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# Nitrogen Loss in Vegetable Field under the Simulated Rainfall Experiments in Hebei, China

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**Abstract:** Agricultural non-point source pollution is one of the main factors contaminating the environment. However, the impact of rainfall on loss of non-point nitrogen is far from well understood. Based on the artificial rainfall simulation experiments to monitor the loss of dissolved nitrogen (DN) in surface runoff and interflow of vegetable field, this study analyzed the effects of rainfall intensity and fertilization scheme on nitrogen (N) loss. The results indicated that fertilizer usage is the main factor affecting the nitrogen loss in surface runoff, while runoff and rainfall intensity play important roles in interflow nitrogen loss. The proportion of DN lost through the surface runoff was more than 91%, and it decreased with increasing rainfall intensity. There was a clear linear trend ($r^2 > 0.96$) between the amount of DN loss and runoff. Over 95% of DN was lost as nitrate nitrogen (NN), which was the major component of nitrogen loss. Compared with the conventional fertilization treatment (CF), the amount of nitrogen fertilizer applied in the optimized fertilization treatment (OF) decreased by 38.9%, and the loss of DN decreased by 28.4%, but root length, plant height and yield of pak choi increased by 6.3%, 2.7% and 5.6%, respectively. Our findings suggest that properly reducing the amount of nitrogen fertilizer can improve the utilization rate of nitrogen fertilizer but will not reduce the yield of pak choi. Controlling fertilizer usage and reducing runoff generation are important methods to reduce the DN loss in vegetable fields.

**Keywords:** rainfall intensity; fertilization scheme; dissolved nitrogen loss; nitrogen utilization

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## 1. Introduction

Agricultural cultivation, livestock and poultry farming, and rural domestic pollution have been recognized as the three major sources of agricultural non-point source pollution [1,2]. Nutrients loss in farmland is one of the main components of agricultural pollution. In the process of agricultural production, farmers often apply higher level of fertilization than the recommended value for crops in order to pursue higher yield, resulting in a large amount of nitrogen surplus and accumulation in the soil and water [3,4], with the threats to ecosystem and human health [5,6]. For example, a total of 58.594 million tons chemical fertilizer was applied in China, ranking the first in the world in 2017, which was an increase of 47% compared to 1997 [7]. Overall, China applies approximately 1/3 of the world's chemical fertilizers to its cultivated land that accounts for only 7% of the world's total cultivated land, which causes excessive use of chemical fertilizers in most farmland across the country [8]. As a result, the utilization rate of chemical fertilizer in Chinese farmland is low, with a nitrogen utilization rate of only 35% in the current season and only 10% in the greenhouse [9]. Excessive non-point source pollutants enter surface water bodies, which is one of the important causes of eutrophication and harmful algae outbreaks in lakes, reservoirs and coasts, and seriously threatens the safety of the aquatic ecosystems [10–12]. From the beginning of the 21st century, agriculture has surpassed industry to become the largest polluter of the water environment in China [13].

Around the world, 30–50% of the surface soil is affected by agricultural non-point source pollution [14]. The generation of agricultural non-point source pollution is a continuous and dynamic process [15]. The pollutants in the soil include soluble pollutants and pollutants adsorbed in the soil, which dissolve and seep from the soil driven by rainfall and runoff, and finally enter the water body through ditches or slopes, resulting in water pollution [16]. Rainfall is the source of power, the runoff is the carrier of non-point source pollutants, and the erosion intensity of the runoff on the soil affects the degree of nutrient loss [17,18]. The sediment yield rate markedly influenced the losses of sediment bound available nitrogen and phosphorus [19]. Based on the field data of natural rainfall monitoring in the Three Gorges Reservoir area, China, Ma et al. [20] found that purple soil suffered from the most severe soil and nutrient loss. Land use also affected soil erosion and nitrogen loss [21,22]. In particular, farmland is the most susceptible land use [23]. Experiments on the effects of different vegetation types on soil water erosion show that the soil and water conservation benefits of forest and grassland are obviously larger than those of cropland [24].

Many studies have shown that soil nutrient loss is affected by various factors, such as geographical location, topography, soil types, crop types, farming methods, and others [25–27], which limits the application of existing research conclusions in local areas to wider regions, for example, the North China Plain, one of the most important agriculture areas in China. Nitrogen loss is essentially a very complex process. All factors that influence runoff generation and nitrogen concentration can affect the process of nitrogen loss. Due to the large heterogeneity between areas, the findings in other areas cannot be directly applied in North China. In view of this, this study conducted artificial rainfall simulation experiments to analyze the comprehensive effects of rainfall intensity and fertilization scheme on the loss of nitrogen in vegetable fields in Hebei, North China. The main aims of the research are to (1) determine the change rates of plant growth and nitrogen loss of surface runoff and interflow in the researched soil troughs; (2) analyze the change trends of ammonia nitrogen (AN), nitrate nitrogen (NN) and dissolved nitrogen (DN) in surface runoff and interflow; and (3) explore the relationship between fertilizer usage, rainfall intensity, and nitrogen loss in farmland. The results provide reference for the control of soil fertilizer loss and agricultural non-point source pollution.

