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Study on Vertical and Lateral Leaching of Nitrate from a Wheat Field in China

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Abstract: Vertical and lateral leaching of nitrate from a wheat field was studied through one season in a field in China by applying increasing amount of N fertilizers (e.g. 90, 180, 270 and 360 kg ha^{-1}). Results showed that nitrate leaching was the dominating way of nitrate loss from wheat land during the first two month after sowing seeds. After irrigation, the nitrate concentration in the leachate of 30 cm soil layer was higher than that of 60 cm, while the concentration of nitrate leaching at the five N treatments through the two depth soil layer came into the same level with the value of 13.48 mg l^{-1} to 27.91 mg l^{-1} for 30 cm soil layer and 16.48 mg l^{-1} to 28.65 mg l^{-1} for 60 cm soil layer, respectively. As the plot scale (20 m^2) concerned, the amount of nitrate loss varied from 101.13 mg l^{-1} to 209.35 mg l^{-1} for 30 cm and from 123.63 mg l^{-1} to 214.89 mg l^{-1} for 60 cm. Peak nitrate concentration was 3.47 mg l^{-1} during the third rainfall event. However, nitrate losing by lateral leaching in subsoil was less than that by vertical leaching. At the position that has 0.5 m distances from one side of each plot, the highest nitrate concentrations in lateral leachate among the plots was 10.75 mg l^{-1} and only has 13.43 mg l^{-1} the highest lose amount value. By comparison of nitrate concentration in two position of 0.5 m and 1.5 m from one side of each plot, it was not easy for nitrate that transported by lateral leaching from wheat land, in that, nitrate horizontal movement potential in shallow subsoil could be negative. Based on these results, it was suggested that the nitrate vertical leaching had a greater pollution potential to water body than the lateral leaching during the wheat growth period in the fields.

Key Words: Wheat field, nitrate, vertical leaching, lateral leaching, horizontal movement potential, China.

Introduction

Wheat is mostly grown under dry land conditions; therefore, its growth, development and yield depend mainly on available water and fertilizer (Halitligil et al., 2000). Plant nitrogen (N) status is highly dependent on the level of nitrogen fertilization (Hernandez et al., 1974). Crops with high water and nitrogen requirements tend to increase the potential risk of nitrate pollution to groundwater (Fox et al., 2001; Randall and Mulla, 2001). Wheat is a type of shallow-rooted crop and the domain root zone was 20 cm below the soil surface, which can lead to considerable nitrate loss by leaching under irrigated or high rainfall conditions (Ren et al., 2003; Yu et al., 2003). Increasing fertilizer N inputs to agricultural land beyond crop needs results in gaseous and leaching loss and/or an enhanced N input by runoff to surface water (Spalding and Exner, 1993; Xing and Zhu, 2000). As the nation with the largest agricultural production, China consumed 23 million tons of fertilizer N in 2000 (MOA, 2001), accounting for about 28% of total world N consumption (Fixen and West, 2002). Nitrogen losses through leaching vary across a field due to differences in soil physical properties and N statues of soil. Amounts of nitrate leaching from soil may be decreased by site-specific application of N fertilizers. However, to precisely vary N fertilizer applications requires knowledge on variability in the parameters that control N availability (Blackmore, 1994; Delcourt et al., 1996; Earl et al., 1996). Many field experiments have been carried out to study N fertilization in wheat and to assess the efficiency of the different forms of N supply. Fertilizer uptake by the crop can be estimated with unlabeled fertilizer, but to measure the recovery of fertilizer N in the soil and the N loss, a labeled fertilizer has to be used. Environmental factors influence plant growth, N uptake and N losses. Many researches have been carried out to study N fertilization in wheat and to assess the efficiency of the different forms of N supply

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(Cassman et al., 2002; Yadav, 2004). However, there was a lack of in situ integrated studies on vertical and lateral leaching for N loss pathways under high fertilizer N inputs in winter wheat crops. So that, integrated research is essential to understand N behavior and balance in specific soil-crop systems. Our aims were to measure: (1) the overall N leached from irrigation and natural rainfall condition, (2) the timing and magnitude of peak nitrate concentrations and (3) the interaction of nitrate concentration at 30 and 60 cm depth and rate of fertilizer N application on vertical and lateral leaching loss of nitrogen.

