

Soil-pit Method for Distribution and Leaching Loss of Nitrogen in Winter Wheat's Soil, Weishan Irrigation District

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Abstract. Unreasonable application of irrigation and fertilizer will cause the waste of water and nitrogen and environmental pollution. In this paper, a series of soil-pit experiments were carried out to study the distribution and leaching loss of nitrogen in winter wheat's soil. The results showed that NO_3^- concentration at 20-80cm depth mainly responded to fertilizer application at the beginning of field experiment, but the amount of irrigation became the dominant factor with the growth of winter wheat. It is noteworthy that the distribution of NO_3^- was mainly affected by the amount of fertilizer applied at the depth of 120-160cm in the whole period of growth of winter wheat. The accumulation position of NH_4^+ was deepened as the amount of irrigation increased, however, the maximum aggregation depth of ammonium nitrogen was no more than 80cm owing to its poor migration. It can be concluded that the influence of irrigation amount on the concentration of NH_4^+ in soil solution was more obvious than that of fertilizer. Compared with fertilizer, the amount of irrigation played a leading role in the utilization ratio of nitrogen and the yield of winter wheat. In summary, the best water and fertilizer treatment occurred in No.3 soil-pit, which meant that the middle amount of water and fertilizer could get higher wheat yield and less nitrogen leaching losses in the study area.

1. Introduction

Chemical fertilizer application is the main measure of increasing grain output to ensure food security in China. At the same time, the heavy application of chemical fertilizer has a great influence on the stability of agricultural ecosystem [1], which, however, has limited recovery ability, so overuse of chemical fertilizer will result in a series of environmental problems, such as groundwater pollution, river pollution, and damage the local ecological system [2].

In recent years, fertilizer application has been increasing continuously in China, with lower utilization efficiency than that of western developed countries. According to the data, the amount of fertilizer used by agriculture accounted for about 40% of the total amount of fertilizer in the world, in 2011 [3]. Moreover, International Fertilizer Industry Association data showed that the amounts of chemical fertilizer application in China will keep increasing [4]. In recent years, fertilizer application growth rate reached to 3%, while utilization ratio is 30%~40% in China, which, however, is 50%~60% in developed countries [5].



The amount of fertilizer application per unit area was 460kg/hm² in China, 3.7 times more than that of the world average [6], with an average annual growth rate of 5.49%, which exceeds the maximum amount of fertilizer application in agriculture.

Water and nitrogen are two essential factors of the growth of winter wheat. The unscientific use of water and nitrogen will cause the waste of water and nitrogen and environmental pollution. A large amount of chemical nitrogen fertilizer was applied in order to increase crop yield. However, the utilization ratio of chemical nitrogen fertilizer was less than 50%, and improper application of nitrogen fertilizer will cause nitrogen loss as high as 89% [7]. For most agro-ecosystems, under normal circumstances, the ways for the loss of chemical nitrogen fertilizer are leaching loss, erosion, surface runoff and gas volatilization and so on. Excessive fertilization will not only reduce the efficiency of nitrogen fertilizer application, but also cause a large number of nitrogen leaching and environmental pollution. Excessive irrigation can leach the nitrate to below the root of the plant, making it difficult to be recycled by crops, and then continue leaching into deeper soil layer, resulting in waste of water and fertilizer and environmental pollution [8], which is the most important reason for nitrogen leaching.

NH₄⁺ and NO₃⁻ are major plant available forms of N in soil. Owing to its positive charge, NH₄⁺ has very poor mobility and is so easily absorbed by soil colloids that few is displaced into soil solution. On the other hand, NO₃⁻ movement in soil profile is six times higher than NH₄⁺ with flowing water and is therefore prone to leaching loss. Duan believed that the runoff loss of nitrate nitrogen accounts for about 80%-90% of total nitrogen runoff loss, and about 0.5%-1% of ammonium nitrogen [9], Zhang's study showed that nitrate nitrogen leakage loss, total nitrogen leakage loss about 30%-40%, ammonium nitrogen accounted for about 2%-7% [10].

