

Original Research

Nitrogen Utilization Characteristics and Their Influence on Groundwater in the Weishan Irrigation Region

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Abstract

In agricultural production, the main cause of groundwater pollution has been the leakage of total Nitrogen (TN) caused by excessive water and fertilizer application. In this study, an experiment combining a field and indoors was used to seek optimal coupling scheme and prevent groundwater pollution caused by excessive fertilization. Results showed that in recent years, groundwater quality has been deteriorating, and nitrate levels have increased by approximately three times (2014-2016). The TN accumulated significantly in a different soil layer, along with crop growth. The N accumulated mainly in the bottom of the studied soil layer (80-160 cm) over time. Under different water fertilizer treatments, the crop yield, leakage, and N use efficiency (NUE) were obviously various. The effect of irrigation water quantity was more significant for N leakage than fertilizer ($P < 0.05$), and more water resulted in more N leakage. Additionally, considering the comprehensive benefits for winter wheat, medium fertilizer (N, 225 kg ha⁻¹) is an optimal scheme with medium water (3150 m³ ha⁻¹). For summer maize, medium water (1350 m³ ha⁻¹) and high fertilizer (N, 162 m³ ha⁻¹) were optimal treatment. The above schemes have the best comprehensive benefits for agricultural production in the case area.

Keywords: crop yield, groundwater quality, leakage characteristic, N use efficiency, Weishan Irrigation Region

Introduction

In agricultural production activities, the problem of excessive application of water and fertilizer exists all

over the world, and the agroecological environment is destroyed to some extent [1-5]. In particular, the water environment is contaminated severely, which impacts normal production activities [6,7]. Agricultural nonpoint source (NPS) pollution is now the No. 1 pollution source in waterways, with excessive application of water and fertilizer being the single largest contributor.

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Statistically, the world's water bodies (30-50%) are contaminated by NPS pollution [8]. Thus, water pollution control is extremely urgent.

Nitrogen (N) is the most important essential element for living organisms on the earth. The utilization of N fertilizer for cereal production has made prominent contributions to meeting the grain demands of the world with seven billion people [9]. Therefore, the N pollution is one of the main threats to human health and the ecological environment [10-14]. At present, many researchers have carried out relevant research work. Some researchers focus on improving the NUE in order to reduce the N leaching (e.g., crop rotation patterns, higher splitting frequency of fertilizer N application, controlled-release N fertilizer, lower basal N fertilizer proportion and optimal N rate based on soil N test) [15-18]. Nevens et al. indicated that rotation of different fields was one of the main ways to prevent nutrient loss [19]. The TN content in the topsoil under crop rotation has been found to increase by 25% compared with monocropping [20].

For soil testing and fertilizer recommendation, many researchers have made great advances. The NUE of soil testing and fertilizer recommendation increased by 5.95% in one study [21], and it increased by 1.89% in another [22]. These findings show that the planting structure and fertilization method are extremely vital measures to reduce fertilizer loss, especially in intensive crop-growing areas. Excess N fertilizer can leach through the soil profile, most commonly as nitrate, emerging into surface waters with high mobility [23] and causing agricultural NPS pollution, water eutrophication [24]. $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ accounted for 80-90% and 0.5-1%, respectively, in runoff loss [25]. N amount by plant uptake varied among these different crops but with little variation in fertilizer use efficiency [16].

The migration process of N is very complex, including absorption, fixing, nitrification, and denitrification [26]. Different soil textures, as well as hydrological conditions, have obvious effects on interactions. Reasonable application of water and fertilizer not only enhances NUE, but also increases crop yield. According to previous studies, high, medium, and low fertilizer were applied to the irrigation water volume. For precise quantification, the exact ration of water and fertilizer is rigorously calculated by rotation, soil testing, and optimized fertilizer application.

However, considering crop yield and the coupling of water and fertilizer, studies are rare on groundwater pollution, especially in irrigated agricultural areas. Furthermore, the overall environmental impacts of fertilizer application among different crops have not been evaluated thoroughly and systematically. Taking the Weishan irrigation region as the research area, N leakage, utilization characteristics, and effects on groundwater combined with local crop yield and reasonable water and fertilizer treatment were studied to explore the leakage characteristics of N in farmland

and the effect on groundwater. The purpose was to seek the optimal solution to prevent groundwater pollution due to excessive watering and fertilization.

Material and Methods

Study Area

Located in Dong'e County of Shandong Province ($35^{\circ}47'\text{-}37^{\circ}03'\text{N}$, $115^{\circ}16'\text{-}116^{\circ}30'\text{E}$), the Weishan irrigation region is one of the five largest irrigated regions in the downstream of the Yellow River, as shown in Fig.1. Climatologically, the Weishan irrigation region is located in a semi-arid region with a mean annual precipitation of approximately 566.7 mm; nearly 70% of the total annual rainfall is received between July and September. The main crops are winter wheat and summer maize. Economic crops include vegetable greenhouses and cotton. The experiment was conducted at the Weishan irrigation region test station ($36^{\circ}39'\text{N}$, $116^{\circ}14'\text{E}$). The irrigation water source is primarily derived from Yellow River (the first canal) and rainfall. The soil is dominated by an alluvial layer, which includes loam, clay, and sandy loam. In the study, the research layer of the experimental station is mainly loam (0-80 cm) and sandy loam (80-160 cm). The groundwater depth is between 1 and 3 m. The groundwater is replenished mainly by rainfall, and its hydrochemical type is predominantly $\text{HCO}_3\text{-SO}_4^{2-}$. The initial soil solution properties of the plough layer (0-20 cm) before the experiment began in 2015 were presented in Table 1.