Materials and methods

Site description

The experimental site was located at the Shuang Qiao farm of Jiaxing city through which the Great Canal flowed and had each 100 km distance from Shanghai and Hangzhou city of China. The annual precipitation of the site was 1205.5 mm of which about 400 mm occurred during the wheat growing period. According to USDA, the experimental field soil is red loam or krosnozem that comprises 21.12% sand, 35.24% silt and 43.64% clay. The soil in the plot trail contains 0.05% total N, 0.03% total P, 1.2-1.4% organic matter. Also, the soil was coastal saline with medium fertility that had pH 6.78, total N 2.747 g kg^{-1}, Cation Exchange Capacity 15.6, Permeability 180 m h^{-1} and P 70.23 mg kg^{-1} respectively.

Plot design

Forty-five individual plots separated by ridges of a field were build in a grid. Each plot was at 4×5 m in size and infiltration-proof nylon was inserted into the soil to 40 cm depth at the three edges of the plots to isolate the soil water lateral movement and left one edge open to measure the nitrate loss by soil water lateral movement. Each plot had its independent irrigation branch controlled by the hydrant and one 20 cm diameter PVC pipe was lying in the center of field as the main irrigation supported system.

In the center of each plot, two-soil solution in situ samplers was put into the 30 and 60 cm soil depth to collect nitrate leachate from the upper soil. Specific-designed containers (as described in Leachate collection section) were vertically inserted into the 40 cm subsoil at the position of 0.5 and 1.5 m apart from the open side of each plot.

Fertilizer and water source

Urea was applied as N fertilizer and 40 kg ha^{-1} P_2O_5 was added in the form of single super phosphate as a P fertilizer. Application of 180 kg N ha^{-1} as urea was the typical N application rate (TNAR) in the region. There were five treatments: (1) N_0, no N application (control); (2) N_1, 90 kg N ha^{-1} as urea (the 50 percent of the TNAR); (3) N_2, 180 kg N ha^{-1} (the TNAR); (4) N_3, 270 kg N ha^{-1} (1.5 fold of the TNAR) and (5) N_4, 360 kg N ha^{-1} (double the TNAR).

During the experiment period, the soil was irrigated once and three natural rainfalls occurred. The soil was irrigated after planting of wheat seeds and fertilization. Three natural rainfals occurred on Dec. 14th (2003), Jan. 2nd and Jan.11th. The third was the longest, continuing for up to 5 days. The sampling time, rainfall amount, mean leachate amount and nitrate concentration after the irrigation and each rainfall are given in Table 1.

Five rainwater collectors were placed randomly in the large wheat field to collect water and determine available nitrate concentration in the rainwater. Nitrate concentration of irrigation water and rain water varied significantly in each sampling period. Average nitrate concentration in collected water after irrigation, first rain, second rain and third rain were 2.18, 1.66, 2.09 and 3.47 mg l^{-1} respectively. Maximum leaching (100 ml) happened at the time of irrigation. Also, amount of leaching varied with rainfall amount. Leaching amounts were 39, 48 and 60 ml for each 27, 31 and 45-50 mm rainfall, respectively.

Leachate collection

According to the investigation of the local ground water table (about 50 cm to 70 cm depth), a series of small lysimeters were installed in 2003 at both 0.30 m and 0.60 m below the soil surface in the vertical leachate collection for the N_0, N_1, N_2, N_3 and N_4 treatments six months before wheat seed planting. Figure 1 shows the schematics of the in situ lysimeter. There were three 8 cm deep layers one by one inside the samplers with pebble layer at the bottom, granular sand in the middle and quartz sand layer overlaying. Besides, one piece of 40

Table 1. Irrigation and rainfall situation.

Water source	Irrigation or rainfall		Sampling date	Nitrate conc. (mg l^{-1})	Mean leaching amount (ml)
	Period	Rainfall			
Irrigation	-	-	Dec.4th, 2003	2.18 ± 0.24	100
The first rain	Dec.13th-14th	31 mm	Dec.14th, 2003	1.66 ± 0.20	48
The second rain	Jan.1st - 2nd	27 mm	Jan.2nd, 2004	2.09 ± 0.38	39
The third rain	Jan.11th -15th	45-50 mm	Jan.15th, 2004	3.47 ± 0.06	60

× 40 cm fiber cloth was fixed in the surface of the lysimeter to prevent large soil particles entering the lysimeter. At the bottom of the lysimeter, some space was left to store the leachate.

