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The Influence of Climate, Soil Properties and Vegetation on Soil Nitrogen in Sloping Farmland

Shanshan Liu [1], Tianling Qin [1,*], Biqiong Dong [1], Xuan Shi [2], Zhenyu Lv [1] and Guangjun Zhang [3]

1 State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing 100038, China; liushanshan198705@163.com (S.L.); bqdong92@126.com (B.D.); lvzyiwhr@163.com (Z.L.)
2 College of Engineering, San Jose State University, San Jose, CA 95192, USA; xuan.shi@sjsu.edu
3 College of Conservancy Engineering, Zhengzhou University, Zhengzhou 450000, China; zgj1111007663@163.com
* Correspondence: tianling406@126.com; Tel.: +86-010-6878-1316

Abstract: Soil nitrogen in farmland ecosystems is affected by climate, soil physical and chemical properties and planting activities. To clarify the effects of these factors on soil nitrogen in sloping farmland quantitatively, the distribution of soil total nitrogen (TN) content, nitrate nitrogen (NO_3-N) content and ammonium nitrogen (NH_4-N) content at depth of 0–100 cm on 11 profiles of the Luanhe River Basin were analyzed. Meanwhile, soil physical and chemical properties, climatic factors and NDVI (Normalized Difference Vegetation Index) were used to construct a structural equation which reflected the influence mechanism of environmental factors on soil nitrogen concentration. The results showed that TN and NO_3-N content decreased with the increase of soil depth in the Luanhe River Basin, while the variation of NH_4-N content with soil depth was not obvious. Soil organic carbon (SOC) content, soil pH, soil area average particle size (SMD) and NDVI6 (NDVI of June) explained variation of TN content by 77.4%. SOC was the most important environmental factor contributing to the variation of TN content. NDVI5 (NDVI of May), annual average precipitation (MAP), soil pH and SOC explained 49.1% variation of NO_3-N content. Among all environmental factors, only NDVI8 (NDVI of August) had significant correlation with soil NH_4-N content, which explained the change of NH_4-N content by 24.2%. The results showed that soil nitrogen content in the sloping farmland ecosystem was mainly affected by natural factors such as soil parent material and climate.

Keywords: sloping farmland; soil nitrogen; structure equation; soil physicochemical properties; climate; NDVI

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1. Introduction

In a sloping farmland ecosystem, the soil nitrogen content not only affects soil fertility [1], but also affects the non-point source pollution load into the water body due to rainfall runoff [2]. In a sloping farmland ecosystem, TN, NO_3-N and NH_4-N content are affected by the input and output process and the internal nitrogen cycle process of the soil. Fertilization, crop absorption, crop litter entering the soil, runoff and sediment, and nitrogen-fixing microbial absorption directly affect the process of soil nitrogen input and output. Meanwhile, the content of different forms of nitrogen in the soil are mineralized, nitrificated and denitrificated under the action of microorganisms. During the process, temperature, soil physical and chemical properties, and soil moisture content affected by precipitation play a key role in the reproduction and growth of soil microorganisms (Figure 1).

Up to now, few studies have focused on the distribution of soil nitrogen in soil profiles, especially for agricultural ecosystems. Farmland soil nitrogen in different regions showed a variety of changes in soil profile: the alkaline hydrolyzable nitrogen contents below 20 cm varied extensively (increased, reduced, or constant) compared with that above 20 cm in

Southern Brazil [3]. The dissolved organic nitrogen (DON) content showed a steep decrease with the increase of paddy soil depth in Fuzhou, China, while the proportion of DON to total dissolved nitrogen (TDN) increased from 54–64% to 63–97% [4]. On the Loess Plateau of China, the TN content of surface soil (0–10 cm) was significantly higher than that of deeper soil (10–30 cm). The NO_3-N content at depth of 10–30 cm was higher than that at 0–10 cm and 30–60 cm, but it was contrary for NH_4-N content [5]. Other scholars found that the NO_3-N content at depth of 0–10 cm was the highest and decreased significantly along depth of 10–40 cm in the Loess Plateau of China [6]. The natural content of soil nitrogen is influenced by the soil-forming process which is controlled by climate, soil physical and chemical properties, topography, etc., [7]. Climate is the initial controlling factor of the biogeochemical cycle of soil nitrogen [8]. Several researchers have reported that warming accelerated nitrogen fluxes in forest or grassland soils [9,10], and precipitation affected soil nitrogen content by influencing plant community growth in semi-arid ecosystems [11]. As the parent material of soil, soil type determines the initial value of soil nitrogen [12]. Particle distribution determines soil texture, soil aeration and water retention characteristics. Due to the different specific surface area and chemical binding capacity of soil particles of different sizes, the absorption of soil nutrients by soil particles of different sizes is different [13]. In agricultural ecosystems, fertilizer input is an important factor for the increase of soil total nitrogen content [14]. Long-term fertilization tends to increase the nitrogen content in the surface layer and accelerate nitrogen fixation and retention [15].