In this paper, the soil-pit experiments were conducted to study the nitrogen accumulation and distribution characteristics of soil profile and its leaching rule during winter wheat growing season in the Weishan Irrigation District. Focused on the analysis of the concentration changes of nitrogen on wheat in soil solution, leaching characteristics of nitrogen and nitrogen distribution in Wheat Soil of different depth were discussed, which can provide scientific basis for the reasonable use of nitrogen fertilizer and the prevention of nitrogen pollution to the environment.

2. Materials and methods

2.1. Test facilities and materials

The experimental field is located in Dong'e County of Weishan Irrigation District, Shandong, and the test time was a growth period of winter wheat in 2015. The agriculture in the experimental area is mainly irrigated by Yellow River. The crops are mainly planted with summer corn and winter wheat, with economic crops such as vegetable greenhouses, cotton. The soil is dominated by alluvium, which is clayey sand, sandy loam and clay. The depth of groundwater is about 1~3m, recharged mainly rainfall infiltration. Groundwater is dominated by type HCO₃⁻-SO₄²⁻. The experimental area is a typical semi-arid and semi humid climate. The average annual rainfall was 566.7mm, and the total rainfall is 492.4mm during the test period.

There are six soil-pits in the experimental field, as shown in Figure 1. Each soil-pit specification is 4m×4m, isolated with dividing walls of cement down to a depth of 2 m in order to avoid horizontal leaching, as shown in figure 1. Each soil-pit has an outlet for the collection of runoff. In order to measure the nitrogen content of soil solution in different depth soil, each measuring pit is embedded with clay head at the depth of 20cm, 40cm, 80cm, 120cm and 160cm. In addition, 160cm polyethylene pipes were embedded in each soil-pit to determine soil moisture content.

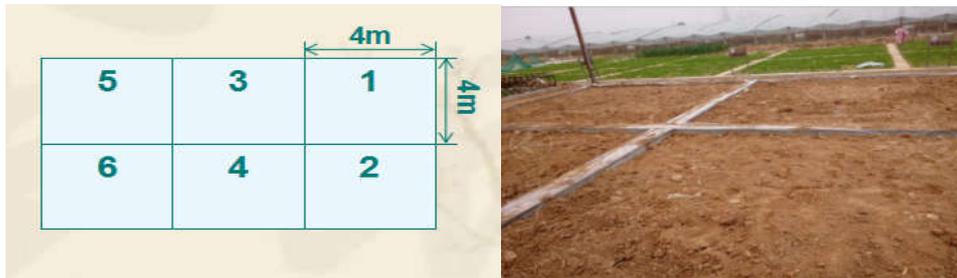


Figure 1. Design of Soil-pit

2.2. Fertilization and irrigation schemes

This study adapted the experimental data of winter wheat growth period in 2015, and the type of winter wheat is Ludan 981. N-P₂O₅-K₂O compound fertilizer was used as base fertilizer, with the amount of 630kg/hm²; Additional fertilizer, urea, was used at turning green stage of winter wheat according to two topdressing schemes with conventional fertilization of 225kg/hm² in soil-pit of NO.1, NO.3 and NO.5 while low fertilization of 141kg/hm² in soil-pit of NO.2, NO.4 and NO.6. 50% of nitrogenous fertilizer was used at the bottom as base fertilizer and 50% used as furrow application in the jointing stage. Winter wheat was irrigated at the following four stages overwintering stage, turning green-elongation stage, heading stage, and grain filling stage. The irrigation water had the same amount of 675m³/hm² in six soil-pits at overwintering stage, while three design levels at other three stages: soil- pit of NO.1 and NO.2 with 810 m³/hm², soil-pit of NO.3and NO.4 675 m³/hm², soil-pit of NO.5 and NO.6 540 m³/hm², as shown in Table 1.