Experimental Design and Statistical Analysis

Soil-Pit Test Design

For the study, soil-pit tests were conducted to complete correlative measurements. Experimental pit (bottomed pit) with a $9 \times 3 \times 4$ factorial design was adopted, with nine design levels from 1 to 9 and three replicates. The length and width of each pit were $4 \text{ m} \times 4 \text{ m}$. Moreover, lining walls 300 cm deep were constructed among the soil pits to avoid mutual influence, and a blank control (CK) was set up in each treatment. The soil depth in the pit was 280 cm, and the pit was equipped with pipes at different depths, directly connecting the seepage fluid of different deep soils. The soil solution was gathered by a soil solution collector (clay head) at different depths (20, 40, 80, 120, and 160 cm).

Water and Fertilizer Implementation Plan Design

The experiment was conducted from October 2015 to July 2016. The type of winter wheat was Tainong 18. For winter wheat, the base fertilizer (N, 15%; P_2O_5 , 15%; K_2O , 15%) was the same for the nine treatments

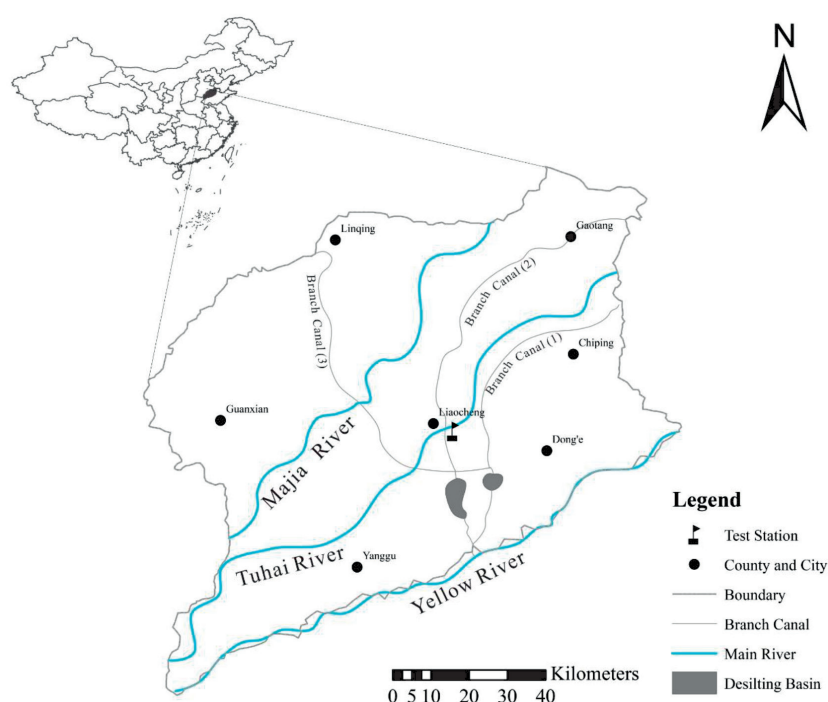


Fig. 1. Location of experiment field site.

Table 1. The initial soil solution properties of plough layer.

Soil depth (cm)	TN (mg L ⁻¹)	Olsen-P (mg L ⁻¹)	Olsen-K (mg L ⁻¹)	NH ₄ -N (mg L ⁻¹)	NO ₃ -N (mg L ⁻¹)
0-20	220	12.9	103.6	5.6	150

(1 to 9), and the topdressing was urea (U; N, 46%). The urea was applied twice, with 1/2 in the elongation stage and 1/2 in the heading stage. P and K fertilizers in all treatments were applied at the bottom application dose of 94 kg ha⁻¹. Three fertilization schemes were used ('low' means below the average of fertilization or irrigation water in actual agricultural production, 'medium' equal to the average of fertilization or irrigation water in actual agricultural production, 'high' means above the average of fertilization or irrigation water in actual agricultural production): low fertilization treatment (1, 2, 3), medium fertilization (4, 5, 6), and high fertilization (7, 8, 9). Winter wheat was irrigated in the following four stages: overwintering stage (OW, November, 2015 to February, 2016), turning green/elongation stage (TGE, mid-February to mid-March, 2016), heading stage (HD, April to early May, 2016), and grain-filling stage (GF, late May to early June, 2016). In the overwintering stage, the irrigation water was consistent with nine soil-pit treatments, and then three layout levels were designed in the other three stages respectively: pits 1, 4 and 7 were high water treatment; pits 2, 5 and 8 were medium water treatment; and pits 3, 6 and 9 were low water treatment (Table 2). The seeds were seeded on October 8, 2015 and harvested on June 1, 2016.