## 2. Materials and Methods

### 2.1. Study Area

The simulation experiments were carried out in the irrigation experimental field, Haihe River Basin (36°35′ N, 114°29′ E, CHCNAV LT700), Hebei, North China (Figure 1) from June to November 2019. The research area is in the warm temperate continental monsoon climate zone, with obvious seasonality of temperature and precipitation. Mean annual temperature and frost-free period are 13.5 °C and 200d, respectively. Average annual precipitation is 539.4 mm. Precipitation from June to September accounts for about 70–80% of the entire year value. The maximum six-hour rainfall since 2000 is 339.5 mm. The vegetable planting area is approximately 787,600 hectares in Hebei Province, accounting for 9.6% of the total planting area of crops. In 2017, Hebei Province applied around 3.22 million tons of agricultural fertilizer [7].

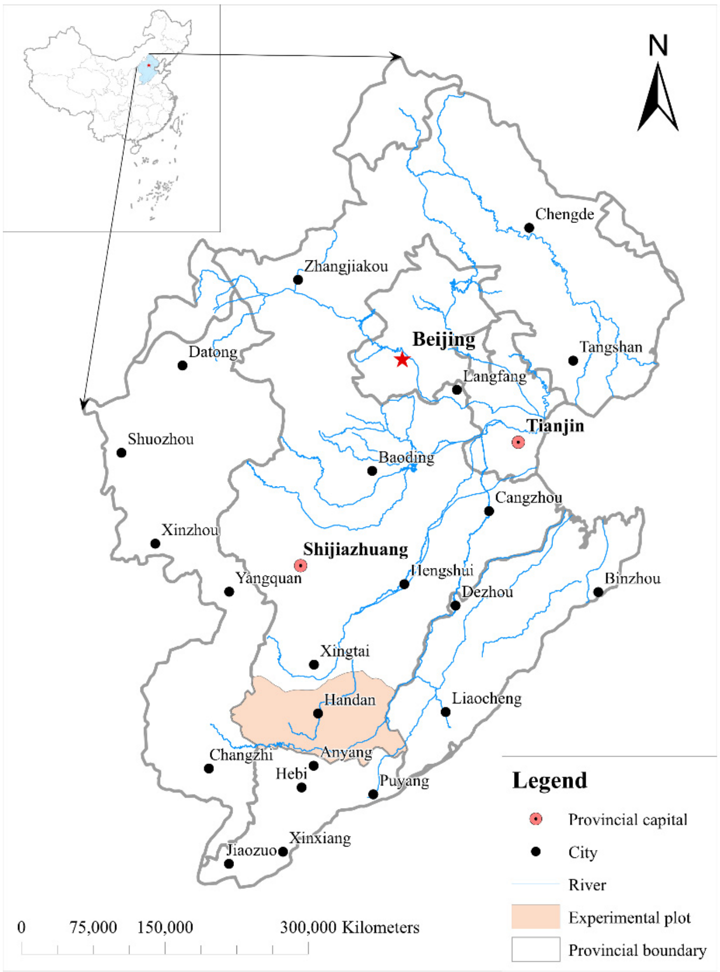

**Figure 1.** Location of the study area in the Haihe Watershed, Hebei Province, China.

### 2.2. Experimental Design

The dimensions of the soil troughs are 840 × 620 × 450 mm outside and 820 × 600 × 430 mm inside. To simulate the natural infiltration of soil moisture, the bottom of soil trough is uniformly perforated and covered with permeable gauze to ensure that the permeability of the soil is close to the natural condition. To maintain the original soil layered state, soil samples were placed in the trough. Surface runoff and interflow water samples were collected from the soil surface and 30 cm deep, respectively. Soil troughs were randomly divided into three groups, and each of the three soil troughs was used as a control check (CK), a conventional fertilization treatment (CF) and an optimized fertilization treatment (OF). Different fertilization schemes—N, $P_2O_5$ and zeolite—and rainfall intensities were applied in soil troughs (Table 1). The fertilizer was evenly mixed with the surface soil of the soil trough. Pak choi seeds were planted in soil troughs with row spacing of 10 cm, and soil troughs were watered every day. The simulated rainfall experiment was carried out for two weeks after the pak choi was planted. According to historical rainfall data, the rainfall intensity gradients for this experiment were set to 54 $\text{mm}\cdot\text{h}^{-1}$, 75 $\text{mm}\cdot\text{h}^{-1}$ and 99 $\text{mm}\cdot\text{h}^{-1}$. The rainfall intensity value was the actual rain intensity of the rainfall device and the rainfall time was set to 60 min.

