ISSN 1819-1894

Asian Journal of Agricultural Research

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Asian Journal of Agricultural Research 3 (2): 38-46, 2009
ISSN 1819-1894

Assessment of Nitrogen Accumulation and Movement in Soil Profile under Different Irrigation and Fertilization Regime

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Abstract: Nitrate and ammonium leaching from agricultural soil can represent a substantial loss of fertilizer nitrogen (N), but a large variation in losses has been reported. The objectives of this study were to assess the accumulation of NO_3^--N and NH_4^+-N in the soil profile over a 1-year period under different irrigation and fertilization conditions in sugarcane area of the Khuzestan, Iran. Three irrigation and fertilizer treatments were applied. The first treatment I1 is consisted of full irrigation and others I2 and I3 were 80 and 75% of I1, respectively. N application consist of (N1) 150, (N2) 250 and (N3) 350 kg ha^{-1}. Soil samples were collected from field plots in 0.3 m depth increments to 1.2 m on a periodic basis. NO_3^-N values increased with rise of fertilizer consuming and decreasing of water application. It depended to NH_4^+-N transformation and irrigation regimes. In all treatments, NH_4^+-N decreased from the surface to 120 cm depth. Maximum concentration of NO_3^-N and NH_4^+-N accrued in I3N3 and I2N3 treatments respectively. This study showed that the moisture was the important parameter because nitrification and denitrification dependent on it and had a direct relationship to nitrate and ammonium accumulation in soil profile.

Key words: Deficit irrigation, sugarcane, nitrogen losses, nitrate movement

INTRODUCTION

Nutrient losses and nutrient efficiencies are important issues in agriculture in many regions of the world (Janssen, 1998; Smaling *et al*., 1999; Carberry *et al*., 2002; Mosier *et al*., 2004; Sheldrick *et al*., 2002). Especially the fate of nitrogen has received extensive attention, because of its crucial role in crop production (potentials) and its possible negative environmental impacts (Mosier *et al*., 2004). Currently, global application of N fertilizer is about equally distributed between developed and developing countries. Galloway *et al.* (1995) estimate that global N fertilizer production will increase 60 to 90% by the year 2025 and two-thirds of the total will be applied in the developing world. Understanding N leaching from fertilized agriculture is important for several reasons. First, the largest components of N leachate nitrate (NO_3^-) and nitrite (NO_2^-), can impact human (Mansouri and Lurie, 1993; NRC, 1978) and ruminant health. Second, enhanced N loading can alter nutrient balances and ecological processes in rivers, lakes and estuaries, potentially leading to eutrophication (NRC, 1978), net phytoplankton productivity and increased bottom water hypoxy (Justic *et al*., 1995; Rabalais *et al*., 1996). Third, N leaching can represent a significant

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economic loss to the farmer. Finally, predicting other environmental impacts of agriculture (i.e., N trace-gas effluxes) requires an understanding of the factors which control soil N levels. Baseline concentrations of nitrate in groundwater beneath natural grassland in temperate regions are typically below 2 mg L^{-1} (Foster *et al*., 1982). In urban areas in Vietnam different crop types are subjected to different irrigation and fertilization regimes, or different land units are irrigated from different waste water sources.

One of the loss pathways in the nitrogen cycle is nitrate leaching from the soil. The magnitude of leaching also strongly varies, depending on such factors as soil type, cropping system, weather conditions and fertilizer regime (Di and Cameron, 2002; Hauggaard-Nielsen *et al*., 2003; Verloop *et al*., 2006). High leaching losses from intensive agriculture may cause high nitrate concentrations in groundwater, which potentially carries health risks. Measuring nitrate leaching from agricultural non-point sources is complicated and requires extensive field and laboratory measurements. Liu *et al*. (2003) calculated nitrate-nitrogen loss on the basis of measured nitrate-nitrogen concentrations in the course of time at different soil depths and Chikowo *et al*. (2004) used differences in mineral N concentration at different sampling dates to calculate N leaching per soil layer and for the whole soil profile. Nitrate leaching losses are directly associated with percolation of water and fertilizer application.