For summer maize, the type of seed was Ludan 981, sown immediately after the winter wheat harvest (June 2016). Both bases are compound fertilizers (N, 15%; P₂O₅, 15%; K₂O, 15%), and the topdressing was U (N, 46%). Half of the fertilizer application was at base application, and the remaining half was in the tasseling stage (July 14 to August 1, 2016). Three levels of fertilization were designed: pits 1, 2 and 3 high fertilizer treatment; pits 4, 5 and 6 medium fertilizer treatment; and pits 7, 8 and 9 low fertilizer treatment. Summer maize was irrigated in the following seeding stage (late June 2016) and tasseling stage (July 21 to August 6, 2016). High water treatment (1, 4, 7), medium water treatment (2, 5, 8), and low water treatment (3, 6, 9; 1080 m³ ha⁻¹) were implemented, respectively (Table 3). The seeds were sown on June 2, 2016 and harvested on October 4, 2016.

Sampling and Measurement

Soil solution samples (27 soil pits) were collected from March 14, 2016 to July 28, 2016. The soil solution was extracted one day after fertigation. In the summer maize growth period, soil solution samples were obtained one day after seeding and tasseling stage fertigation for indoor determination. Each sample

Table 2. Fertilization and Irrigation Plan of Winter wheat.

Treatment	Schemes (fertilizer)	Fertilizer inputs (kg ha ⁻¹)			Schemes (water)	Amounts of irrigation (m ³ ha ⁻¹)			
		N	P ₂ O ₅	K ₂ O		OW	TGE	HD	GF
1	High	300	94	94	High	675	1050	1050	1050
2		300	94	94	Medium	675	825	825	825
3		300	94	94	Low	675	600	600	600
4	Medium	225	94	94	High	675	1050	1050	1050
5		225	94	94	Medium	675	825	825	825
6		225	94	94	Low	675	600	600	600
7	Low	178	94	94	High	675	1050	1050	1050
8		178	94	94	Medium	675	825	825	825
9		178	94	94	Low	675	600	600	600

Table3. Fertilization and Irrigation Plan of Summer Maize.

Treatment	Schemes (fertilizer)	Fertilizer inputs (kg ha ⁻¹)			Schemes (water)	Amounts of irrigation (m ³ ha ⁻¹)	
		N	P ₂ O ₅	K ₂ O		Seeding	Tasseling stage
1	High	162	94	94	High	750	750
2		162	94	94	Medium	675	675
3		162	94	94	Low	540	540
4	Medium	134	94	94	High	750	750
5		134	94	94	Medium	675	675
6		134	94	94	Low	540	540
7	Low	108	94	94	High	750	750
8		108	94	94	Medium	675	675
9		108	94	94	Low	540	540

leakage was measured using 10 litre plastic containers, gathered 15 days after each irrigation or rainfall. Moreover, groundwater samples were collected from March 2014 to October 2016 from the 76 groundwater observation wells at intervals of 10-15 days. The contents of TN were accurately gathered with a polyethylene bottle (50 ml), which is the main monitoring index of groundwater quality standard. All the absorbances of the samples (soil solution, groundwater samples, and stem, leaves, and seeds of crops) were scrupulously measured by UV spectrophotometer (UV-2200) and FT-NIR spectrophotometer (IR-960), with professional guidance.

Statistical Analysis

(1) Calculation of N and P use efficiency

The formula to calculate the TN (the total nitrogen) and A-P (available phosphorous) utilization ratio is as follows [27, 28]:

$$M_{NP} = \frac{(A \times a + B \times b)}{A} \times 100 \quad (1)$$

$$N_1 = A/100 \times M_{NP} \quad (2)$$

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

...where M_{NP} is the amount of N absorbed by crops for 100 kg economic yield, kg; A is Grain yield of crops, kg ha⁻¹; a is Grain N content, %; B is Stem and leaf yield of crops, kg ha⁻¹; b is Stem and leaf N content, %; N_0 is N uptake by blank test crops, kg ha⁻¹; N_1 is Total amount of N in soil, kg ha⁻¹; N_2 is the total amount of N fertilizer application in test pit, kg ha⁻¹; P is NUE, %.

(2) Calculation of TN or A-P leakage

The formula to calculate TN or A-P leakage is as follows [29]:

$$L = C \times V_s/100 \quad (4)$$

...where L is the leaching amount, kg ha⁻¹; C is the TN or A-P concentration, mg L⁻¹; V_s is the sum of leaching volume, ml.

Results

The Characteristics of TN Leakage in Soil Solution Treated with Different Water and Fertilizer

The variation of TN concentration was fairly obvious in the crops' growth period in different soil layers, as identified in Fig.2. The TN concentration of the shallow layer (0-40 cm) was significantly higher than that in the lower soil (80-160 cm) in the pre-stage of the growth period. Subsequently, the TN concentration of the lower soil gradually increased until harvest time. Under high water irrigation, the TN accumulation concentration of the lower soil layer increased more rapidly than the low irrigation. The TN concentration of the shallow soil layer was steady to some extent, with an average of 292.68 mg L⁻¹, and there was no obvious distinction between different treatments, with a balance range of 263.12-310.46 mg L⁻¹. The TN concentration of 0-20 cm declined gradually in the heading stage, with a minimum of 260.1 mg L⁻¹, and then rose to within the balance range. Comparatively speaking, a smooth trend of 20-40 cm was similar to 0-20 cm in the middle and late stages of crop growth. After the heading stage, the accumulation effect of the TN concentration was more significant at 120-160 cm, especially under

high water condition. However, the TN concentration of all treatments was significantly decreased at 0-20 cm between the heading stage and the filling stage of winter wheat. Above that, the aggregation layer of the TN concentration was affected by different treatments, and the main influencing factor was dominated by irrigation levels. Noticeably, for summer maize, the TN concentration of the lower soil layer was significantly higher than that of winter wheat, and mainly concentrated at 120-160 cm.