**Table 1.** Fertilization schemes and rainfall intensity of soil troughs in the experiments.

| Soil Trough (ST) | Control Check (CK) | | | Conventional Fertilization (CF) | | | Optimized Fertilization (OF) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| N ($kg \cdot hm^{-2}$) | 0 | 0 | 0 | 135 | 135 | 135 | 82.5 | 82.5 | 82.5 |
| $P_2O_5$ ($kg \cdot hm^{-2}$) | 0 | 0 | 0 | 105 | 105 | 105 | 67.5 | 67.5 | 67.5 |
| Zeolite ($kg \cdot hm^{-2}$) | 0 | 0 | 0 | 0 | 0 | 0 | 3000 | 3000 | 3000 |
| Rainfall intensity ($mm \cdot h^{-1}$) | 54 | 75 | 99 | 54 | 75 | 99 | 54 | 75 | 99 |

### 2.3. Sampling and Analysis

In August 2019, three repeated rainfall simulation experiments were carried out. Time was recorded when surface runoff and interflow occurred, and water samples were collected every 3 min within the first 15 min after the runoff occurred, and then every 5 min until the end of the runoff. Freshwater samples and plant samples were immediately taken back to the laboratory and stored at 4 °C. Surface runoff and interflow water samples were determined for nitrogen content within 72 h. During the experiment, a total of 125 surface runoff water samples and 89 interflow water samples were collected. For runoff water, the AN in the filtrate was measured by using the colorimetric method (640 nm) after quantitative reaction with hypochlorite and phenol in alkaline solution with sodium nitroprusside as catalyst to produce dark blue indophenol dye. The NN in the filtrate had strong absorption of UV light (220 nm), and dissolved organic matter had absorptions at both 220 nm and 275 nm while nitrate had no absorption at wavelength 275 nm, thus nitrate value can be corrected by measuring the absorbance at 275 nm. All the above measurements were based on the standard analytical methods [28] and analyzed by using UV-756 spectrophotometry. In this experiment, the sum of AN and NN concentrations in the water sample was regarded as the DN concentration. The collected pak choi plant samples were measured for fresh weight, dry weight, plant height and root length.

### 2.4. Statistical Analysis

The loss of different forms of nitrogen ($L$, unit: mg) from runoff in the soil trough during the artificial rainfall experiment was calculated by using the integral method [29]:

$$L = 6 \times 10^4 \sum_{i=1}^{n} Q_i t_i c_i \tag{1}$$

where $Q_i$, $c_i$ and $t_i$ represent the runoff flow rate in the $i$-th sampling period, the nitrogen concentration in the water sample and the sampling interval time, respectively.

The nutrient runoff loss coefficient ($R$) was calculated to evaluate the nutrient loss of vegetable fields under different rainfall intensities and fertilization schemes:

$$R = \frac{L - L_0}{I} \times 100\% \tag{2}$$

where $L_0$ represents the amount of nitrogen loss in the vegetable field without fertilization, and $I$ represents the amount of nitrogen input in the vegetable field under different fertilization treatments.

The least significant difference tests (LSD, significance level $p < 0.05$) and the Pearson correlation analysis were conducted by using SPSS 25 statistical software (IBM Corp., Armonk, NY, USA). LSD test was used to assess the effects of fertilization schemes on growth indicators of pak choi. Pearson correlation analysis was applied to determine the relationships between AN, NN and DN losses with the selected environmental factors (rainfall intensity, nitrogen fertilizer amount and runoff).

## 3. Results

### 3.1. Plant Growth

Figure 2 shows that the growth indicators of the pak choi in nine soil troughs. Root length is one of the most important indicators of plant morphology. The average pak choi root length of CK, CF and OF were 6.07 cm, 7.57 cm, and 8.04 cm, respectively. Compared with CK, the root length increased by 24.6–32.5% after using chemical fertilizer. The average plant height of pak choi without fertilization treatment was 8.92 cm, while after fertilization treatment heights increased by 31.8–35.4%. The fertilizer treatment increased plant dry weights by 42.1–49.0% and the fresh weight by 52.4–61.9%. The LSD tests of plant growth indicators showed a significant difference in the morphological indices between fertilization and non-fertilization treatments of pak choi ($p < 0.05$, Table 2), indicating that fertilizer application has a significant promotion on pak choi growth.

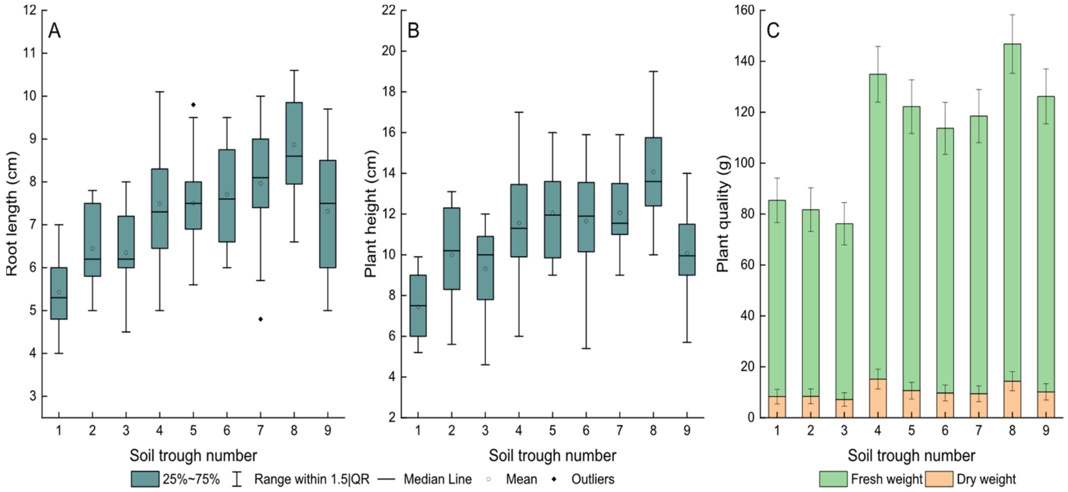

**Figure 2.** Root length (**A**), plant height (**B**), fresh weight, and dry weight (**C**) of pak choi in nine soil troughs.