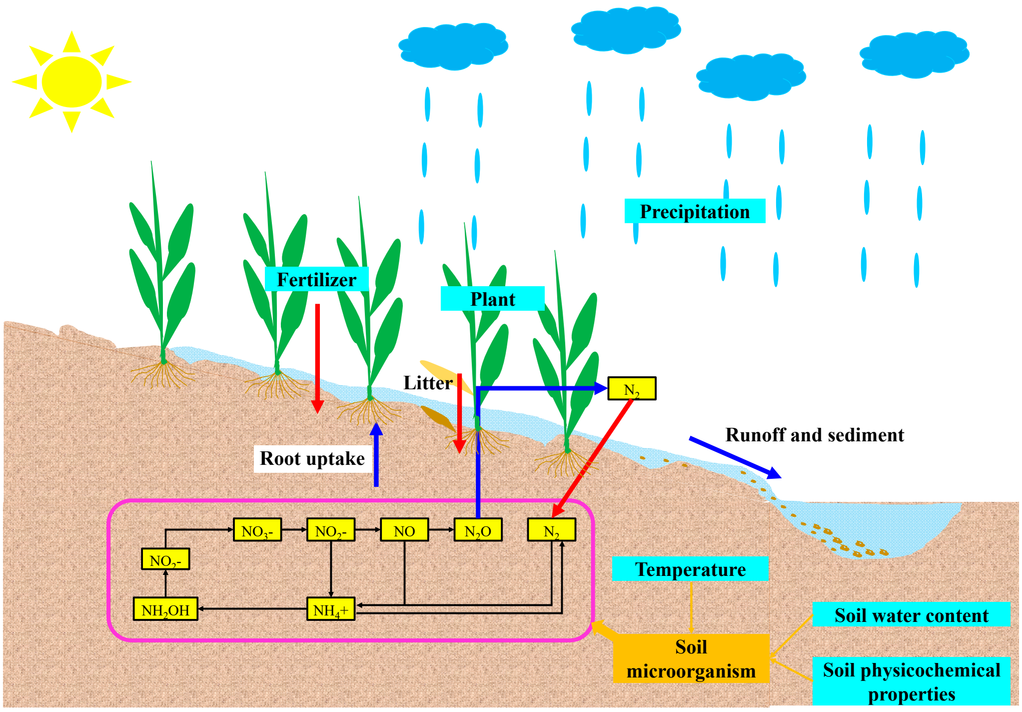

Figure 1. Soil nitrogen cycle in sloping farmland.

Focusing on the vertical distribution characteristics and influencing factors of soil nitrogen, the middle and upper reaches of the Luanhe River Basin, where the sloping farmland accounts for more than 20%, was selected as the study area. The content of TN, NO_3-N and NH_4-N were selected as soil nitrogen indices. The objectives of this study are: (1) to analyze the variation patterns of soil TN content, NO_3-N content and NH_4-N content with soil depth on sloping farmland in arid and semi-arid areas; (2) to evaluate the effects of soil physical and chemical properties, climate and vegetation on soil TN content, NO_3-N content and NH_4-N content quantitatively.

2. Study Area

The Luanhe River Basin, ranging from 115°34′ E to 119°50′ E and 39°02′ N to 42°43′ N, which is located in the northeastern part of the North China, is a sub-basin of the Haihe River Basin (Figure 2). This area experiences a typically temperate semi-humid and semi-arid continental monsoon climate. The climate is rainy and hot in summer and cold and dry in winter. The annual average temperature is 7.8 °C. The annual average precipitation is 538.5 mm. Dry land is the main land use form in the Luanhe River Basin, accounting for 26.27% of the total area of the basin, of which the area of sloping farmland with slope of 3–15 degrees accounts for 89%. Under the comprehensive influences of climate, geology, geomorphology, biology, hydrothermal and other land surface processes and human activities, 12 types of soils were formed in the basin, including brown soil, cinnamon soil, chestnut soil, alluvial soil, gray forest soil, skeleton soil, meadow soil, aeolian sandy soil, chisley soil, bog soil, chernozem and saline soil. Among them, cinnamon soil, brown soil and alluvial soil are the main soil types in dry land.