Table 1. Fertilization and Irrigation Plan of Winter Wheat

Treatment Scheme	Amounts of Fertilizer Inputs kg/hm ²			Amounts of Irrigation (m ³ /hm ²)			
	N	P ₂ O ₅	K ₂ O	Overwintering Water	Turning Green to Elongation Water	Heading Water	grain filling Water
1	197	94	94	675	810	810	810
2	158	94	94	675	810	810	810
3	197	94	94	675	675	675	675
4	158	94	94	675	675	675	675
5	197	94	94	675	540	540	540
6	158	94	94	675	540	540	540

2.3. Determination items and methods of analysis

2.3.1. Determination of nitrogen in soil solution, the concentration of ammonia nitrogen, nitrate and nitrogen in soil solution, seepage solution and runoff fluid in different soil layers of wheat field were determined to analyze the distribution and leaching characteristics of nitrogen in winter wheat under different irrigation scenarios.

Before the experiment, soil samples of 0-20cm soil layer were collected to determine the background fertility of the soil in the experimental field. Then soil samples in 0-20cm, 20-40cm, 40-60 cm, 60-80 cm and 80-100 cm soil layers were respectively collected in the six soil-pits, and background values of soil N content in different depth were determined.

After laying the polyethylene plastic pipes at each soil-pit and before the experiment, soil samples were collected at 0-20 cm, 20-40 cm, 40-80 cm, 80-120 cm and 120-160 cm deep soil layer for measuring the background concentration of nitrogen content, referred to as interflow concentration.

At the beginning of the experiment, soil solution was sampled before and after water and fertilizer application. When rainfall in the study area was formed runoff, runoff water was collected at each of the soil-pit runoff collection ports and was taken back to the laboratory for determination.

The total nitrogen, nitrate nitrogen and ammonium nitrogen were determined by ultraviolet spectrophotometry method.

2.3.2. Data processing, (1) Calculation of nitrogen utilization ratio

The formula to calculate nitrogen utilization ratio as follows:

$$M_N = (A \times a + B \times b) / A \times 100 \quad (1)$$

$$N_1 = A \times M_N / 100 \quad (2)$$

$$P = (N_1 - N_0) / N_2 \times 100 \quad (3)$$

Where: M_N —The amount of N absorbed by crops for 100 kg economic yield, kg;

A —Grain yield of crops, kg/hm²;

a —Grain N content, %;

B —Stem and leaf yield of crops, kg/hm²;

b —Stem and leaf N content, %;

N_0 —Nitrogen uptake by blank test crops, kg/hm²;

N_1 —Total amount of nitrogen in soil, kg/hm²;

N_2 —Total amount of nitrogen fertilizer in test-pit, kg/hm²;

P —Nitrogen use efficiency, %.

(2) Calculation of nitrogen loss

$$C_1 = (\sum C_{12} \times V) \times 625 \quad (4)$$

$$C_2 = (\sum C_{22} \times V) \times 625 \quad (5)$$

$$C_3 = (\sum C_{32} \times V) \times 625 \quad (6)$$

Where: C_1 —Total nitrogen concentration of runoff, mg/hm²;

C_{12} —Total nitrogen concentration of water sample, mg/L;

C_2 —Nitrate nitrogen concentration of runoff, mg/hm²;

C_{22} —Nitrate nitrogen concentration of water sample, mg/L;

C_3 —Ammonium nitrogen concentration of runoff, mg/hm²;

C_{32} —Ammonium nitrogen concentration of water sample, mg/L;

V —Water sample volume, L.

(3) Nitrogen leaching characteristics analysis

Nitrogen leaching is likely to happen when excessive irrigation makes nitrate nitrogen leaching below plant roots, and makes it difficult to be recycled for crops, eventually to deeper soil and leading to groundwater pollution. The amount of nitrogen leaching is the nitrogen that cannot be used by crops. According to the leaching characteristics of nitrogen in the soil of winter wheat, the nitrogen in the soil solution at 1.6 meters is no longer available to wheat, so it can be used as a characteristic analysis of the amount of nitrogen leaching.