The distribution characteristics of TN concentration in the soil profile were obvious in the different growth stages of crops. Between the turning green and elongation stages (winter wheat), the TN concentration was mainly concentrated at 20-40 cm, with an average of 304.43 mg L⁻¹, and other soil layers at 0-20 cm (280.93 mg L⁻¹), 40-80 cm (265.3 mg L⁻¹), 80-120 cm (214.35 mg L⁻¹), and 120-160 cm (189.17 mg L⁻¹). In the heading stage, the TN concentration was accumulated in the soil layer (40-80 cm, average 332.68 mg L⁻¹), and the TN concentration was increased more apparently in the lower soil layer, under high water and fertilizer (treatment 1). Although the trend above was similar to all treatments, the TN concentration of low water and fertilizer (treatment 9) at 120-160 cm was less obvious than medium-high water. In the filling stage, the soil

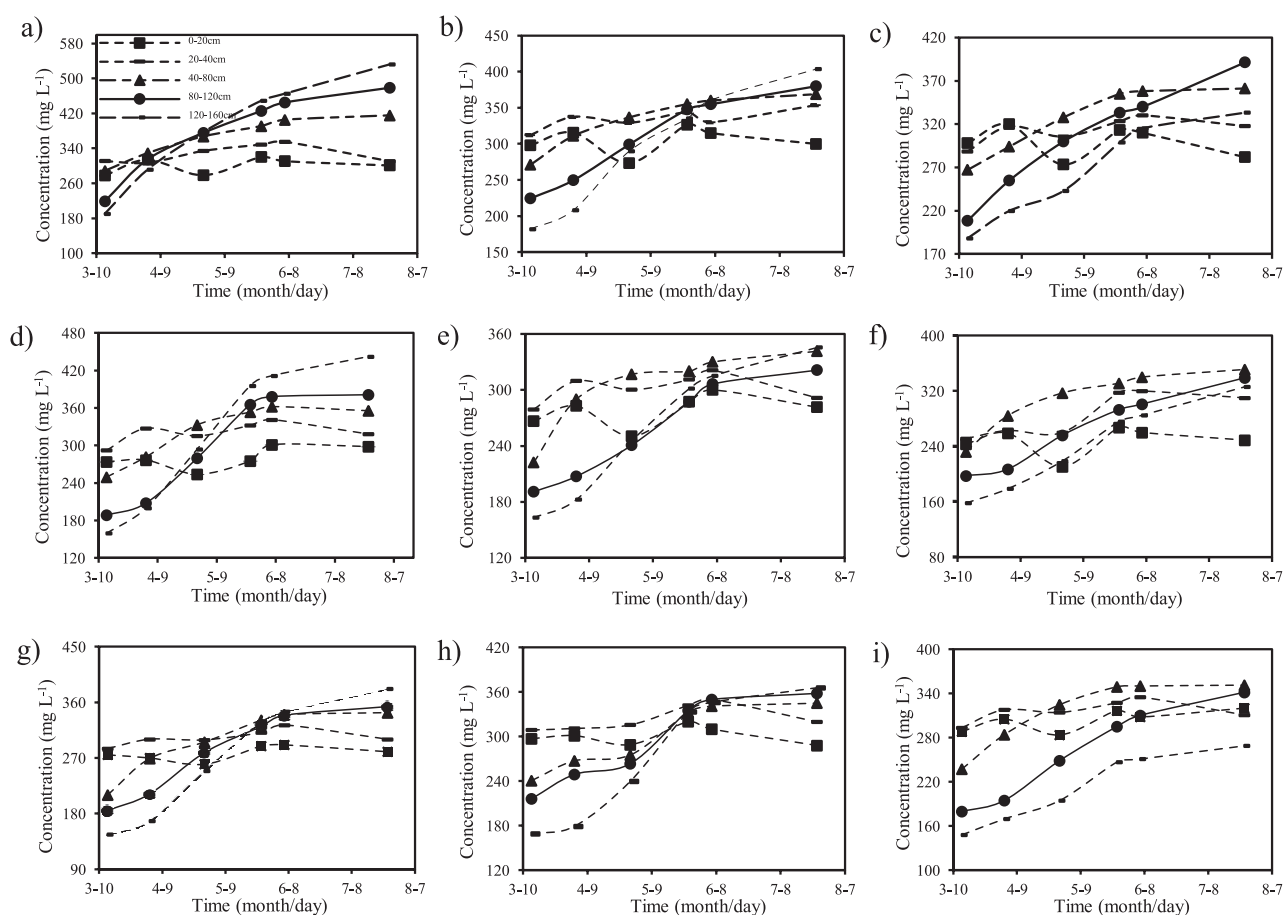


Fig. 2. TN concentration distribution in different treatments.

above Charts: a, b, c, d, e, f, g, h, i represents treatments 1, 2, 3, 4, 5, 6, 7, 8, 9 respectively.