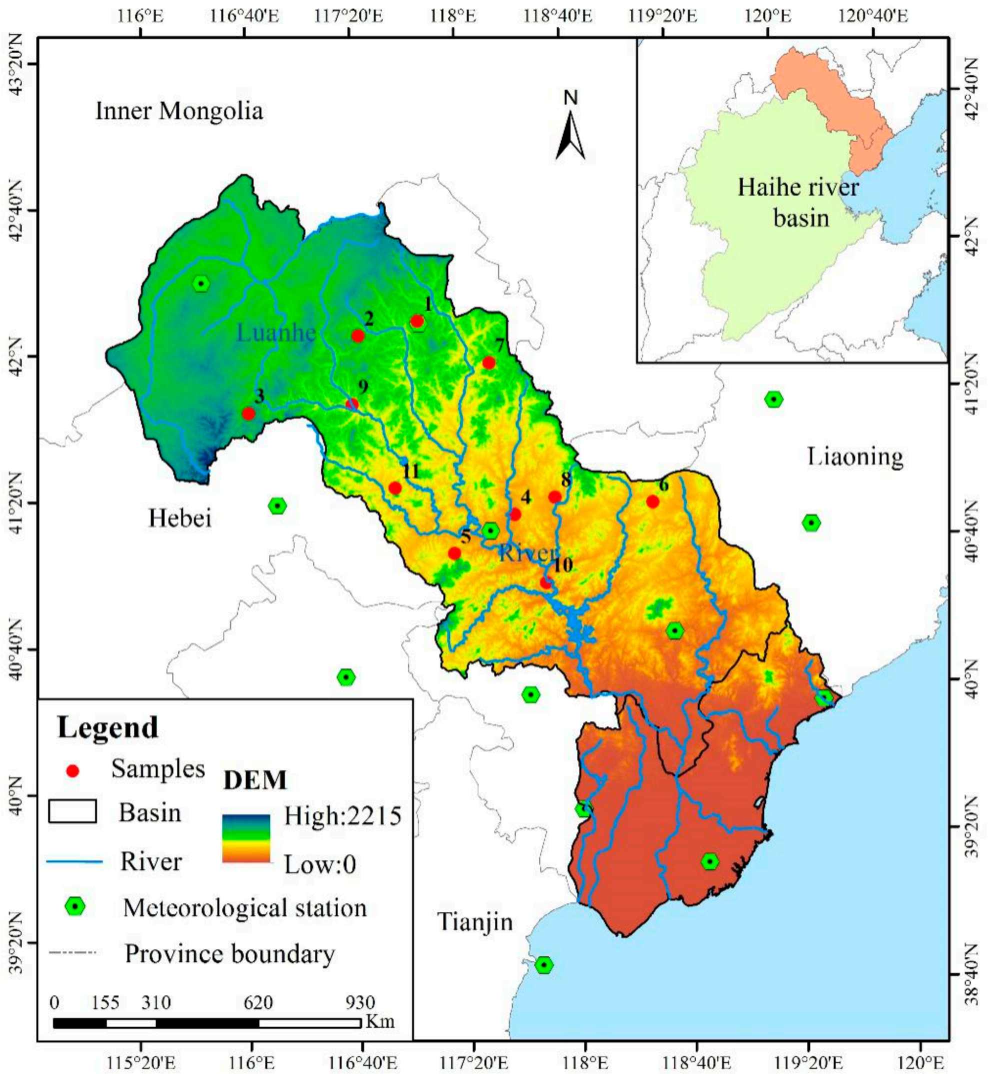

Figure 2. Study area and sampling points.

3. Materials and Methods

In this study, the content of TN, NO_3-N and NH_4-N in soil, SOC content, soil pH and SMD of sloping farmland within 0–100 cm depth were obtained by field sampling and laboratory testing, as listed in Table S1. Secondly, the distribution characteristics of TN content, NO_3-N content and NH_4-N content in different soil depths and different soil types were analyzed. Finally, a structural equation which contains the functional relationship among soil physical and chemical properties, climate and vegetation data on soil TN, NO_3-N and NH_4-N content was constructed, and the contribution of each factor to soil nitrogen content change was determined (Figure 3).

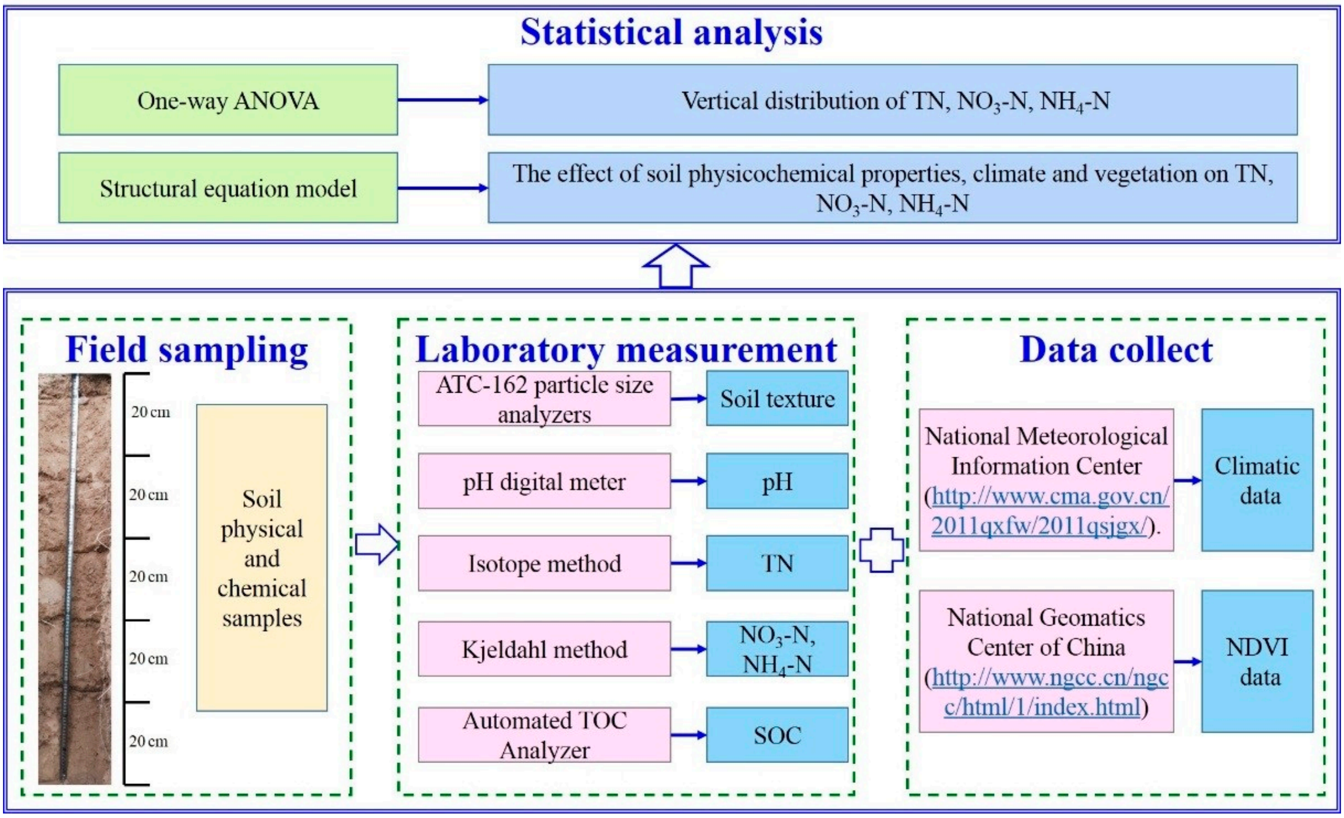

Figure 3. Research workflow.