3. Results and analysis

3.1. Content distribution characteristics of nitrogen in soil

(1) Distribution of nitrate nitrogen concentration in soil solution

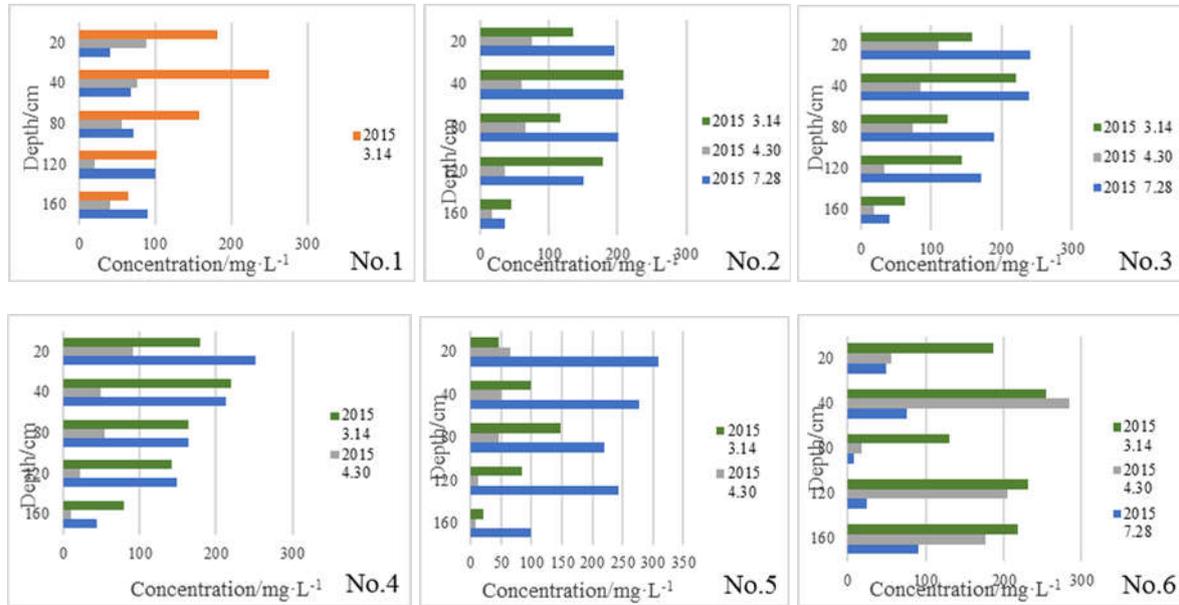


Figure 2. Nitrate Nitrogen Concentration Distribution Characteristics

Vertical distributions of soil solution NO₃⁻ concentrations are shown Figure 2. Different water and fertilizer treatments have obvious influence on the distribution of nitrate nitrogen in soil solution. NO₃⁻ is distributed mainly in the depth of 20~80cm of the soil-pit No.1&2, in the depth of 20~40cm of the test-pit No.3&4 and in the depth of 20~120cm of the test-pit No.5&6. Since nitrate nitrogen is easily soluble in water and is highly migratory with water, most of nitrate nitrogen is mainly distributed in the middle and lower layers of soil.

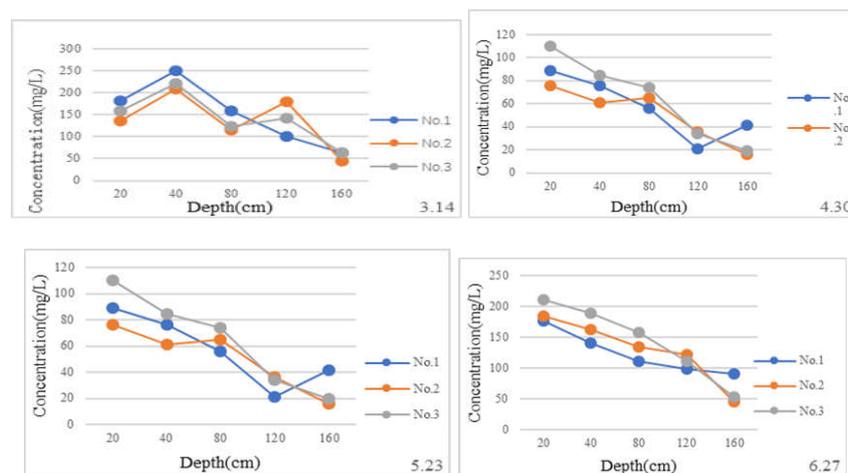


Figure 3. NO₃⁻ concentration in No.1, 2 &3 soil-pits during the experimental period.