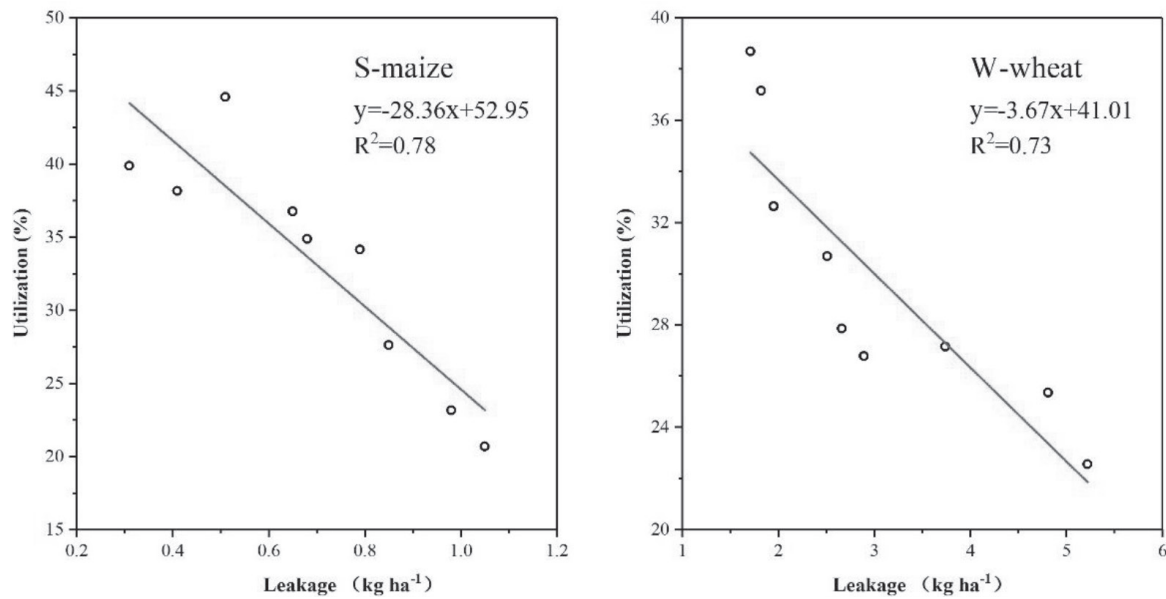


Fig. 3. The correlation between the N utilization and fertilization leakage.

Table 4. NUE by W-wheat and S-maize, Grain yield, total leakage during the 2014 and 2015 crop growing seasons.

Crop species	Treatment	NUE (%)	Yield (kg ha ⁻¹)	TN leakage (kg ha ⁻¹)
W-wheat	CK	-	4709.13	-
	1	22.50de	6300.51c	5.22a
	2	37.15a	6610.21b	3.74ab
	3	24.69cde	5861.36e	2.51bcd
	4	33.35b	6173.00cd	4.81a
	5	38.69a	7000.25a	1.91cd
	6	24.94cd	5855.55e	1.82f
	7	27.78c	5877.32de	2.89bc
	8	27.86c	5996.50de	2.66bcd
	9	20.63e	4991.05f	1.61f
S-maize	CK	-	4954.04	
	1	34.69d	8600.11cd	1.05a
	2	40.63a	9750.51a	0.85bc
	3	34.15d	7985.35e	0.79c
	4	38.78b	9150.21b	0.57de
	5	36.75c	8750.01c	0.65d
	6	34.89d	8425.67d	0.68d
	7	33.15d	7889.12e	0.98b
	8	30.16e	7500.17f	0.51e
	9	28.89e	5350.05f	0.41f

The CK represents blank control, the letters (a, b, c, d, e, f) represent significant difference ($p < 0.05$). Different letters indicate significant differences, the same letter means the difference is not significant.

depth at 40-80 cm showed an accumulation layer for treatments 3, 6, and 9, with the TN concentration reaching an average of 327 mg L⁻¹. Accumulation was noticed in the bottom soil (120-160 cm) for treatments 1, 4, and 7, reaching an average of 390.67 mg L⁻¹. Other treatments (2, 5, 8) were concentrated at 80-120 cm, with a mean of 360.05 mg L⁻¹. For summer maize, from the seeding to tasseling stage, the TN concentration was distinctly higher than that for winter wheat in the lower soil layer (80-160 cm). Particularly in the tasseling stage, the TN concentration was accumulated at 120-160 cm, and treatment 1 was typical, with the peak value of 532.12 mg L⁻¹.