3.1. Sample Points and Sample Collection

The location of sampling points was determined based on DEM (Digital elevation model), land use, soil and river data. The specific method was: (1) The slope of the Luanhe River Basin was calculated by DEM data, and the area of 3–15° was selected. (2) Dry land was picked based on land use data, and then dry land with 3–15° was considered sloping farmland. (3) The proportion of soil types of sloping farmland was calculated based on soil type data. The number of sampling points of different soil types were determined. (4) According to the principles of uniformity between left and right banks, 11 sampling points were set up in the upper reaches of the basin. In the actual sampling process, appropriate adjustments were made according to the site conditions and whether the sampling point could be reached. The actual sampling point distribution is shown in Figure 2. In the period from 23 to 28 April 2018, 55 soil samples were collected. After choosing sampling points, a profile of 2 × 1 × 1 m was excavated by tools to collect soil samples. The sampling depths were 0~20, 20~40, 40~60, 60~80 and 80~100 cm, respectively. Five hundred grams of fresh soil samples were taken back to the laboratory to measure soil particle grading, soil pH, TN content, NO_3-N content, NH_4-N content and SOC content. According to the international standard system, soil particle grading was obtained by ATC-162 particle size analyzers (HELOS/RODOS/M SYMPATEC GmbH, Clausthal-Zellerfeld, Germany). TN content was measured by the isotope method (stable isotope mass spectrometer, Isoprime 100, Beijing Jiade Element Technology Co., Ltd., Beijing, China). Kjeldahl method (KDY-9820, Beijing Tongrunyuan Electrical and Mechanical Technology Co., Ltd., Beijing, China) was used to measure NH_4-N and NO_3-N content. Soil pH was measured by pH meter (pH510, OAKTON). SOC content was determined using an automated TOC analyzer (Shimadzu, TOC-VCPH, Japan). The soil types at Nos. 1, 2, 3 and No. 11 sampling points were brown soil, at Nos. 4, 5, 6, 7 and 8 were cinnamon soil, and that at Nos. 9 and 10 were alluvial soil. Both field investigations and the Hebei Rural Statistical Yearbook [16] showed that the average application rate of nitrogen fertilizer was 218.8 kg/ha in the sloping farmland of the Luanhe River Basin. We assumed that the fertilization amount at all sampling points was the same, eliminating the effect of fertilization on soil nitrogen content. The input of nitrogen deposition in the Luanhe River Basin was less than 10% of the amount of nitrogen fertilizer [17]. Nitrogen deposition was negatively correlated with the distance from the provincial capital [18]. Although the Luanhe River Basin belongs to Haihe River Basin, all sampling sites were far away from Beijing, Tianjin and other big cities, so the effect of nitrogen deposition was not considered in this study.

3.2. Climate and Vegetation Data Sources

The daily air temperature and precipitation data of the basic meteorological stations over the years (1959–2016) were obtained from the National Meteorological Information Center (http://www.cma.gov.cn/2011qxfw/2011qsjgx/). The available stations of the Luanhe River Basin were selected according to the Thiessen polygon. The method first divides the area into a large number of acute triangles by connecting adjacent meteorological stations, then makes vertical bisectors in each of the triangles. The intersecting vertical bisectors around each station form a polygon; if the polygon covered the sampling points, the meteorological stations could be used. In our study, the inverse distance weighted method was used to distribute the above data in space, and the climate data of the sampling points were obtained. Vegetation cover data (Normalized Difference Vegetation Index, 500 m $\times$ 500 m) were derived from the National Geomatics Center of China (http://www.ngcc.cn/ngcc/html/1/index.html). The monthly NDVI data in the growing season (April to October) were obtained. NDVI4, NDVI5, NDVI6, NDVI7, NDVI8, NDVI9 and NDVI10 represented NDVI in April, May, June, July, August, September and October.

3.3. Statistical Analysis Method

The maximum (MAX), minimum (MIN), mean, variance and coefficient of variation (CV) of TN, NO_3-N and NH_4-N content were obtained by SPSS 18.0. The CV determined the degree of spatial variation of the variables. In general, when the CV is less than 0.1, the variability is classified as weak, when in the range from 0.1 to 1.0 the variability is classified as moderate, and when the CV is larger than 1.0 it represents high variability [19]. One-way analysis of variance (ANOVA) and the LSD test were used to evaluate the differences of TN, NO_3-N and NH_4-N content in different soil depths and of different soil types. Structural equation modeling (SEM) [20] was conducted to evaluate effects of climate, soil physicochemical properties and plant communities on TN, NO_3-N and NH_4-N content. The SEM analysis was performed using Amos 24.0 (IBM, SPSS, Armonk, NY, USA). The K-S test was used to test the normality of the variables. Logarithm transformation and Box–Cox transformation were used to transform the variables that did not meet normality and homoscedasticity of errors.

4. Results

4.1. Distribution Characteristics of Soil Nitrogen

TN content and NO_3-N content decreased with the increase of soil depth vertically. TN content decreased from 0.84 to 0.58 g/kg, and NO_3-N content decreased from 6.12 to 3.99 mg/kg, which reduced by 31% and 22%, respectively. The variation range of NH_4-N content with soil depth was relatively small. The spatial variation degree of TN content increased with the increase of soil depth, the spatial variation degree of NO_3-N content decreased with the increase of soil depth, and the spatial variation degree of NH_4-N with soil depth was not obvious. The content of TN and NO_3-N in different soil depths was classified as moderate spatial variation. The content of NH_4-N in the 0~20 cm soil layer was classified as moderate spatial variation, while that below the 20 cm soil layer was weak spatial variation. Significant difference was found for TN content between 0–20 and 80–100 cm soil depth. There was no significant difference in NH_4-N content and NO_3-N content in each soil layer (Table 1).