**Table 2.** LSD tests of growth indicators of pak choi under different fertilization schemes.

| Pak Choi Growth Indicators | Fertilization Schemes | | Mean Difference | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|
| | I | J | (I–J) | | | Lower Bound | Upper Bound |
| Root length | CK | CF | −1.5027 * | 0.2673 | <0.001 | −2.031 | −0.974 |
| | | OF | −2.0159 * | 0.273 | <0.001 | −2.556 | −1.476 |
| | CF | OF | −0.5133 | 0.2673 | 0.057 | −1.042 | 0.015 |
| Plant height | CK | CF | −2.8472 * | 0.541 | <0.001 | −3.917 | −1.777 |
| | | OF | −3.2545 * | 0.5526 | <0.001 | −4.348 | −2.162 |
| | CF | OF | −0.4074 | 0.541 | 0.453 | −1.477 | 0.663 |

CK is control check, F is conventional fertilization treatment, and OF is optimized fertilization treatment. * indicates the mean difference is significant at the 0.05 level.

### 3.2. Nitrogen Loss at Different Rainfall Intensities

Over the course of the experiments, rainfall intensities had larger effect on interflow duration than surface runoff duration. In the early stage of rainfall, rainwater was mainly consumed in filling the depression, infiltration and replenishing the water shortage in soil. There was obvious lag from rainfall to runoff production, which is called the initial loss duration. For all three rainfall intensities, surface runoff always started to produce flow within 4 min, while the initial loss duration of interflow decreased with the increase of rainfall intensity (Table 3). After 39 min 46 s of rainfall, soil trough 1 (ST1) began to produce interflow, with the longest initial loss duration, while ST6 had the shortest initial loss duration of interflow, only 4 min 50 s.

**Table 3.** Initial loss durations of surface runoff and interflow in soil troughs.

| Soil Trough | Surface Runoff | Interflow |
|---|---|---|
| 1 | 3 min 27 s | 39 min 46 s |
| 2 | 2 min 40 s | 25 min 50 s |
| 3 | 2 min 10 s | 12 min 20 s |
| 4 | 3 min 20 s | 38 min 40 s |
| 5 | 3 min 58 s | 13 min 3 s |
| 6 | 2 min 30 s | 4 min 50 s |
| 7 | 3 min 10 s | 33 min 50 s |
| 8 | 2 min 48 s | 16 min 47 s |
| 9 | 2 min 20 s | 8 min 30 s |

Figure 3 shows the variations in AN, NN and DN concentrations over time in surface runoff and interflow of nine soil troughs. AN concentration in the initial runoff was highest in ST8 (1.026 mg·L$^{-1}$) and lowest at in ST2 (0.278 mg·L$^{-1}$). NN concentrations in surface runoff peaked at the beginning of runoff generation, gradually declined, and then stabilized around 15 min of runoff generation. The initial concentration of NN in surface runoff declined with the growth of rainfall intensity, which manifested as $C_{54\ \mathrm{mm \cdot h}^{-1}} > C_{75\ \mathrm{mm \cdot h}^{-1}} > C_{99\ \mathrm{mm \cdot h}^{-1}}$. DN concentrations showed a trend of first decreasing and then stabilizing in surface runoff. The cumulative losses of DN in surface runoff from the nine soil troughs were lowest in ST1 (234.30 mg) and highest in ST6 (775.40 mg). Under the same fertilization scheme, the proportions of surface runoff DN loss with the rainfall intensity of 99 mm·h$^{-1}$ were the lowest, which were 96.1% (ST3), 91.5% (ST6) and 92.9% (ST9), respectively.