TN Leakage During Crop Growth Period

N leakage was an important factor causing groundwater source pollution, and the N leakage calculated accurately was the key to the analysis of the regional agricultural source pollution. In the whole experimental period, there were a total of nine rainfalls. The minimum rainfall recorded was only 0.5 mm d⁻¹, and the maximum rainfall was 40.5 mm d⁻¹. The designed irrigation amount was 67.5 mm. The TN leakage of winter wheat in the turning green-jointing stage was larger than that of other periods, up to the peak of leakage in the period, gradually declining after that with the lowest leakage. Compared with winter wheat, the leakage of summer maize during the jointing stage and silking stage was larger than others. As shown in Table 4, the leakage of the winter wheat test was more than that of summer maize. Under high water and fertilizer treatment, winter wheat and summer maize (treatment 1) leakage were larger, reaching 5.22 kg ha⁻¹ and 1.05 kg ha⁻¹, respectively. In contrast, treatments 5 and 2 were the higher yield and

utilization rate, but the leakage only was 1.91 kg ha⁻¹ and 0.85 kg ha⁻¹. Thus, N elements were not beneficially absorbed under high water and fertilizer treatment, posing a risk of groundwater pollution. In addition, there was a significant negative correlation between the TN leakage and the N utilization (Fig. 3). These results suggested that high water and high fertilizer were not conducive to N absorption.

Effects of Different Processing Interactions

The aim of this experiment was to improve the N utilization rate in order to ensure improvement of the groundwater environment and to respond to green agriculture. In this section, SPSS statistical software was used in $p < 0.05$ (LSD). The use efficiency of N and crop yield was noticeably affected by different water and fertilizer treatments (Fig. 4). The TN leakage quantity ranged from 2.02 to 6.27 kg ha⁻¹ a⁻¹ in the study period (Table 4). The higher leakage was demonstrated in the high water and fertilization treatment, along with the severe pollution risk of underground water. Furthermore, the effect of irrigation water quantity was more significant on the N leakage in crops (winter wheat - summer maize). For treatments (1, 4, 7), the average leakage was 5.13 kg ha⁻¹, and medium water treatments (2, 5, 8) indicated an average of 3.44 kg ha⁻¹. The minimum average was 2.61 kg ha⁻¹ for water treatments (3, 6, 9). For the crop yields, with the same fertilizer application, the following yields were shown: medium water > high water > low water. However, with the same water application, the yield of high fertilizer was similar to medium fertilizer treatment. The effect of fertilizer application was more significant than water between high fertilizer and low fertilizer. For the high fertilizer treatments (1, 2, 3), winter wheat and summer maize average yield were respective of 6257.36 kg ha⁻¹ and 8778.33 kg ha⁻¹, and medium fertilizer treatments (4, 5, 6) were 6342.93 kg ha⁻¹ and 8775.21 kg ha⁻¹. Low fertilizer treatment (7, 8, 9) were 5569.32 kg ha⁻¹ and 6913.05 kg ha⁻¹. The N contents in the stem, leaf, and grain from winter wheat and summer maize are shown in Table 5 for calculating NUE. For summer maize, the NUE and yield were highest in treatment 2 (40.63% and 9750.51 kg ha⁻¹, respectively) with leakage (0.85 kg ha⁻¹). On the contrary, treatment 9 was lowest (28.89% and 5350.05 kg ha⁻¹, respectively) with

leakage (0.41 kg ha⁻¹). The effect of water was more obvious than fertilizer on yield for summer maize (high water > medium water > low water overall). The leakage was highest in high water and fertilizer treatment 1 for application to winter wheat.

For winter wheat, NUE and yield were the highest (38.69% and 7000.25 kg ha⁻¹, respectively) in treatment 5, significantly different from other treatments, with low leakage (1.91 kg ha⁻¹). However, low water and fertilizer treatment 9 was opposite to the medium water and fertilizer treatment, with the lowest use efficiency, yield, and leakage (20.63%, 4991.05 kg ha⁻¹, and 1.61 kg ha⁻¹, respectively). Additionally, for high water and fertilizer treatment 1, the NUE was similar to treatment 9 at 22.50%, and the yield was 6300.51 kg ha⁻¹, but the leakage was the highest (5.22 kg ha⁻¹), approximately triple that of treatment 5. According to the above research results, considering the local economy and environmental protection, treatment 5 was the optimum coupling of water and fertilizer for winter wheat, and treatment 2 was the optimum for summer maize to improve the NUE, reduce the risk of groundwater pollution, and in Fig. 4.

In the last three years, the groundwater NO₃-N content was increasing in the study area, while the NH₄-N fluctuation was imperceptible, only with a significant increase in the heading stage and grain filling stage (winter wheat) (Fig. 5). The average annual variation trend of TN was similar to that of NO₃-N, and the content increased by nearly three times

Table 5. N, P content in stem-leaf and grain from W-wheat and S-maize.

Crop Species	Nutrient Content (%)			
	Stem-Leaf		Grain	
	N	P	N	P
W-wheat	0.564	0.067	2.140	0.370
S-maize	0.748	0.408	1.466	0.317