Another kind of sampler was also specially designed to collect nitrate lateral leachate in the horizontal direction as shown in Figure 1. These samplers were vertically inserted into the 40 cm depth subsoil with an effective section area of 0.12 m^2 (0.3 m height × 0.4 m width) for 10 cm at the bottom was left to store the leachate. Additionally, fifty 20 mm-diameter holes were drilled and laid randomly at the vertical section face. One 40 × 40 fiber cloth was fixed inside at the section face. In this experiment, two positions 0.5 m and 1.5 m apart from the open side of the field plot were selected to put these samplers in in situ.

Sampling

Water samples, which were corrected both from runoff and water lateral seepage in subsoil, were placed in plastic vials. In all samples, determination of nitrate was conducted in the field or immediately upon return to the laboratory and were stored at 4 °C or frozen until analyzed. Samples were shaken, filtered through Whatman No. 1 paper to remove particulate matter and split into separate vials immediately before analysis.

Nitrate analyze

Standards of NO_3^- -N concentrations ranging from 0.1 to 3.0 mg l^{-1} were prepared by dilution from a 1000 mg l^{-1} solution of NO_3^-. Standards and samples were measured for NO_3^- by using at 224 nm UV/VIS 1206 spectrophotometer interfaced to a microcomputer, with ultrapure water used as a blank in the spectrophotometer reference cell (De Vos et al., 2000). A standard curve was developed by linear regression of the second derivative peak vs. concentration of the standards. The standard curve was then used to quantify all samples. This method allows analysis of N concentrations up to 3 mg l^{-1} without

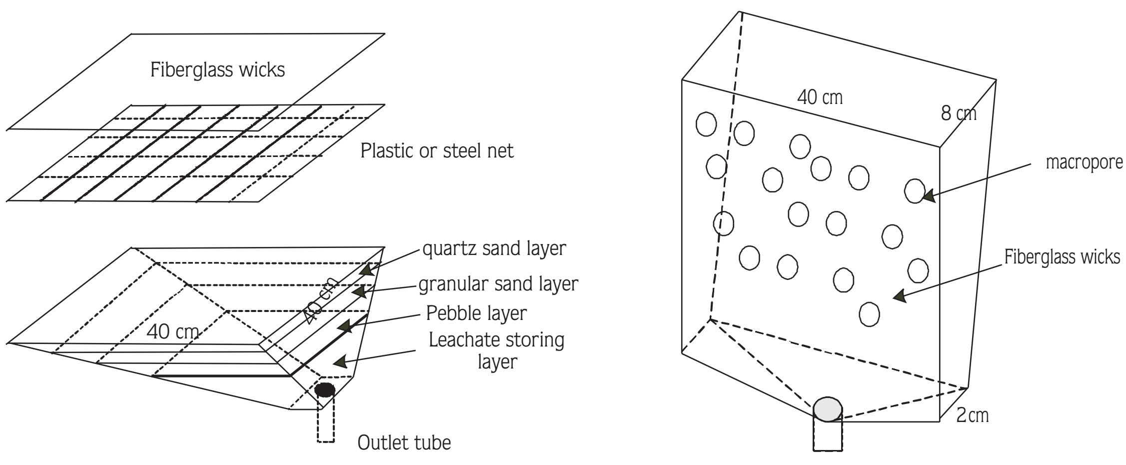

Figure 1. Section schematics of the leachate sampler and lateral seepage collector.

dilution, as the N curve is nonlinear beyond this range. Samples containing more than 3 mg N l^{-1} were diluted to a concentration within the linear range.

Data analysis

The experiment was a randomized split-block design with three replications for each treatment. SPSS (V.10 for Windows), Microcal Origin 6.0 and Abode Photoshop 7.0 programs were used in this paper for data analysis, graph preparation and drawing picture.

Results and Discussion

Nitrate leaching analyses in the wheat-growth season through 30 cm and 60 cm soil layers

Amount of nitrate concentration for different nitrogen treatment during irrigation period at 4th December 2003 in 30 and 60 cm layer of the wheat field was described in Figure 2-a. Nitrate concentration was always higher in 30 cm layer at all treatments (N_1-N_4) except control (N_0) treatment with little variation. Nitrate concentrations for 0 and 90 kg ha^{-1} were below the Chinese allowable level of drinking water (10 mg l^{-1}) both at 30 and 60 cm soil layer. Concentrations of nitrate were low in all treatments at 60 cm depth of soil layer except N_4 treatments. But for the N treatments of 180 and 270 kg ha^{-1}, nitrate concentrations exceeded the level of drinking water at 30 cm of soil layer, and also for 360 kg N ha^{-1} treatment nitrate concentration exceeded allowable level in both layers.