The soil-pit 1&2 have the same amount of irrigation and different amounts of fertilizer, and soil-pit 1&3 have the same amount of fertilizer and different irrigation water, so average NO₃⁻ concentration in No.1, 2 &3 soil-pits were comparable during the experimental period as shown in Figure 3. At the

beginning of the experiment (before 2015.4.30), the distribution of NO_3^- was mainly affected by the amount of fertilizer applied at the depth of 20-80cm, but later the amount of irrigation became the dominant factor. However, at the depth of 120-160cm, it was mainly affected by the amount of fertilizer in the whole period of growth of winter wheat. High amount of fertilizer and high amount of water could lead nitrate nitrogen to move downward, and the difference was not obvious between normal and low amount of water-fertilizer treatment. By significant analysis, it can be seen that irrigation has more significant influence on vertical movement of nitrate nitrogen than fertilizer. Therefore, excessive N application, and the way of flood irrigation will increase risk of NO_3^- -N leaching to groundwater, and cause groundwater pollution.

(2) Distribution of ammonium nitrogen concentration in soil solution

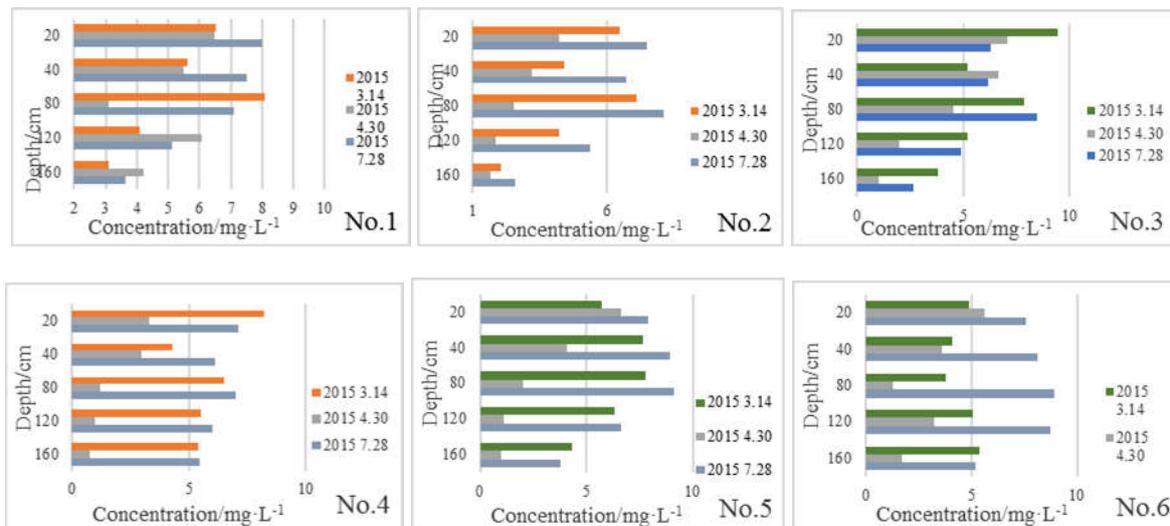


Figure 4. Ammonium Nitrogen Concentration of soil solution in six soil-pits.

As shown in Figure 4, NH_4^+ is distributed mainly in the depth of 20~80cm of the soil-pit No.1&2, mainly in the depth of 20~40cm of the soil-pit No.3&4, and mainly in the depth of 40~120cm of the soil-pit No.5&6. The results showed that influence of water quantity on leaching characteristics of NH_4^+ is more significant than that of fertilizer. The more the irrigation amount is, the deeper the location of ammonium nitrogen gathered is. The most depth of its aggregation is no more than 80cm, because ammonium nitrogen is easily adsorbed by soil colloids, and its migration is poor. When the application of ammonium fertilizer exceeds the soil transformation and fixation ability, the shallow soil layer is rich in ammonium nitrogen. Great rainfall or full irrigation, consequently, contribute to water and ammonium nitrogen deep seepage and risk for groundwater pollution.