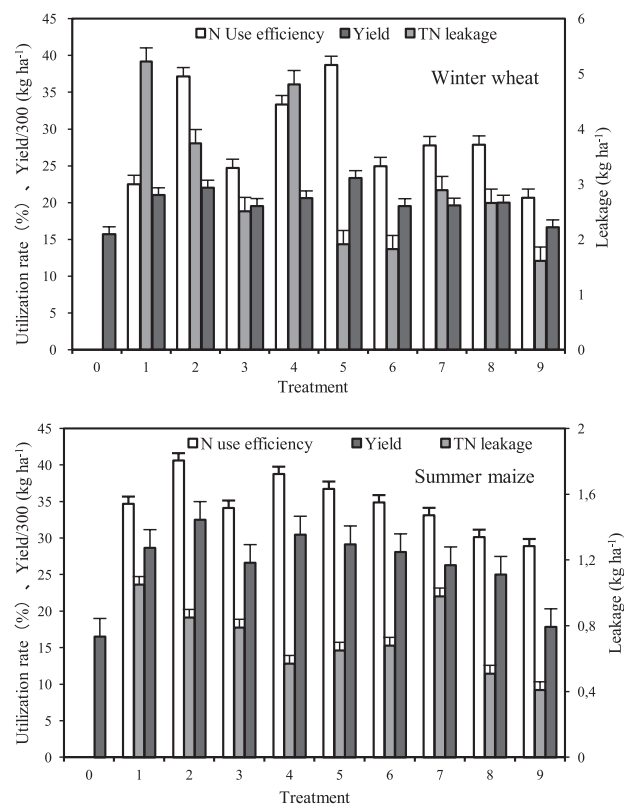


Fig. 4. The relationship between the use efficiency and yield.

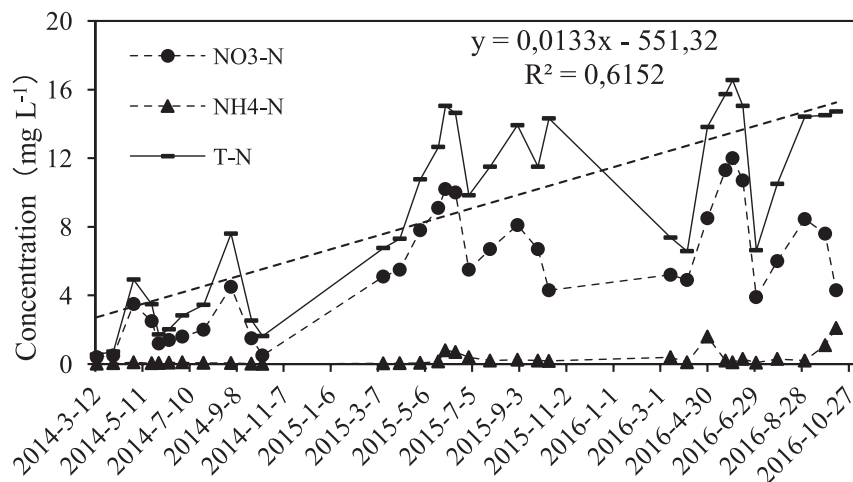


Fig. 5. Variability of N content in groundwater.

(TN, 13.82 mg L⁻¹), with a determination coefficient of 0.6152. The nitrate content in the groundwater quality added up to nearly 4.23 times. According to the groundwater quality standard [30], the groundwater belonged to category III (NO₃-N, 4-12 mg L⁻¹). The maximum limit of the underground water source for drinking water standard was almost approached (≤ 20 mg L⁻¹) and continuously deteriorated, which should arouse concern and prompt appropriate measures to further improve the groundwater environment. Based on annual average rainfall records of the Liaocheng hydrographic office in recent years, N seepage has been concentrated in the irrigation and rainfall period.

Discussion

Effects of Different Water-Fertilizer Treatments on TN Leakage Characteristics in The Soil Profile

The TN leakage characteristics in farmland were affected by the irrigation quantity, rainfall, rainfall intensity, soil characteristics and land use mode, planting structure, agricultural activities, and so on [31]. The leakage occurred when fertilizer used exceeded crop demand. Furthermore, the environment might be damaged through migration and denitrification [32]. In this experiment, fertilizer and irrigation quantities were an important factor influencing distributing characteristics (TN), with apparent variation of 80-160 cm, which was an accumulative effect. The TN content of 80-160 cm gradually increased in the crop growth period with the N element infiltrating, and the NO₃-N was the main ingredient contributing to infiltration, which was easily dissolved and strong mobility. However, the TN content of 0-40 cm was more directly affected by irrigation water with wash action than 120-160 cm, which had inconspicuous fluctuation. The measure, integration of water and fertilizer, prompted the N element to transfer faster

from the surface to the bottom of the studied soil layer, indirectly contributing to the balance of N at 0-40 cm without much peak or valley value. Above that, eventually, the study indicated that the TN content was accumulated at 120-160 cm, accelerating the pollution of underground water. Compared with previous studies, the study results still have some differences which may be caused by nature factors (precipitation, temperature, climate, etc.) [33] or human factors (experiment operation, standard, etc.).