Figure 2-b visualizes nitrate concentration for different nitrogen treatments during the first rainfall period in 14th December at 30 and 60 cm soil layer of the wheat field. In this figure, it was observed that nitrate concentration was higher (22.5 mg l^{-1}) in 30 cm depth of soil of the control treatment. The high nitrate concentration was probably a result of large applications of nitrogen fertilizer in the part of the field previously. In all treatments, nitrate concentrations were above permissible level except 360 kg ha^{-1} treatments for 60 cm layer of soil. Amount of nitrate concentration for 60 cm soil layer was lower as compared to 30 cm soil layer. But for the N treatments of 90 kg ha^{-1} nitrate concentration was higher in 60 cm soil layer as compared to 30 cm soil layer. As shown in Figure 2-a and 2-b, nitrate concentration was higher in less soil depth and lower in more soil depth. The same result was observed in other studies showing that NO^{-}_3-N increased from 1.5 to 2.5 m, and decreased from 2.5 to 5 m in the soil profile (Zhu et al., 2003).

Soil water nitrate concentrations differed significantly as a result of various nitrogen treatments for 60 cm during second rainfall (2nd January'2004) (Figure 2-c). Data are not shown for 90 kg ha^{-1} and 180 kg ha^{-1} treatments in 30 cm of soil layer due to faulty collection. From the existing data, the nitrate concentration found was below the limit given in China for drinking water at 60 cm depth in control and 90 kg ha^{-1} treatments, but was above the limits for other treatments.

Nitrate concentrations at 30 and 60 cm depth showed distinct peaks in all nitrogen treatments at the third rainfall period (15th January 2004) (Figure 2-d). The change in nitrate concentration at both 30 and 60 cm layer was less pronounced on this rainfall period. The nitrate concentrations found at 30 and 60 cm soil depth were much higher than the limits given by both China (10 mg NO_3-N l^{-1}) and WHO (11.3 mg NO_3-N l^{-1}) for drinking water. The increase in nitrate concentration at a soil depth of 30 and 60 cm was much greater in the third rainfall period, indicating a relatively a pronounced movement of nitrate concentration in the soil profile due to excess rainfall.

Our results suggest that loading of nitrate was related to irrigation, natural rainfall and fertilizer application. From Figures 2a-d, it is clearly shown that vertical leaching of nitrate concentration varied with respect to nitrogen treatment, irrigation and non-uniformly natural rainfall at 30 and 60 cm soil layer. Plants absorb only about 50% of the N applied to the soil and then a large amount of N is lost through leaching (Craswell and Godwin, 1984). Kengi et al. (1994) indicated also substantial endogenous variability of nitrogen loss by leaching occurred through irrigation and fertilizer application. These authors, however, reported higher actual variation in the treatments in which N fertilization was coupled with non-uniform irrigation water distribution. Soil physical and chemical properties and weather can also affect nitrogen leaching. Nitrogen losses through leaching vary across a field due to differences in crop types, soil physical properties, fertilizer rate, weather conditions and so on (Drury et al., 2001; Kuo et al., 2001; Gasser et al., 2003).