(3) Distribution of total nitrogen concentration in soil.

Total nitrogen includes nitrate nitrogen, ammonia nitrogen and organic nitrogen, which is the main index to reflect the eutrophication of water body. The distribution of total nitrogen concentration can indicate the accumulation characteristics of nitrogen in soil resulted from nitrogen fertilization.

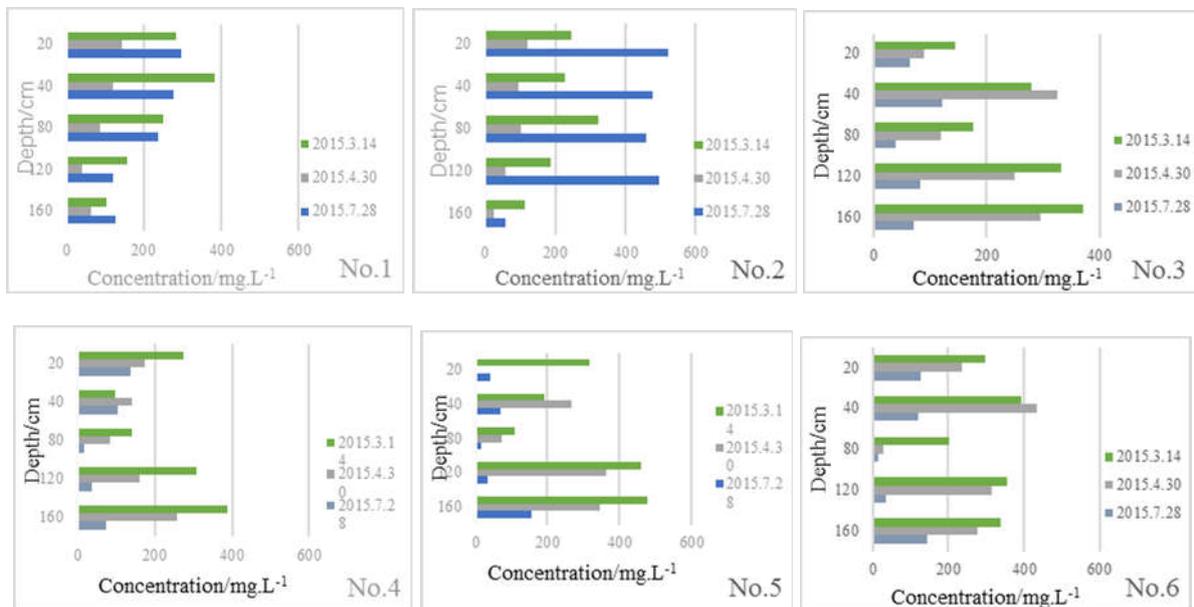


Figure 5. Total Nitrogen Concentration Distribution Characteristics

As shown in Figure 5, total nitrogen is distributed mainly in the depth of 40~80cm of the soil-pit No.1&2, mainly in the depth of 80~120cm of the soil-pit No.3&4, and mainly in the depth of 120~160cm of the soil-pit No.5&6. The results indicated that the total nitrogen is gathered in the middle and lower part of the soil layer, and its concentration distribution characteristics are similar to that of nitrate nitrogen, which showed that nitrate nitrogen is an important component of total nitrogen.

3.2. Nitrogen utilization ratio and leaching loss characteristics

3.2.1. *Nitrogen Utilization Ratio*, By the formula 3, we obtain the Nitrogen utilization ratio of each soil-pit, as shown in Table 2.