Table 1. Statistic summary of TN, NO_3-N and NH_4-N at different soil depths.

	Soil Depth	Max	Min	Average	Variance	CV
TN(g/kg)	0~20 cm	1.05	0.45	0.84 a	0.19	0.22
	20~40 cm	1.05	0.31	0.75 ab	0.26	0.34
	40~60 cm	1.26	0.23	0.65 ab	0.30	0.46
	60~80 cm	1.25	0.31	0.63 ab	0.32	0.51
	80~100 cm	1.13	0.15	0.58 b	0.30	0.52
NO_3-N(mg/kg)	0~20 cm	95.2	8.96	26.10 a	23.33	0.89
	20~40 cm	91	4.21	23.08 a	22.51	0.98
	40~60 cm	46.1	7.59	18.45 a	11.98	0.65
	60~80 cm	47.8	6.43	16.65 a	11.12	0.67
	80~100 cm	49.2	3.83	19.94 a	14.31	0.72
NH_4-N(mg/kg)	0~20 cm	3.28	2.36	2.73 a	0.38	0.14
	20~40 cm	2.94	2.38	2.62 a	0.21	0.08
	40~60 cm	2.94	2.13	2.55 a	0.28	0.11
	60~80 cm	2.88	2.41	2.61 a	0.15	0.06
	80~100 cm	2.94	2.35	2.59 a	0.19	0.07

Different letters indicate significant differences ($p < 0.05$).

By comparison, there was no significant difference for soil TN content and NH_4-N content in different soil types. The NO_3-N content in cinnamon soil was significantly higher than that in the other two soils, which was more than twice of that in brown soil and alluvial soil (Figure 4).

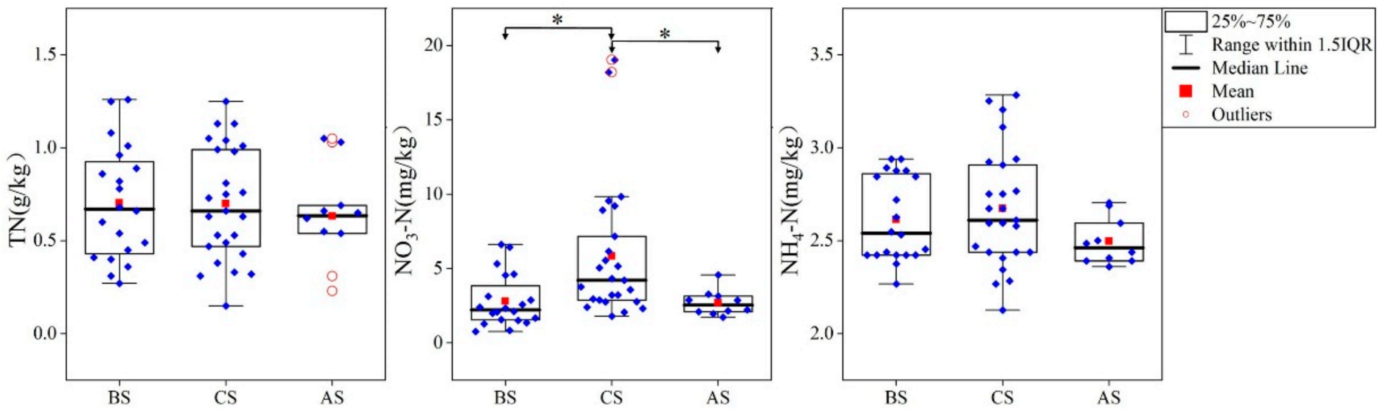

Figure 4. TN, NO_3-N and NH_4-N in three soil types. * mean that NO_3-N in BS were significantly different from that in other two types of soil with significance level ($p < 0.05$) using the LSD test. BS represents brown soil, CS represents cinnamon soil and AS represents alluvial soil.

4.2. Effect of Environmental Factors on Soil Nitrogen Content

Based on correlation analysis, environmental factors were filtered, and the structural equations of environmental factors on soil TN, NO_3-N and NH_4-N content were constructed (Figure 5). Overall, SOC, pH, SMD and NDVI6 explained 77.4% of the variation of TN content. The SOC was found to be the most important contributor to soil TN content (Table 2). The direct influence of SOC on TN was demonstrated in our study through path analysis, which showed a positive relationship (0.787, $p < 0.001$). NDVI6 was the second most important contributor to variation of TN content, which was positively related to TN

(0.37, $p < 0.001$). pH and SMD were positively (0.209, $p = 0.003$) and negatively (−0.215, $p = 0.001$) related with TN respectively.