Xing and Zhu (2000) showed that in paddy fields in China, total leaching losses ranged from 6.75 to 27.0 kg N/ha/year, while runoff losses were between 2.45 and 19.0 kg/ha/year. Recently, various studies in Asia have shown a positive correlation between fertilizer application rates and NO_3^--N leaching (Kumazawa, 2002; Zhu *et al*., 2003; Hai, 2004). A number of studies quantified NO_3^--N leaching potential under different crops (Robbins and Carter, 1980; Bergstrom, 1987; Owens, 1990; Randall *et al*., 1997). In general, they found the highest nitrate-N levels under maize, intermediate levels under less-fertilized annual crops e.g., soybeans (*Glycine max* L.) and wheat (*Triticum aestivum* L.) and the lowest levels under perennial crops (e.g., alfalfa and grasses). Besides estimates of plant availability, these studies also provide insight into potential environmental losses. Since, urea-to- NH_4^+-N and NH_4^+-N to NO_3^--N transformations may occur within a time period of several days (Kirchmann, 1991), Reviews addressing a range of N leaching issues have also been prepared for developed and temperate agricultural regions (Addiscott *et al*., 1991; Follett, 1989; Ritter, 1989). However, less information is available for tropical, subtropical and developing world agricultural systems. We know nitrogen fertilizer and irrigation affect on concentration of soil nitrate and ammonium accumulation but we want to show how. In this study, we report on seasonal inorganic N accumulation in irrigated sugarcane systems in the south of Khuzestan, Iran. The objective of this experiment was to determine the amount of mineral N, including NO_3^--N and NH_4^+-N, in soil profile with different levels of N and water application.

MATERIALS AND METHODS

This experiment was conducted in 2007 at the research farm of Amir Kabir sugarcane research center that district lies between 31° 15' and 31° 40' N latitude and 48° 12' and 48° 30' E longitude. In growth season the mean of maximum and minimum temperatures were 38.7 and 18.8°C, respectively and the mean rainfall was 36.6 mm in during study time.

Subsamples of the soil samples that taken on 21 May 2007 were air dried and then passed through a 2 mm sieve and analyzed for particle size distribution (Table 1).

The experiments were carried out on 50 m furrows and each experiment included five irrigated furrows with 9.15 m width. The layout of the field plot design consists of 27 plots. The experimental design was a split plot with a randomized complete block arrangement with three replications. Three irrigation regimes were allocated to the main plots and three amount

Table 1: Soil characteristics of the study area for different soil depth increments

	Soild depth (cm)			
Soil characteristics	0-30	30-60	60-90	90-120
Organic matter (%)	0.76	0.31	0.33	0.34
Bulk density (g cm^{-3})	1.41	1.56	1.63	1.62
EC (dS m^{-1})	4.30	2.60	2.20	2.40
Na+ (Meq L^{-1})	5.43	4.07	3.80	2.44
SAR	3.30	2.80	2.50	1.50
pH	7.70	7.90	7.90	7.80
Clay (%)	22.60	33.80	36.80	40.20
Silt (%)	17.80	26.00	30.20	33.00
Sand (%)	59.60	40.20	33.00	26.80