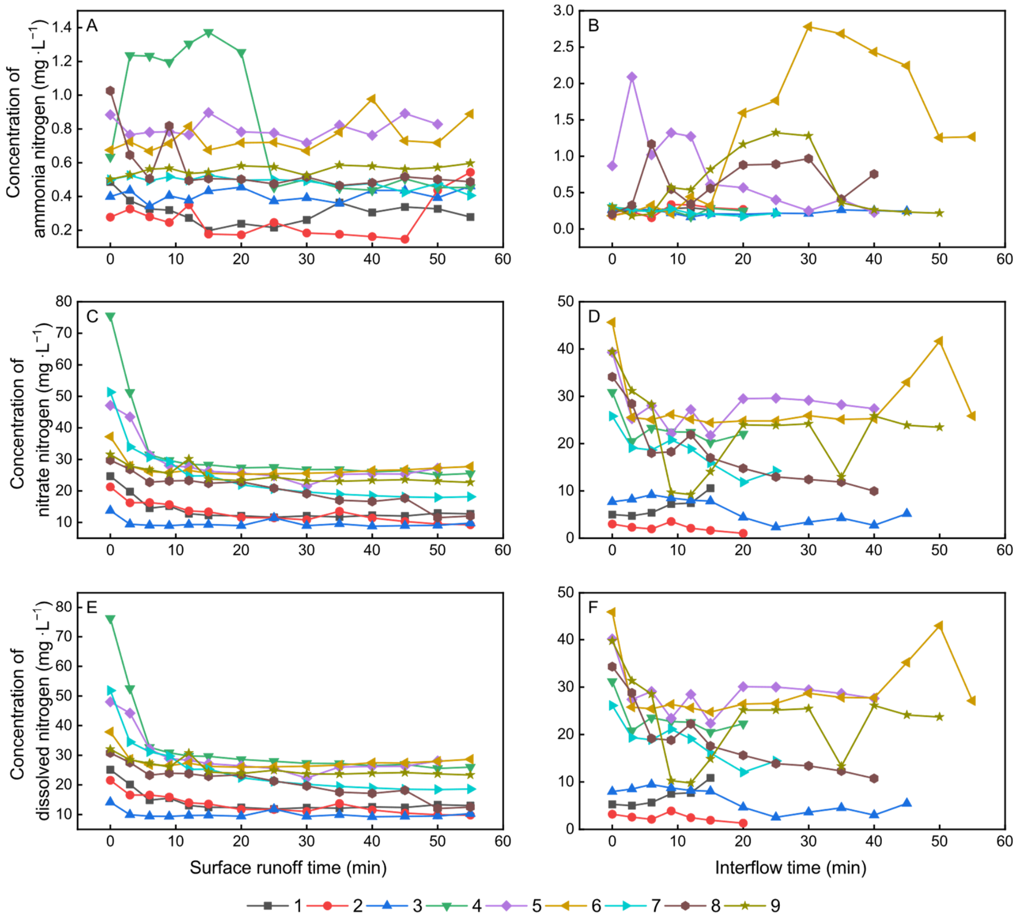

**Figure 3.** Changes of ammonia nitrogen (AN) (**A**,**B**), nitrate nitrogen (NN) (**C**,**D**), and dissolved nitrogen (DN) (**E**,**F**) concentrations over time in surface runoff (**A**,**C**,**E**) and interflow (**B**,**D**,**F**) in nine soil troughs.

### *3.3. Nitrogen Loss under Different Fertilization Schemes*

When the rainfall intensity was 54 mm·h$^{-1}$, the losses of AN and NN in surface runoff of the ST4 were the highest, 14.41 mg and 540.53 mg, respectively, while those in ST7 were the lowest, 0.05 mg and 4.10 mg, respectively. Under the rainfall intensity of 54 mm·h$^{-1}$ and 75 mm·h$^{-1}$, the DN runoff loss coefficients of CF were 5.00% and 6.00%, respectively, which were higher than those of OF (Table 4). When rainfall intensity increased to 99 mm·h$^{-1}$, the DN runoff loss coefficient of OF increased to 10.93%, which was larger than that of CF (9.14%). The amount of interflow DN loss grew gradually with the increasing nitrogen fertilizer application and rainfall intensity, and the largest proportion of DN loss in interflow was in ST6 (8.71%). The DN losses of CF were always the largest under three rainfall intensities, which were 558.90 mg (54 mm·h$^{-1}$), 663.85 mg (75 mm·h$^{-1}$) and 849.39 mg (99 mm·h$^{-1}$), respectively (Figure 4). Reducing the use of nitrogen fertilizer markedly reduced the loss of DN in runoff, with the most obvious effects at rainfall intensities of 54 mm/h and 75 mm/h, reducing the DN loss by 33.0% and 36.8%, respectively.

**Table 4.** Ammonia nitrogen (AN), nitrate nitrogen (NN) and dissolved nitrogen (DN) losses (mg) from soil troughs, and the proportion of nitrate nitrogen in dissolved nitrogen loss ($P_{NN}$), the proportion of dissolved nitrogen loss through surface runoff ($P_{SR}$) and dissolved nitrogen runoff loss coefficient (*R*).

| Soil Trough | AN | NN | DN | $P_{NN}$ | $P_{SR}$ | *R* |
|---|---|---|---|---|---|---|
| 1 | 5.16 | 230.17 | 235.33 | 97.8% | 99.6% | - * |
| 2 | 5.42 | 269.75 | 275.17 | 98.0% | 99.6% | - * |
| 3 | 10.68 | 246.95 | 257.63 | 95.9% | 96.1% | - * |
| 4 | 14.46 | 544.45 | 558.90 | 97.4% | 99.3% | 5.00% |
| 5 | 18.59 | 645.26 | 663.85 | 97.2% | 93.9% | 6.00% |
| 6 | 25.33 | 824.05 | 849.39 | 97.0% | 91.3% | 9.14% |
| 7 | 8.03 | 366.63 | 374.67 | 97.9% | 98.9% | 3.52% |
| 8 | 11.40 | 407.92 | 419.33 | 97.3% | 95.4% | 3.64% |
| 9 | 16.00 | 674.25 | 690.25 | 97.7% | 92.8% | 10.93% |

* In the control check (CK) group, *L* (Formula (2)) represents the amount of nitrogen loss in the vegetable field without fertilization, and $R = 0$.