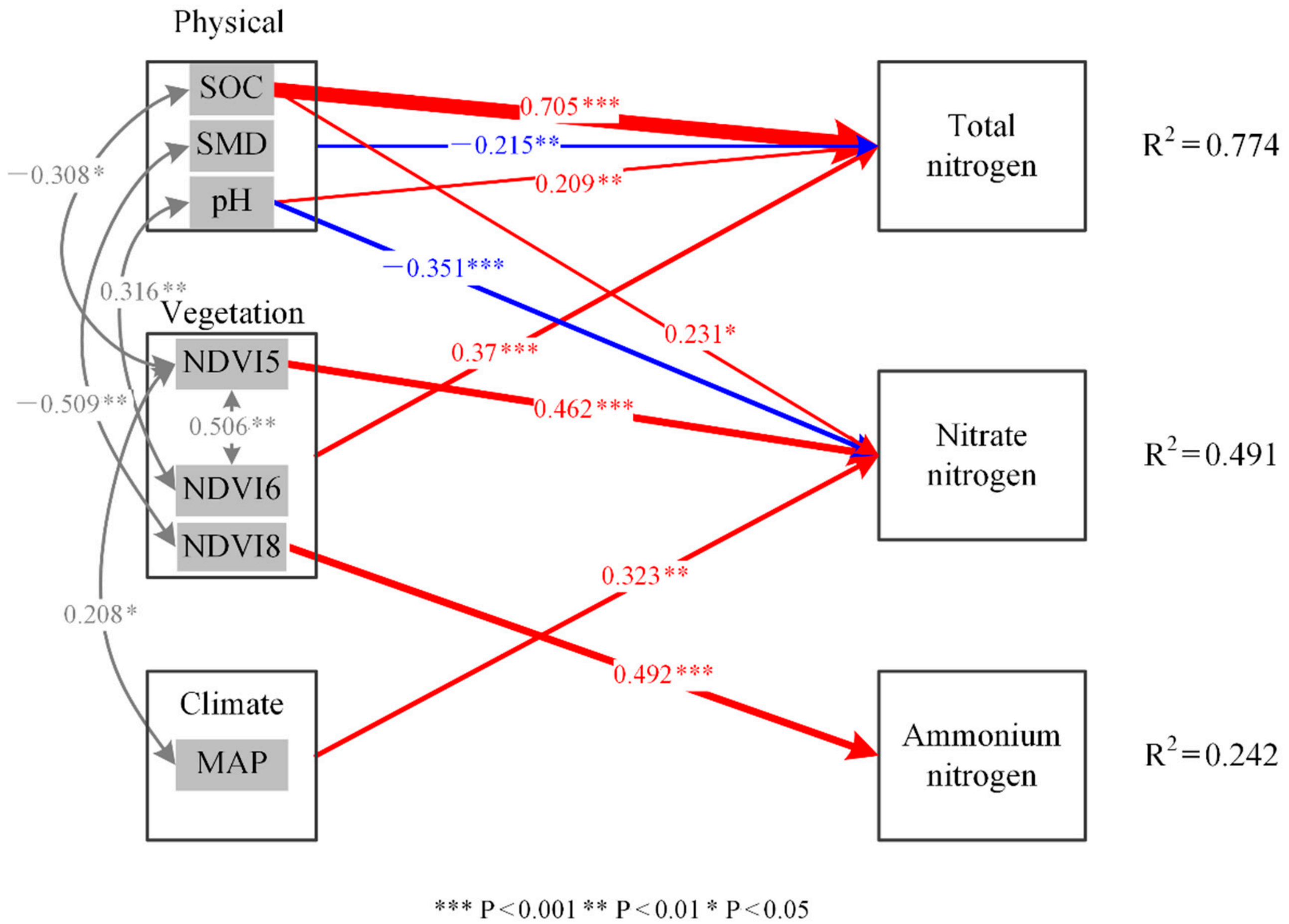

Figure 5. Structural equation models which explore the direct and indirect effects of environment factors on TN, NO_3-N and NH_4-N. Red arrows indicate positive relationship; blue arrows indicate negative relationship; gray arrows indicate the relationship between environment factors. Arrow width is proportional to the impact of environmental factors on different nitrogen content and the numbers above the arrows are standardized path coefficients.

Table 2. The contribution of environmental factors to TN, NO_3-N and NH_4-N alone and combined.

Soil Nitrogen	Contribution of the Individual Predictor (R^2, %)							Adj (R^2, %)
	SOC	**pH**	**SMD**	**NDVI5**	**NDVI6**	**NDVI8**	**MAP**	**Full Model**
TN	49.7	6.81	4.62	/	16.13	/	/	77.4
NO_3-N	2.03	12.32	/	21.16	/	/	13.53	49.1
NH_4-N	/	/	/		/	24.21	/	24.2

Contribution = correlation coefficient × path coefficient.

Path analysis results showed that NDVI5, MAP, pH and SOC explained 49.1% of the variation of soil NO_3-N content. Higher NDVI5 predicted higher NO_3-N content (0.492, $p < 0.001$). MAP and pH were positively (0.323, $p = 0.002$) and negatively (−0.351, $p < 0.001$) correlated with NO_3-N content respectively. SOC had a weak positive effect on soil NO_3-N content (0.231, $p = 0.025$). NDVI8 was positively correlated with NH_4-N content with a significant level (0.492, $p < 0.001$) and acted as the sole predictor of NH_4-N, which explained 24.2% of the variation of NH_4-N content (Tables 2 and 3, Figure 5).

Table 3. The path coefficient and significance of linear regression analysis for soil nitrogen.