of N to the subplots. Irrigation treatments consisted of full irrigation (I1) that equal to evaporation from a standard US Class A pan and a crop-coefficient curve and other treatments were 80 (I2) and 75 (I3) percent of I1 treatment. Nitrogen fertilizer were applied as granular urea and added with irrigation water. Urea application accrued in the sugarcane third ratoon and consist of (N1) 150, (N2) 250 and (N3) 350 kg ha^{-1}. On 21 May 2007 the first phase of fertilization accrued and 50, 100 and 150 kg fertilizer urea per hectare applied for plots and the second fertilization occurred on 23 June 2007 in 100, 150 and 200 kg ha^{-1} levels for N1, N2 and N3 treatments, respectively. Soil was sampled with augers in 30 m increments to a depth of 120 cm. In each field, soil was sampled in triplicate and the samples bulked for each depth. Sub-samples were taken to the laboratory in polyethylene bags and stored at 4°C prior to extraction, usually within 2 days of collection. Twenty grams of soil were extracted in 100 of 2 M KCl by shaking on a rotary shaker for one hour, followed by filtering through Whatman No.1 filter paper into polyethylene containers. Nitrate nitrogen (NO_3^--N) and ammonium nitrogen (NH_4^+-N) in KCl extracts were determined by the steam distillation method. N was determined by the micro-Kjeldahl method (Bremner, 1996).

Data was statistically analyzed separately for each depth for each treatment for each date and for the total of all depths to 120 cm with regard to NH_4^+-N and NO_3^--N. Data were considered as GLM and analyzed statistically using SAS package

RESULTS AND DISCUSSION

In Fig. 1a-d the effects of treatments on NO_3^--N in the soil layers at different dates is shown. Increasing of NO_3^--N value was shown when the amount of fertilizer increased. A peak level, 18 mg kg^{-1}, accrued in the I3N3 treatment at 30-60 cm depth, was recorded at the 7 July 2007 sampling. With passing time the NO_3^--N concentration in deeper depth increased. At end time, NO_3^--N was low, especially in the top layers, as soil-N was partly taken up by the crop and partly leached to deeper soil layers. Approximately at all sampling dates there was more NO_3^--N in the soil profile of the high N treatments, (N3), compare with the others. Soil N leaching rate was most sensitive to precipitation and fertilizer application rate. This result is basically in agreement with observations reported by other researchers (Bakhsh *et al*., 2000, 2001).

The NH_4^+-N values in soil layers at different dates are shown in Fig. 2a-d. In all treatments decrease in NH_4^+-N from the surface to 120 cm accrued. All NH_4^+-N values, at 0-120 cm depth, were lower than the corresponding NO_3^--N. The ammonium concentration in the soil profile was much lower than that of NO_3^--N. This meant that the differences between the surface and lowest layers were greater than for NO_3^--N. The NH_4^+-N decreased with increasing depth, as it easily nitrified and was converted to nitrate in the

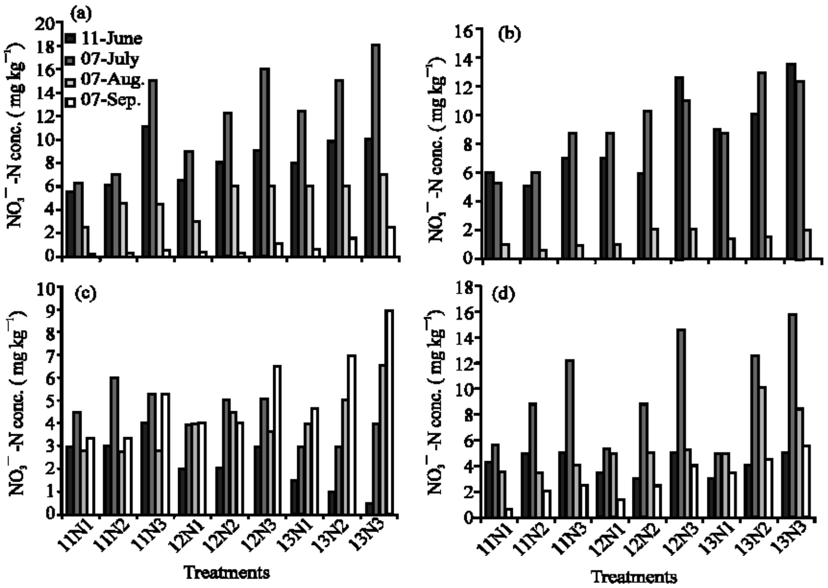

Fig. 1: NO_3^--N concentrations at different soil depths (a) 30-60, (b) 0-30, (c) 90-120 and (d) 60-90 cm for sampling dates