Table 2. Nitrogen Utilization Ratio

Soil-pit	1	2	3	4	5	6
Utilization Rate	0.17	0.21	0.28	0.25	0.22	0.21

As shown in table 2, the utilization ratio of nitrogen fertilizer was highest in soil-pit No.3, and No.1 has the lowest utilization ratio. More amount of irrigation could make nitrogen washed down to the ground by the water, resulting in the waste of water and fertilizer, while less amount of irrigation will affect the absorption of nitrogen by plants. It shows that irrigation water has a significant influence on the utilization ratio of nitrogen fertilizer, and the proper irrigation quota should be chosen to improve the utilization of fertilizer. Under the same irrigation treatment, the utilization ratios of nitrogen fertilizer in soil-pit No.1, No.3 and No.5 were obviously higher than that of soil-pit No.2, No.4 and No.6, which indicated that fertilizer amount is also an important factor affecting the growth of Winter Wheat, but water holds a greater proportion in the coupling relationship of water and fertilizer. In general, the utilization rate of nitrogen and the yield of winter wheat were highest under medium amount of water and fertilizer treatment and lowest under high amount of water and middle amount of fertilizer treatment.

3.2.2. *Nitrogen leaching loss*, the concentration of nitrogen in the soil solution at the depth of 1.6m was measured by experiment, and the characteristics of N leaching-loss were obtained, as shown in Figure 6.

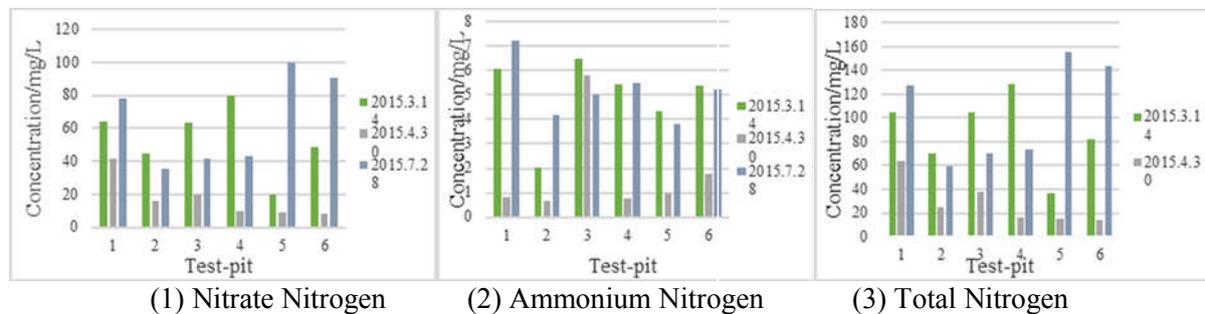


Figure 6. Nitrogen Leaching-loss Characteristics

As shown in Figure 6, leaching characteristics of NO_3^- . Soil-pit No.1 has the largest leaching loss, and soil-pit No.4 has the smallest leaching loss. Excessive irrigation and fertilization have great influence on leaching of nitrate nitrogen. Leaching loss characteristics of NH_4^+ : Soil-pit No.3 has the largest leaching loss, and soil-pit No.2 has the smallest leaching loss. The leaching law of total nitrogen is basically consistent with that of nitrate nitrogen. Larger irrigation quota will lead to greater nitrogen leaching loss, and higher fertilizer amount can't be absorbed by winter wheat completely, and is leached to deeper soil by water, resulting in leaching of nitrogen fertilizer.

4. Conclusion

Both irrigation and fertilizer application have obvious influence on the distribution of NO_3^- in soil solution, and NO_3^- concentration at 20-80cm depth mainly responded to fertilizer application at the beginning of field experiment, but the amount of irrigation became the dominant factor with the growth of winter wheat. It is noteworthy that the distribution of NO_3^- was mainly affected by the amount of fertilizer applied at the depth of 120-160cm. The influence of irrigation amount on the concentration of NH_4^+ in soil solution was more obvious than that of fertilizer. The accumulation position of NH_4^+ was deepened as the amount of irrigation increased, however, the maximum aggregation depth of ammonium nitrogen was no more than 80cm owing to its prone to adsorbed by soil colloids and poor migration. The leaching of nitrogen was affected by the combined effects of water and fertilizer. The irrigation amount played a leading role in the growth and yield of wheat in the study area. In summary, the best water and fertilizer treatment occurred in No.3 soil-pit, which meant that the middle amount of water and fertilizer could get higher wheat yield and less nitrogen leaching losses in Weishan Irrigation District.

Acknowledgments

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