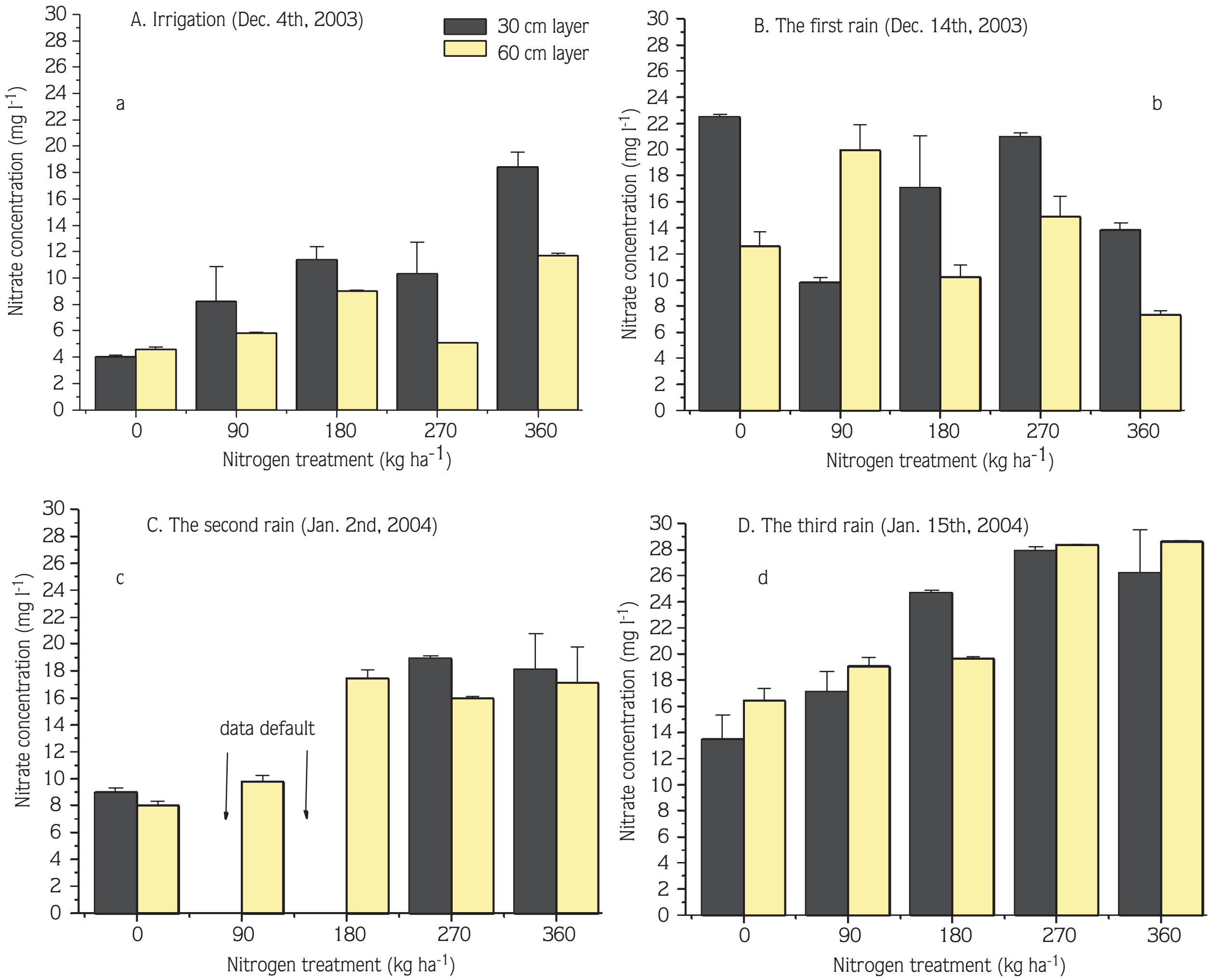

Figure 2a-d. Nitrate concentration for different nitrogen treatments in 30 cm and 60 cm soil layer percolate under irrigation or rainfall condition.

Nitrate loss potential in wheat land

Nitrate leaching in both vertical and lateral direction for the different nitrogen treatments in 30 and 60 cm layer of soil at irrigated and rain fed condition is described in Table 2. Vertical leaching amount of nitrate increased linearly with respect to nitrogen fertilizer treatments at 30 cm depth of soil during irrigation. For the first rainfall period, much greater vertical nitrate leaching was observed in the control treatment at 30 cm soil layer, probably by limiting the movement of water and nitrate in the soil profile. Vertical leaching amounts for the treatments of 90, 180, 270 and 360 kg ha^{-1} were 58.87, 102.49, 125.73 and 83.11 mg l^{-1}, respectively. Tenure of the second rainfall in 30 cm depth of soil data were not collected due to default data in the 90 and 180 kg ha^{-1} treatments. Among the other treatments, maximum nitrate leaching amount was 92.38 mg l^{-1} for 270 kg ha^{-1}, and the minimum nitrate-leaching amount was 43.95 mg l^{-1} for the control treatment. During the third rainfall period, the amount of nitrate leaching was higher at the 90, 180 and 270 kg ha^{-1} treatments as compared to irrigation, first and second rainfall. From Table 2, it was clearly shown that in both of 30 and 60 cm depth of soil layer at the third rainfall period, nitrate-leaching amount increased in all the treatments as compared to other irrigation and rainfall periods. However, surprisingly, nitrate lateral leaching did not increase progressively with the increase in the rate of fertilizer application. The lateral nitrate leaching was 5.79 mg l^{-1} at the beginning of the experiment in the control plot. Also, for the 90,

Table 2. Nitrate leaching (vertically and horizontally) in wheat field.