Effects of Different Water and Fertilizer Treatments on TN Leakage

According to the study, the different TN leakages occurred under a certain amount of water (precipitation, irrigation) in the field. The leakage can be strengthened in a high irrigation amount: The leakage of treatment 1 with high water was the greatest (TN, 6.27 kg ha⁻¹) during the whole experiment, and treatment 9 with low water was the least (N, 2.01 kg ha⁻¹), infiltrating into groundwater and resulting in groundwater pollution [34]. In addition, when the rainfall intensity exceeded the infiltration rate of the local soil, surface runoff would be generated, and then the accumulated N in the soil surface entered the surface water body, causing surface water body pollution (lake, rivers, ditches, etc.). The groundwater investigation based on outdoor test also indicated that an increasing trend of groundwater NO₃-N and TN content was clearly observed during recent years, referring to a vital indicator of groundwater quality. Tang et al. argued that the groundwater quality deteriorated year by year in the Weishan irrigation region [35]. In the past 10 years, the growth rate of agricultural fertilizer application was approximately 23% [36]. Combining with the groundwater NO₃-N and TN content increasing trend, the increase of fertilizer application actually contributed to the groundwater pollution, which was consistent with previous research conclusions. At present, flooding irrigation methods

(3600-4500 m³ ha⁻¹) are still applied in the study area, resulting in low groundwater depth (1.5-3 m) and enhanced soil leaching, which leads to high content of NO₃-N in shallow groundwater. Excessive water and fertilizer were widespread in the main grain area of the north China plain (southwest of Shandong, northwest, etc.). Excessive application of N fertilizer had been identified as a major source of groundwater pollution [37]. Hence, optimizing the combination of water and fertilizer is an important measure to solve N pollution, suggesting water and fertilizer optimum management has a significant effect on improving groundwater quality.

Effect of Different Water and Fertilizer Treatments on N Utilization

The NUE was obviously distinct between different water and fertilizer treatments ($p < 0.05$). Treatment 5 for winter wheat was optimal (N, 38.69%), with medium water and fertilizer. For summer maize, treatment 2 was optimal (N, 40.63%), with high fertilizer and medium water. Other researchers have come to similar conclusions. For instance, Chen et al. found that the use efficiency of N was 52.4% after medium fertilizer treatment [38]. Compared with conventional water and fertilizer application, the use efficiency for N increased by 10.19% for winter wheat and 7.29% for summer maize. Based on the approximate amounts of N fertilizer application, the growth rate was slightly higher than that previously reported for the soil testing formula experiment [39]. One possible reason may be different measurement methods. As noted above, in agricultural production, the optimization of water and fertilizer was a key measure to improve the use efficiency of water and fertilizer and to decrease water body pollution. Compared with other research results, the optimization effect in this study is different, and the causes might be the differences on crop strains, regional climate, the experiment site (in situ experiment), or treatment standards.

Groundwater Quality

Protecting the groundwater quality is one of this study's purposes, and the NO₃-N was uppermost contributor. The main factor causing groundwater pollution is fertilizer application in agricultural activities [40], and excessive application of N fertilizer has been identified as a major source of groundwater pollution [37]. In Fig. 4, the TN (NO₃-N, NH₄-N) content is increasing, illustrating the groundwater quality's deterioration in the case. For this reason, unreasonable application of water and fertilizer adopted by local farmers is a critical factor, and excessive application of water and fertilizer was widely popular, as it was deeply rooted in local ideology. In this paper, excessive application of water and fertilizer resulted in more N accumulating in the bottom soil layer, causing

vast quantities of N in groundwater and, consequently, groundwater pollution.

In the Weishan irrigation region, the content of NO₃-N in shallow groundwater had been studied by many researchers. The results showed that the N content in the shallow groundwater was higher than that of the national primary drinking water standard, except for deep groundwater [41]. Shallow groundwater would be severely contaminated with long-term unreasonable water-fertilizer application [42]. The trend of groundwater quality in recent years is consistent with the previous research conclusions, and the conclusions provided a scientific basis for local control of the groundwater environment.

Reasonable application of water and fertilizer played an important role in protecting the groundwater environment. Generally, the irrigation water and fertilizer application quantities are at an average of approximately 4050 m³ ha⁻¹ and N, 325 kg ha⁻¹, respectively, which are greater than the design values. Therefore, the TN leakage in the study area may be more serious. In this study, the conclusion provided a scientific basis for local control of the groundwater environment. Local authorities should develop countermeasures to keep the situation in check as early as possible.

Conclusions

To study the deteriorating groundwater in the Weishan irrigation region, pit tests of nine treatments were carried out in the Weishan irrigation region station. Results showed that (1) the TN leakage characteristics were significant in different water-fertilizer treatments, and high water caused more N element accumulation at 120-160 cm, becoming more apparent over time; however, TN content fluctuation of the upper layer was not evident. (2) Medium water-fertilizer application (N, 225 kg ha⁻¹, 3150 m³ ha⁻¹) for winter wheat as well as high fertilizer and medium water treatment (N, 162 kg ha⁻¹, 1350 m³ ha⁻¹) for summer maize were optimal schemes to maintain balance between farmers' income and environmental protection; excessive application of water and fertilizer resulted in significant quantities of N elements in groundwater, causing water pollution. (3) A higher fertilizer used more than N, 225 kg ha⁻¹ was the main cause of local groundwater quality deterioration in recent years (III groundwater quality), which would possibly pose a greater threat to the local eco-hydrological environment.

There are still many defects in the process of applying water and fertilizer. For instance, the design levels of water and fertilizer and the number of samples need to increase in order to be more persuasive. The optimal coupling of water and fertilizer may vary in different regions, and leakage experiments can be carried out in different temperature zones (South China, Northwest China, etc.). In future studies, P can be taken

into account as another major element causing NPS pollution.

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Conflict of Interest

The authors declare no conflict of interest.

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