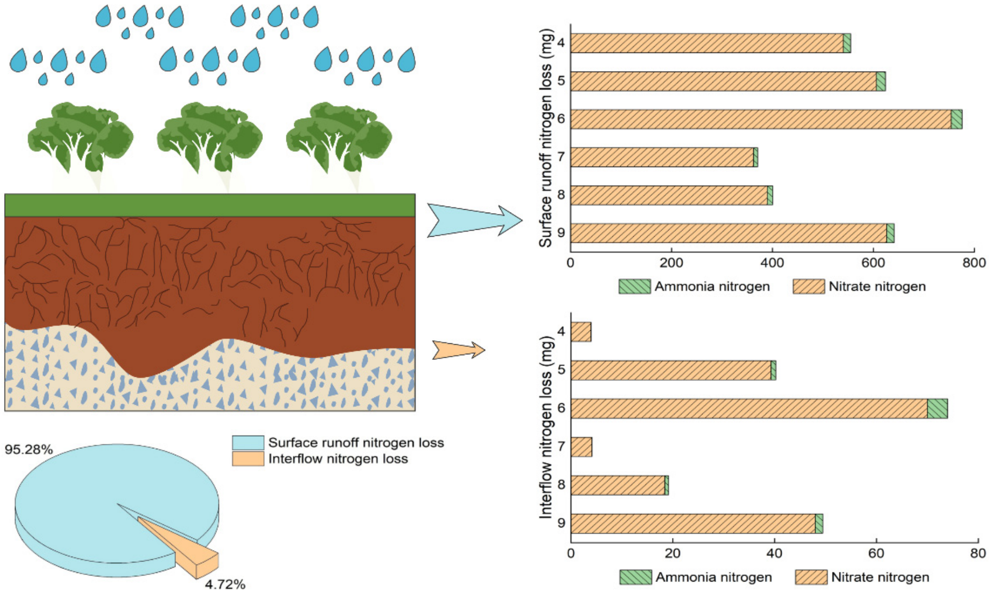

**Figure 4.** The amount of ammonia nitrogen (AN) and nitrate nitrogen (NN) loss, and the proportion of nitrogen loss in surface runoff and interflow.

### 3.4. Runoff and Nitrogen Loss

NN was a major component of DN loss, with the contribution of more than 95%. NN was more soluble in water than AN, and NN was more affected by runoff in interflow (Table 5). Surface runoff was the main approach for DN loss, and more than 91% of the DN was lost through surface runoff. The cumulative losses of DN in surface runoff were 10.77 ~ 271.25 times larger than those in interflow. The losses of AN and NN in ST6 were the largest, which were 25.33 mg and 824.05 mg, respectively, while those in ST1 were the smallest, which were 5.16 mg and 230.17 mg, respectively.

**Table 5.** Correlations between ammonia nitrogen (AN), nitrate nitrogen (NN) and dissolved nitrogen (DN) with rainfall intensity, fertilizer usage and runoff in surface runoff and interflow.

| **Influencing Factors** | **Surface Runoff** | | | **Interflow** | | |
|---|---|---|---|---|---|---|
| | **AN** | **NN** | **DN** | **AN** | **NN** | **DN** |
| Rainfall intensity | 0.485 | 0.365 | 0.369 | 0.659 | 0.687 * | 0.688 * |
| Fertilizer usage | 0.833 ** | 0.877 ** | 0.877 ** | 0.481 | 0.59 | 0.587 |
| Runoff | 0.638 | 0.535 | 0.539 | 0.786 * | 0.847 ** | 0.847 ** |

** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed).

Table 6 shows the fitting equations of nitrogen loss ($y$) and runoff ($x$) in surface runoff and interflow ($y = ax + b$). There were significant positive relationships between the amount of nitrogen loss and runoff ($r^2 > 0.96$, $p < 0.05$). The regression coefficients ($a$) of the NN-Runoff fitted equations were 7.55 ~ 88.99 times larger than those of AN-Runoff in the same soil trough, and the regression coefficients of surface runoff were generally larger than those of interflow. In both surface runoff and interflow, the regression coefficients of the DN-Runoff decreased in the order: $b_{CF} > b_{OF} > b_{CK}$. In addition, the correlation coefficients ($r^2$) of the fitted equations of DN-Runoff for CF were larger than OF under the same rainfall intensity, indicating that the amount of DN lost was closely related to the amount of nitrogen applied per unit area.

**Table 6.** Fitting equations * of ammonia nitrogen (AN), nitrate nitrogen (NN) and dissolved nitrogen (DN) loss ($y$) and runoff ($x$) in surface runoff and interflow.

