subsequent sampling days. Although there was a dry spell in late August, no Br^- was recovered from the profile, indicating that upward flux of Br^- was absent and Br^- might have moved into much deeper layers. For estimating leaching potential for NO_3^- in this soil, if 0.6 m depth is taken as the reference line, because rooting of crops (eg. sorghum, pearl millet, etc.) is largely limited to 0.5 m depth, then the Br^- not recovered could be taken as leached (Table 2). It is evident from the mass-balance estimates for the Br^- profile to a depth of 0.6 m that potential for Br^- (or NO_3^-) leaching of this soil is very high. Nitrate present in soil can leach down easily as it is not held with any kind of force by the soil. This problem is further accentuated if application of N is followed by heavy rainfall as it was during early July and the first half of August in this experiment. Although the climatic data (Table 2) on total rainfall (525 mm) and total evaporation (462 mm) during the experimental period do not clearly suggest that the climatic potential for leaching of NO_3^- is high in this soil, however, when the total rainfall and total evaporation are calculated on weekly basis, then it can be noticed that there were some crucial periods (e.g. early July and first half of August) during which the soil NO_3^- may move down heavily below the root zone. This study also suggest that measurement of climatic potential on monthly basis as made by Smith and Cassel [14] may not be appropriate for predicting NO_3^- leaching from the soils of this region. Perhaps it will be more realistic if such calculations are made at least on weekly basis, because in the SAT of India rain oftenly comes in heavy storms [7]. As an example, in 1992, the ICRISAT center received 85 mm rainfall on just 2 days (1–2 July). One heavy rain on a reasonably permeable soil can result in very deep movement of NO_3^-. Once NO_3^- moves out of the top 0.6 m, it will continue to move out of the soil even though it may be at a slow rate. Further, the dry crust on the Alfisol retards evaporation and this may again encourage NO_3^- leaching in each time a sizable rain occurs. Under such adverse conditions, it can be expected that the crop will not be able to take up all the NO_3^- that is made available during the wet sea son, and appearance of N deficiency at critical stages of crop growth may also be expected. This could be supported by the authors' visual and tissue test observations from a different experiment at the neighbouring fields on sorghum leaves, during its flowering stage, at the end of August, even in the plots with N application at a rate of 120 kg ha^{-1}.

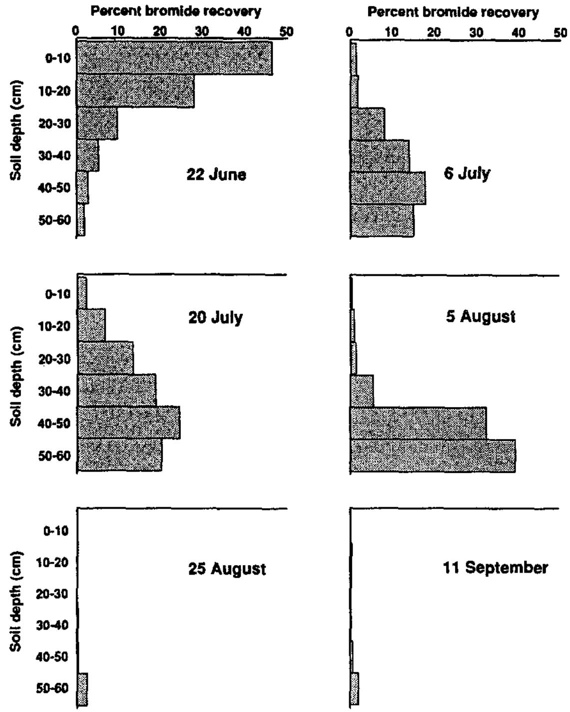

Figure 3. Pattern of bromide distribution in an Alfisol profile (0–0.6 m) on different dates after NaBr application on 15 June 1992

Of course, it should be mentioned here that while this study has demonstrated the high potential of this Alfisol for deep leaching using a mobile tracer Br^-, absorbing ions such as NH_4^+, and urea will undoubtedly move differently through the soil and need to be evaluated. Furthermore, in the absence of root competition for available Br^-, all the readily available Br^- was available for leaching with excess rainfall. Whereas, in an actual field situation with a growing crop, extent of leaching of applied NO_3^- would have been substantially reduced because of plant uptake. However, earlier at ICRISAT center, from a field experiment on a shallow Vertic Ustochrept (mean depth 0.45 m) with sorghum crop, Hong et al [6] have reported N losses as high as 61% of the applied KNO_3 in a less wet year (1984) having a rainfall of 485 mm (June -September), than 1992, with 568 mm rainfall. Although they did not make direct measurements of N losses, however, they explained that such losses were presumably through leaching because of shallow depth of the soil and intense rainfall following fertilizer application.

Thus, it can be concluded from this experiment that leaching of N could be a serious constraint in such a soil if the crop growing season is marked with periods of excessive rainfall. To overcome this problem, adequate attention must be paid while giving fertilizer recommendation. Split application of fertilizer N during the critical stages of the crop, and fertilizer N application by suitable method (e.g. foliar application) immediately after the withdrawal of excessive rainy days may help quick recovery of the crops and better yields. Other practices like early planting, use of deep rooting crops, and temporary immobilization of the NO_3^- in the top soil by crop residues at the beginning of the wet season may be effective to reduce leaching losses considerably. Experiments should be conducted to make a detailed study on this aspect.

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