Soil Nitrogen	SOC	pH	SMD	NDVI5	NDVI6	NDVI8	MAP	Full Model
TN	0.705 (0.000)	0.209 (0.003)	−0.215 (0.001)	/	0.37 (0.000)	/	/	0.774
NO_3-N	0.231 (0.025)	−0.351 (0.000)	/	0.462 (0.000)	/	/	0.323 (0.002)	0.491
NH_4-N	/	/	/	/	/	0.492 (0.000)	/	0.242

5. Discussion

5.1. Descriptive Statistics of Soil Nitrogen Content

The TN content of 0–100 cm soil in sloping farmland of the Luanhe River Basin ranged from 0.15 to 1.26 g/kg, with an average value of 0.69 ± 0.31 g/kg. The TN content of topsoil (0–20 cm) ranged from 0.45 to 1.05 g/kg, with an average value of 0.84 ± 0.19 g/kg. The value was more than twice of that in sloping farmland of the Loess Plateau (0.37 g/kg, [21]), less than half of that in East China (1.75 ± 0.43 g/kg, [22]) and about two-thirds of that in corn fields of Northeast China (1.3 ± 0.36 g/kg, [23]).

With the increase of soil depth, the TN content of sloping farmland in the Luanhe River Basin decreased (Table 1), and the TN content of topsoil (0–20 cm) was significantly different from that of bottom soil (80–100 cm) ($p < 0.01$). The decreasing trend of TN content in soil profile was consistent with the results of other studies [24,25]. With the increase of soil depth, the amount of fertilization and dead plants and animals decreased, and the soil nitrogen source decreased [26,27]. In some agroforestry and complex agricultural areas, the variation of soil TN content with depth was different from the above conclusion. In the semi-arid area of northern Ethiopia, the TN content of 20–30 cm soil was 0.02 g/kg higher than that of 10–20 cm, which may be related to the mixed agroforestry operation in the study area [28]. The variation of TN content in 0–100 cm soil of the Luanhe River Basin was moderate, which was consistent with the variation degree of soil TN content on the Loess Plateau [21], suburban Beijing [29] and East China [22]. The variation coefficient of soil TN increased with the increase of soil depth, which was consistent with the variation trend of the variation coefficient of soil TN content with soil depth of 0–60 cm on the Loess Plateau [5].

NO_3-N content in topsoil (0–20 cm) of sloping farmland in the Luanhe River Basin ranged from 1.79 to 19.04 mg/kg, with an average value of 5.12 ± 4.65 mg/kg, which was slightly higher than that in topsoil (0–10 cm) of farmland on the Loess Plateau (4.34 ± 2.6 mg/kg, [5]). In this study, the variation trend of NO_3-N content along soil depth in sloping farmland was the same as that on the Loess Plateau [6], which may be related to the fact that fertilization is mainly distributed in the crop root layer. The content of NH_4-N in topsoil (0–20 cm) of the study area ranged from 2.36 to 3.28 mg/kg, with an average value of 2.73 ± 0.38 mg/kg, which was lower than that in farmland surface soil of the Loess Plateau (5.37 ± 2.6 mg/kg, [5]). In this study, the variation trend of NH_4-N content with soil depth was not significant, which was different from the decreasing trend of NH_4-N content with increase of soil depth in Loess Plateau farmland [6]. It may be related to the fact that most of the chemical fertilizers used in the Luanhe River Basin are urea and compound fertilizer.

In our study, there was no significant difference in the content of TN and NH_4-N among the three soil types, but a significant difference existed in the content of NO_3-N (Figure 4). The content of nitrate nitrogen in cinnamon soil was more than twice of that in brown soil and alluvial soil. This may be related to soil texture. Excluding plant absorption factors, most NO_3-N in sloping farmland was lost by leaching. Compared with brown soil and alluvial soil, cinnamon soil has a stronger water holding capacity and shear capacity [30].

The functions of soil bacteria relevant to nitrogen metabolism were predicted by the PICRUSt program based on 16S rRNA sequencing data (Table S2). The abundance of enzymes for dissimilatory/assimilatory nitrate reduction, denitrification, complete nitrification, and nitrification decreased significantly along the soil profile. The relative abundances in 0–20 cm soil were significantly greater than those in 20–100 cm. The relative abundance of nitrogen fixation enzymes of 0–20 cm soil was significantly higher than that of 20–40 and 80–100 cm. These results showed that the nitrogen cycle was the most active in the 0–20 cm soil layer.

5.2. Effect of Soil Characteristics on Soil Nitrogen Content

The SEM analysis showed that the most important contributor for the variance of TN content was SOC content with a contribution of 49.7%. Correlation analysis showed that TN and SOC had a significantly linear relationship ($R = 0.705$, $p < 0.000$), which is consistent with results of previous studies [31–34]. With regard to the close correlation between the content of soil TN and organic carbon, many scholars put forward different explanations. On the one hand, the close correlation could attribute to the fact that most nitrogen is presented in organic forms during the soil development process [35,36]. On the other hand, the strong relationship was probably related to tightly coupled cycling of carbon and nitrogen in agricultural systems [33]. Prahl [37] pointed out that the soil microorganisms tend to use a fixed C/N ratio, but due the influence of rhizosphere exudates and litter, the ratios under different tree species or crops were different. The nitrogen transformation processes in soils (such as nitrification and denitrification) utilize energy from organic carbon [38]. Nitrogen supply increases the net uptake of carbon by stimulating biochemical determinants, including the photosynthetic enzymes [39], which in turn leads to higher input of carbon and nitrogen to the SOC pool. In addition, mineralization of organic matter not only leads to the breakdown of carbon substrates and emission of CO_2, but also to the release of plant-available inorganic nitrogen [40].