| **Runoff Type** | **Soil Trough** | **Fitting Equation of AN-Runoff** | | | **Fitting Equation of NN-Runoff** | | | **Fitting Equation of DN-Runoff** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ***a*** | ***b*** | $r^2$ | ***a*** | ***b*** | $r^2$ | ***a*** | ***b*** | $r^2$ |
| Surface runoff | 1 | 0.2849 | 0.1405 | 0.9955 | 12.745 | 12.712 | 0.9961 | 13.03 | 12.852 | 0.9962 |
| | 2 | 0.222 | 0.1431 | 0.9898 | 12.275 | 12.186 | 0.9955 | 12.497 | 12.329 | 0.9956 |
| | 3 | 0.4063 | −0.015 | 0.9998 | 9.44 | 1.6821 | 0.9997 | 9.8463 | 1.6671 | 0.9997 |
| | 4 | 0.7984 | 1.206 | 0.951 | 28.199 | 34.336 | 0.9952 | 28.997 | 35.542 | 0.9949 |
| | 5 | 0.7974 | 0.0249 | 0.9998 | 26.355 | 32.593 | 0.9955 | 27.153 | 32.618 | 0.9958 |
| | 6 | 0.7464 | −0.2006 | 0.9991 | 26.056 | 7.1737 | 0.9999 | 26.802 | 6.9732 | 0.9999 |
| | 7 | 0.4837 | 0.0696 | 0.9994 | 21.223 | 22.554 | 0.9918 | 21.707 | 22.623 | 0.9921 |
| | 8 | 0.5114 | 0.3401 | 0.9983 | 19.492 | 15.199 | 0.9925 | 20.003 | 15.539 | 0.9927 |
| | 9 | 0.5624 | −0.0563 | 0.9999 | 24.155 | 9.5459 | 0.9993 | 24.717 | 9.4896 | 0.9994 |
| Interflow | 1 | 0.2676 | −0.0005 | 0.9991 | 6.6625 | −0.0453 | 0.9814 | 6.9301 | −0.0458 | 0.9825 |
| | 2 | 0.2855 | −0.0042 | 0.9955 | 2.156 | 0.0363 | 0.9819 | 2.4415 | 0.0321 | 0.9862 |
| | 3 | 0.2234 | 0.0017 | 0.9983 | 4.8447 | 0.8503 | 0.9638 | 5.0681 | 0.852 | 0.9671 |
| | 4 | 0.2491 | 0.0006 | 0.9983 | 22.167 | 0.0924 | 0.9987 | 22.417 | 0.0931 | 0.9987 |
| | 5 | 0.6233 | 0.1254 | 0.9274 | 27.318 | −0.0284 | 0.9989 | 27.942 | 0.097 | 0.9992 |
| | 6 | 1.711 | −0.446 | 0.9554 | 27.004 | −0.1365 | 0.996 | 28.715 | −0.5826 | 0.9958 |
| | 7 | 0.2256 | 0.0019 | 0.9945 | 17.327 | 0.179 | 0.9911 | 17.552 | 0.1809 | 0.9911 |
| | 8 | 0.7095 | −0.034 | 0.9924 | 16.001 | 1.593 | 0.9834 | 16.71 | 1.559 | 0.9853 |
| | 9 | 0.7573 | −0.0524 | 0.9636 | 20.356 | 0.4757 | 0.9951 | 21.114 | 0.4232 | 0.9956 |

* The form of the fitting equation is $y = ax + b$, $r^2$.

## 4. Discussion

### 4.1. Effect of Fertilization on Vegetable Growth

Among all the essential nutrients for vegetable growth, nitrogen is one of the primary factors limiting plant growth and yield. The main nitrogen species that could be absorbed and utilized by plants are AN and NN [30]. To pursue high yields of marketable crops, nitrogen fertilizer is widely overused in China and many other countries, with the serious consequence of environmental pollution and health damage [31–33]. In practice, it is not easy to balance the vegetable yield and nitrogen fertilizer usage. Many studies have explored the relationship between the amount of nitrogen fertilizer and the yield, plant height, nitrate content and other vegetable growth indicators [34–36]. One research found that when nitrogen fertilizer usage was less than 531 kg·hm$^{-2}$, the yield of Chinese cabbage and the nitrate content in the plant increased with the growing use of chemical fertilizer, while the vitamin C content showed an opposite trend [37]. In our study, the yield, root length and plant height of pak choi were substantially improved after fertilization treatment, which increased by 52.4%, 24.6% and 31.8%, respectively, with the CF treatments, and 62.9%, 32.5% and 35.4%, respectively, with the OF treatments. Other experiments also suggest when the amount of nitrogen applied exceeded a significant turning point, the yield of Chinese cabbage remained unchanged or even declined, and the utilization rate of nitrogen fertilizer decreased markedly, resulting in a large amount of fertilizer waste.

### 4.2. Effect of Rainfall Intensity, Fertilization Schemes and Zeolite on Nitrogen Loss

Excessive application of chemical fertilizer is the primary cause of serious soil and water degradation [38]. Researches have shown that only around 10% of the 120 million tons of nitrogen used for food production are directly consumed by humans in the world each year [39,40]. In our study, different from CF, OF reduced nitrogen fertilizer application by 38.9% and DN losses by 28.4%, but promoted plant root length, plant height and yield by 6.3%, 2.7% and 5.6%, respectively. The field trials in four consecutive years show that 40% decrease in traditional nitrogen fertilizer usage would not reduce crop yields but reduce nitrogen loss significantly [41]. This is consistent with our experimental results. Reducing the amount of nitrogen fertilizer would improve the utilization rate of nitrogen fertilizer, reduce production costs, and maintain vegetable production.

Runoff loss is the most important way of soil nutrient loss. There are many factors affecting soil nutrient loss with runoff, including rainfall characteristics, soil characteristics, terrain characteristics, land cover and land use types and others [42,43]. They mainly affect soil nutrient loss by affecting runoff or sediment yield [44]. In our experiment, the DN loss in surface runoff and interflow with a rainfall intensity of 99 mm·h$^{-1}$ was the largest in the three rainfall intensities (Figure 4). Meanwhile, the rainfall intensity had a larger effect on the interflow than the surface runoff. When the rainfall intensity increased from 54 mm·h$^{-1}$ to 99 mm·h$^{-1}$, the amount of DN lost in interflow increased by 881–1768%. This is in a good agreement with the research results of Wang et al. [45] on the effect of soil erodibility on effective nitrogen loss under simulated rainfall scenarios. In addition, the correlation analysis results showed that the surface runoff DN loss had a significant positive correlation with rainfall intensity ($p < 0.05$) (Table 5).