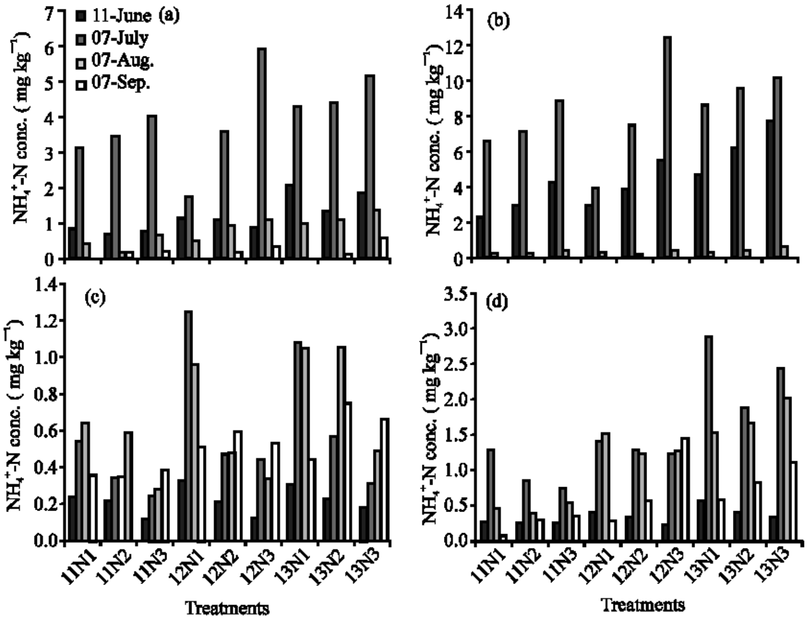

Fig. 2: NH_4^+-N concentrations at different soil depths (a) 30-60, (b) 0-30, (c) 90-120 and (d) 60-90 cm for sampling dates

upper layers. Nitrate, produced through nitrification processes in the upper layers, subsequently moves downward and accumulates in deeper layers (Miller and Gardiner, 2001; Pierzynski *et al*., 2005).

The negative charge on the clay particles retains ammonium ions (NH_4^+-N). Retention of ammonium ions on clay particles protects them (ammonium ions) from leaching. Nitrate ions (NO_3^--N) are negatively charged and are not retained by clay particles. Water does not pass easily through clay soils so nitrates, which only move with water, do not leach to groundwater. Pore space in clay soils is often filled with water. Water-filled pores of clay soils lack oxygen. Lacking oxygen, a group of soil bacteria, called facultative anaerobes, substitute nitrates for oxygen for respiration. When bacteria use nitrates as a substitute for oxygen, they convert nitrates to nitrogen gas through a process called denitrification. More nitrates are lost by denitrification in clay soils. Nitrate losses through denitrification in I1 treatment comparison other irrigation treatments reduced the amount of nitrates that could potentially leach to groundwater. Denitrfication and leaching were the main reasons for low concentration of nitrate in soil profile under I1 treatment. In a study on the fate of N fertilizer applied to a calcareous sandy loam soil in the north China plain (Cai *et al.*, 2002), ammonia volatilization was found an important pathway of N loss, e.g., 30-39% of the applied N in rice, 11-48% in maize and less than 20% in wheat.

This situation may have facilitated the adsorption of NH_4^+-N ions on the clay complex, transport of NH_4^+-N through mass flow was controlled and ammonium leaching and movement to deeper depth had delay.

The influence of subsurface drainage in field experiment helped to improving the soil properties and probably enhanced the urea activity. Also, the pH of soil water solution during the observation period varied between 7.7 and 7.9 which are ideal for the release of NH_4^+-N after the hydrolysis of urea. This led to higher losses of NH_4^+-N. Due to soil salinity in Khuzestan field the exchange complex of the clay was so much saturated with Na^+ ion that it did not allow NH_4^+-N ion to get adsorbed on the clay complex. In the specific situation like this where the exchange complex of the clay is saturated with Na^+ and also the salinity of soil water is relatively high, NH_4^+-N ion may have reminded in diffused layer and moved slowly downward along with continuously percolating water.