It is widely accepted that soil pH is an important factor which influences soil biochemical processes [41], so as to be an important factor for dynamics of soil nitrogen forms and content [40]. In previous research, the effects of soil pH on soil TN content were inconsistent. We found that soil pH had a positive effect on TN content, which is in accordance with the result of Zhang [42]. However, there were also contrary results found by Wang [25] and Xue [5]. The different relationships between TN and soil pH might be concerned with the different pH range of the study area. Meanwhile, soil pH affected nitrogen content by influencing the growth and reproduction of soil microorganisms [41] or by affecting the nitrogen cycle process (nitrification and denitrification) [43].

We found that soil pH had a negative effect on soil NO_3-N content. Early studies showed that when the pH was between 6.5 and 8, the nitrification was the strongest, but autotrophic nitrifying bacteria still had a strong nitrification ability in weak acid soil. When the pH was between 7 and 8, the denitrification was the strongest [44–46]. Further, it was found that a low pH decreases microbial activities and decomposition of soil organic matter. That might partly explain the relationship between pH and soil NO_3-N content.

In this study, the TN content was negatively correlated with SMD (average particle size of soil area); that is, the smaller the soil particles size, the higher the TN content, which was consistent with the previous research [13,47,48]. Soil particle may result in physical or chemical inaccessibility to decomposers through formatting closed environments or strong chemical bonds, and thus regulate soil nitrogen stocks [49,50]. Fine soil particles could physically protect carbon and nitrogen through physical barriers between microbes, enzymes and their substrates and consequently suppress microbial turnover. Soil chemical protection was the result of chemical or physicochemical binding of nitrogen to soil minerals [51,52]. From the perspective of soil and water loss, the soil with finer particles is loam, and its ability to cope with rainfall runoff is greater than that of sandy loam [53–55].

5.3. Effect of Climate and Vegetation on Soil Nitrogen Content

The soil moisture is generally considered as the limiting factor of the biochemical process in many terrestrial ecosystem processes, especially in the water-limited regions.

Rainfall infiltration can directly change soil moisture status. Therefore, similar studies about the positive effect of precipitation on soil nitrogen have been reported [56–58]. On one hand, precipitation could promote the growth of vegetation, which increases the absorption of nitrogen in vegetation and litter into soil, especially in arid and semi-arid areas where vegetation growth is limited by precipitation [59,60]. On the other hand, the increase of precipitation leads to the increase of soil moisture, accordingly a humid soil environment causes microbial activity related to the nitrogen cycle to be more active compared with that under a drought environment [61]. Generally speaking, NO_3-N leaching rarely happens in rain-fed agriculture of arid or semi-arid regions due to higher rates of evaporation compared with the rate of precipitation. However, under the impact of climate change, extreme daily precipitation events may occur in sloping farmland, which may lead to soil NO_3-N leaching in sloping farmland [62]. In this study, no irrigation was carried out in all sampling sites. With the increase of precipitation, the content of soil NO_3-N increased, which indicated that precipitation has a more obvious effect on the increase of soil NO_3-N content. Since temperature affected the rate of soil nitrogen mineralization and the activities of microorganisms related to nitrogen cycling [63,64], temperature was also a key environmental factor affecting soil nitrogen content [57,65]. However, both air temperature and soil temperature had no significant effect on soil nitrogen content in this study, which may be related to the small temperature range of all sampling points.

Vegetation is an important factor affecting soil nitrogen content in the terrestrial ecosystem. NDVI can reflect the type, growth and surface cover status of vegetation, which has been used as the main factor to predict the spatial distribution and storage of soil nitrogen in a variety of studies [66–69]. The planting habit of returning corn straw to the field is widespread in the study area. Previous studies showed that straw returning increased fresh organic matter and provided a rich nitrogen source for soil [70,71], which also provided more substrates for microorganisms and weakened the nitrogen absorption capacity of crops. At the same time, straw returning increased soil water storage capacity and reduced soil nitrogen leaching loss [68]. In this study, NDVI contributed to the variation of TN, NO_3-N and NH_4-N, and NDVI8 even acted as the unique contributor to NH_4-N in soil.

6. Conclusions

Based on the field experiment data of TN, NO_3-N and NH_4-N content and other soil physical and chemical properties of sloping farmland in the Luanhe River Basin, the distribution characteristics of soil nitrogen were analyzed, and the causes of soil nitrogen distribution were explored considering crop growth and climate factors. The main conclusions are as follows:

(1) Soil nitrogen content decreased with the increase of soil depth.

The TN content of topsoil in the Luanhe River Basin was higher than that on the Loess Plateau of China, but lower than that in East China and Northeast China. The content of TN and NO_3-N decreased with the increase of soil depth, and the TN content in the topsoil layer was significantly different from that in the bottom layer. The content of soil NH_4-N did not change significantly with soil depth. Spatially, the content of TN and NO_3-N showed moderate variability, while the content of NH_4-N showed weak variability.

(2) The influence factors of soil TN, NO3-N and NH4-N content were different.

SOC content, soil pH, SMD and NDVI6 explained 77.4% variation of soil TN content. SOC content was the most important environmental factor contributing to the variation of soil TN content. NDVI5, annual average precipitation, soil pH and organic carbon content explained 49.1% variation of soil NO_3-N content. Among all environmental factors, only NDVI8 had significant correlation with soil NH_4-N content, which explained the change of soil NH_4-N content by 24.2%.

The results showed that although affected by human planting activities, soil nitrogen content in a sloping farmland ecosystem in arid and semi-arid areas was mainly affected by natural factors such as soil parent materials and climate.

Supplementary Materials: The following are available online at https://www.mdpi.com/2071-1050/13/3/1480/s1, Table S1: Table with raw data might be useful to appreciate real differences between soils, Table S2: Numbers of KEGG modules related with soil nitrogen cycle difference among soil depths.

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