In our experiments, surface runoff was the main approach of DN loss (91.3–99.6%). The proportion of DN loss through surface runoff decreased with the increase of rainfall intensity. Our experiment results are different from those of Wu et al. [46] and Chen et al. [47] that interflow is the main approach of nitrogen loss on slope. The main reason is the different soil types between studies. Compared with red soil [46] and yellow brown soil [47], sandy loam has better aeration and water permeability, and is not easy to produce water retention, waterlogging, and interflow. In this study, the application of zeolite reduced surface runoff by 3.13–9.56%. Studies have shown that the use of zeolite as a soil conditioner can improve the water-holding capacity and available water content of soil [48,49]. Meanwhile, using zeolite powder as nitrogen fertilizer carrier can effectively absorb AN, reduce the loss of nitrogen in the process of nitrogen application, significantly extend the storage period of N in the soil, and improve the utilization rate of N [49,50].

### *4.3. Relationship between Runoff and Nitrogen Loss*

Studies have shown the significant relationship between runoff output and rainfall [51,52]. Similarly, the correlation analysis of our experimental data showed a significant positive correlation between interflow runoff and the loss of AN ($p < 0.05$), and a strongly significant positive correlation between interflow runoff with loss of NN and DN ($p < 0.01$) (Table 5). The responses of the amount of DN loss in surface runoff and interflow to external factors are different. Fertilizer usage is the main factor affecting DN loss in surface runoff, while runoff and rainfall intensity play stronger roles in interflow. In order to minimize the loss of DN in vegetable field, not only the fertilization scheme should be optimized, but also the water holding capacity of soil should be improved [53]. In practice, it is extremely important to control runoff. Considering the difficulty to change the intensity of natural rainfall, the impact of rainfall intensity on the runoff can be reduced by increasing the canopy retention and surface retention through increasing ground cover and planting hedges, thus reducing the loss of nitrogen from the vegetable field [54,55].

### *4.4. Limitations and Future Research*

Like many studies, there are some limitations in the current study. The experimental method is affected by the uncertainty of the soil condition and stratification of the soil trough to simulate vegetable field. The soil troughs can simulate the plant growth environment and control well the vegetable growth conditions such as water, fertilizer, rainfall, and light, but it is difficult to completely simulate the complex environment of real vegetable plots. Wang et al. [56] compared the effects of bone charcoal powder and algae fertilizer on the remediation of contaminated farmland under laboratory and field conditions. Their results showed that compared with field experiments, the root systems in the potted plant experiments were limited, and the effect of passivation agent was higher. In addition, current research has focused on analyzing the trends of AN, NN and DN in surface runoff and interflow, without involving the analysis of microorganisms such as nitrogen fixing bacteria. Recent studies have shown that the use of biofertilizers can reduce nutrient loss from agricultural fields due to rainfall runoff, thus reducing agricultural non-point source pollution [57,58]. The practice of substituting 50% urea with biofertilizer containing Bacillus subtilis can reduce the nitrogen loss from farmland soil by 54%, which reduces the accumulation of $NO_3$-N in soil and greatly reduces nitrogen runoff and leaching loss [59]. Therefore, future studies can simulate the nitrogen loss process in vegetable plots under near-real conditions by expanding the volume of the soil trough or using field experiments and analyze the effect of soil microorganisms on nitrogen loss from agricultural fields.

## 5. Conclusions

In this study, a series of experiments were conducted to analyze the effect of rainfall intensity and fertilizer scheme on N loss in vegetable fields in Hebei, China. Compared with the CF, the amount of nitrogen fertilizer applied in the OF decreased by 38.9%, and the loss of DN decreased by 28.4%, but plant root length, plant height and yield increased by 6.3%, 2.7% and 5.6%, respectively. Amount of fertilizer application had significant positive correlation with the loss of AN, NN and DN in surface runoff ($p < 0.01$). NN is the main component of DN loss, accounting for more than 95%. Surface runoff is the major approach for DN loss in vegetable fields. The proportion of DN loss through surface runoff was more than 91.3% and it decreased with the increase of rain intensity. The runoff was significantly positively correlated with the AN loss ($p < 0.05$) and strongly significantly positively correlated with the NN and DN losses ($p < 0.01$) in interflow. Runoff and rainfall intensity are the main factors affecting nitrogen loss in interflow, while fertilizer usage is the main factor affecting nitrogen loss in surface runoff. The use of zeolite is effective in reducing field runoff. Reducing the amount of nitrogen fertilizer can properly improve the utilization rate of nitrogen fertilizer, reduce production costs, and maintain vegetable production. Controlling the DN loss in vegetable fields lies in controlling fertilization programs, improving soil water holding capacity, and reducing the generation of runoff, which are important methods to effectively reduce nutrient loss and agricultural non-point source pollution.

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