Fertilizer application kg ha^{-1}	Nitrate vertical leaching (mg)								Nitrate lateral leaching	
	I (30 cm)	F (30 cm)	S (30 cm)	T (30 cm)	I (60 cm)	F (60 cm)	S (60 cm)	T (60 cm)	Amount (mgl^{-1})	Movement Potential (mgm^{-4})
0	50.13	134.74	43.95	101.13	57.12	75.39	43.95	123.63	5.79	1.22×10^{-3}
90	102.62	58.87	-	128.24	72.60	119.54	47.84	143.24	8.97	3.24×10^{-3}
180	142.23	102.49	-	185.17	112.47	61.49	85.27	147.31	5.06	-1.5×10^{-4}
270	129.00	125.73	92.38	209.35	63.57	89.17	77.88	212.39	13.43	7.58×10^{-3}
360	230.28	83.11	88.43	196.71	146.37	43.88	88.43	214.89	4.92	-1.06×10^{-3}

Note: I=irrigation; F= the first rain; S=the second rain; T= the third rain.

180, 270 and 360 kg ha^{-1} treatments nitrate lateral leaching amounts were 8.79, 5.06, 13.43 and 4.92 mg l^{-1}, respectively. At the last stage of the field experiment i.e. after the third rainfall, the nitrate lateral leaching was not influenced by N treatments. The potential of the nitrate lateral movement was greater (7.58×10^{-3}) in the treatment of 270 kg ha^{-1} among all treatments. Indeed, Table 2 showed that vertical and lateral leaching of N losses during winter was less in wheat growing period and were closely related to the nitrate concentration. Aggarwal et al. (1998) observed similar findings and reported that nitrogen-leaching losses were dominated by the amount of NO_3 -N concentration. The loss of nitrogen through leaching during the crop growth period may not be very high as it is considered negligible in wheat crops. In this experiment, nitrification and soil moisture diffusion phenomena were not discussed due to variation and uncertainty. Nitrification losses were negligible in winter wheat and variable under different N rates. This variation is thought to be mainly due to the change in rainfall at the experimental site (Chen et al., 2000). Similarly, losses by nitrification may also have occurred during temporary periods of oxygen deficiency in the micro sites when the soils were very wet (Sanchez et al., 2001).

Conclusions

Nitrate vertical and lateral leaching in unsaturated zone of wheat land, which was triggered by irrigation or natural rainfall, was studied by one season field experiment with five nitrogen fertilization treatments. Results showed that nitrate vertical leaching was the dominating way of nitrate loss from the wheat field tested during about two months after planting seeds. Vertical leachate NO_3-N concentration increased with increasing N fertilizer rates and exceeded the Chinese limits for the drinking water standard of 10 mg N l^{-1}, even in the case of the recommended N rates for wheat in this region. In this study, irrigation and rainfall promoted the downward movement of NO_3-N in the soil profile. As seen from the experiment, each irrigation event caused a rapid decline in NO_3-N in the topsoil and increase in the sub soil. Results also showed that NO_3 concentrations in the irrigation water and rainwater were much lower than those in the ground water samples taken from depths of 30 and 60 cm. The results of this experiment are important due to determining the nitrate lateral leaching from wheat field for a variable nitrogen fertilizer application program based on the NO_3 lateral leaching movement potential. Our results, however, suggest that lateral and vertical leaching of nitrate was related to the irrigation, rainfall and fertilizer application. So, it was clearly indicated that the accumulation of nitrate concentration in the subsoil and leaching of NO_3-N to the groundwater affects the drinking water quality at northern regions of China. Also, nitrate nitrogen concentration varied with the different treatments of nitrogen application and differ each other following the growth of wheat plant. Nitrate leaching through vertical and lateral movement was different in concentration and amount at the wheat field. Further studies would be needed to trace the fate of the NO_3-N concentration from wheat field that was accumulated in the subsoil for other part of the world.

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