Figure 3 and 4 show the NO_3^--N and NH_4^+-N concentration in total depth. These were averaged for overall depths to obtained values for each treatment. In Fig. 3 are shown, I3N3 and I1N1 have a maximum and minimum NO_3^--N concentration. For sampling date on 7 July all treatments had maximum NO_3^--N because the second fertilization accrued on 23 June. With passing the time the nitrate concentration in soil profile decreased and NO_3^--N leached

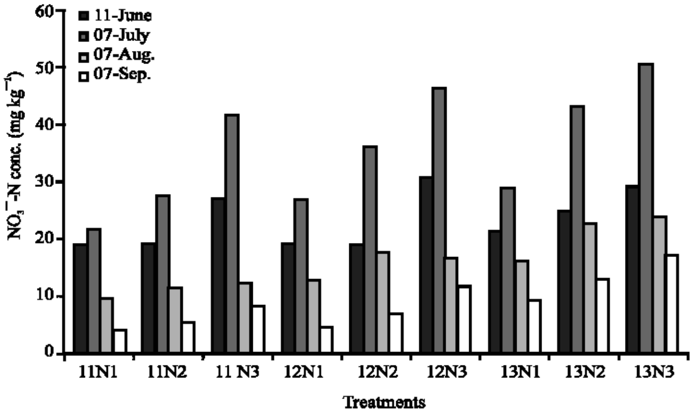

Fig. 3: Total NO_3^--N concentration in 0-120 cm depth in the soil profile

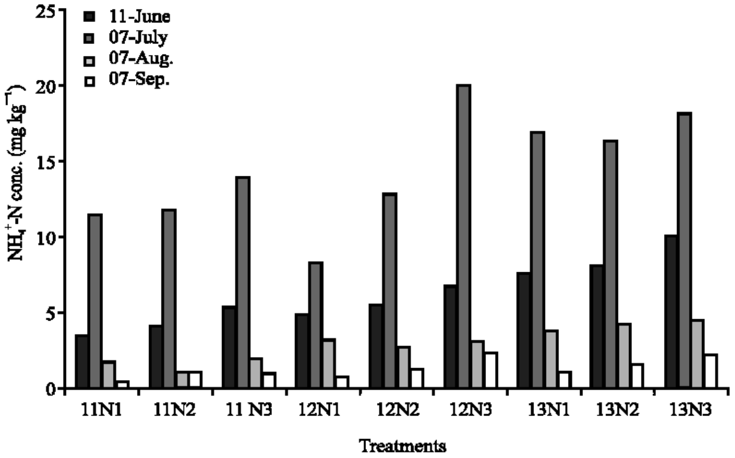

Fig. 4: Total NH_4^+-N concentration in 0-120 cm depth in the soil profile

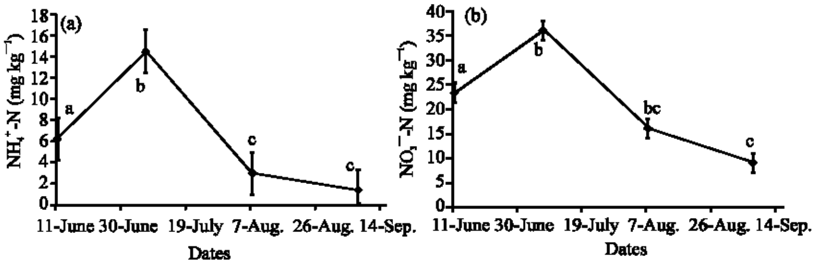

Fig. 5: Means of (a) NH_4^+-N and (b) NO_3^--N accumulation in sampling dates within soil profile (0-120 cm), different letters indicated of significant differently with Duncan's test at 5% level

under root zone, uptake with sugarcane or denitrified. In dry land areas in the US, due to inefficient use or over-application of fertilizer, after harvest up to 90 kg ha^{-1} NO_3^--N had leached below the root zone to between 1.5 and 2.5 m (Fuentes *et al*., 2003). It appears that with increasing amount of N levels, the NO_3^--N concentrations enhanced. Maximum and minimum NH_4^+-N value accrued in I2N3 on 7th July and I1N1 on 7th September. The ammonium concentration in the soil profile was much lower than that of nitrate (Fig. 4). The NH_4^+-N values were lowest in the N1 treatment on all sampling date compare with the other treatments. With the passing the time was seen that NO_3^--N and NH_4^+-N concentration in soil depth decreased, because nitrate is the mobile ion and it leached with irrigation water under root zone and also some of it uptake with sugarcane or denitrified.

Time and N level application affected on NO_3^--N and NH_4^+-N concentration in soil profile. The different between sampling dates was significant during time study, for NO_3^--N and NH_4^+-N concentration in first measurement (11 June) compare with second measurement (7 July) were significant at 5% level, with passing the time in end sampling different was not significant because some of the nitrate and ammonium exited from the soil (Fig. 5a,b).

Figure 6a and b show that different levels of N treatments were the important factor for nitrate and ammonium accumulation in soil profile and the N levels application must be managed because with the increasing of amount of N fertilizer it remained and accumulated in soil and didn't uptake with sugarcane and lost by leaching or denitrification.

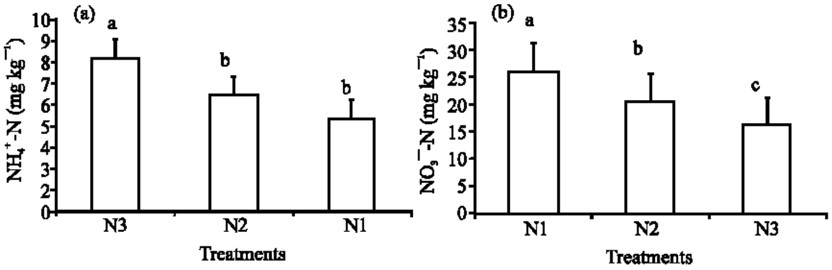

Fig. 6: Means of (a) NH_4^+-N and (b) NO_3^--N accumulation in different N treatments during study period within soil profile (0-120 cm), Different letters indicated of significant differently with Duncan's test at 5% level

CONCLUSION

Land use appeared the most influential factor for the spatial distribution of N concentrations, because it determines the water balance components, such as runoff, evapotranspiration and percolation. The fertilizer and irrigation regimes, in interaction with crop growth, also strongly affected the magnitude of N leaching and, thus, N concentrations in groundwater. Concentrations of NH_4^+-N were low but NO_3^--N were relatively high, associated with favorable conditions for nitrification and the relatively high mobility of the ion.

The results of this fertilizer study indicated that the environmental loss potential of N is strongly influenced by amount of fertilizer and water application and timing. The associated processes are quite complex, but management guidelines can be established to help reduce N-leaching risk. The method aims at determining uncertainty in other areas, where the determining factors are strongly influenced by environmental conditions and management. Moreover we can use models usually take into account dynamic processes, such as crop growth with actual transpiration and nutrient uptake, nitrogen application and its transformation in soil and water.

It concluded that improvements in farm management are required to lower the accumulation of nitrate in soils and groundwater while maintaining or improving agricultural productivity. The key factor behind N overuse is that the majority of farmers do not take account of N inputs from manure and irrigation water when they decide how much fertilizer N to apply and extension workers do not recommend that they should make such adjustments.

This should be achieved by long term studies to determine more accurately crop N requirements and by enhancing the local extension service to persuade farmers to minimize environmental degradation while maintaining high crop yields. Continued research is needed to assess more factors influencing the potential for NO_3^--N leaching in soils under deficit irrigation in production agriculture and to improved irrigation scheduling techniques.

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