Path Analysis for Soil Total Nitrogen in Relation to Selected Soil Properties in a Short-Term Flooding Wetland

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Abstract: Soil samples were collected in a typical short-term flooding wetland with two dominate vegetation types (i.e., *Phragmites australis* and *Suaeda salsa*) of the Yellow River Delta of China. Path analysis was applied to investigate the relationship between soil nitrogen and selected 12 soil properties. Correlation analysis showed that soil total nitrogen was significantly correlated with total carbon, nitrate nitrogen, available phosphorous, total potassium, total sulfur and soil organic matter (*P* <0.01). Path analysis demonstrated that total carbon, nitrate nitrogen and soil organic matter had higher direct and indirect positive effects to total nitrogen, whereas bulk density and salt exhibited higher negative effects. Additionally, available phosphorous, total potassium, total sulfur exhibited indirect effects on total nitrogen through total carbon.

Keywords: Total nitrogen, wetland soils, correlation analysis, path analysis.

1. INTRODUCTION

Nitrogen in the soil is derived from the atmospheric precipitation, runoff input or residue decomposition [1]. Generally, soil total nitrogen content is coupled with soil organic matter, demonstrating consistent profile distribution [2]. The dynamic changes in soil nitrogen content are often influenced by soil physical and chemical properties. For example, Peng *et al.* [3] presented that soil bulk density exhibited a significant negative correlation with soil total nitrogen and microbial nitrogen after the conversions from wetland soils to paddy soils, which is similar to the result presented by Avnimelech *et al.* [4]. Soil pH can affect soil nitrogen absorption or release though influencing the microbial activities [5]. Mineral nitrogen content in the alkaline soil is significantly lower than that in the saline soil. Soil nitrogen mineralization will decrease with increasing soil pH and the degree of alkalisation. However, soil mineralization rate can increase faster with increasing degree of salinization [6] and nitrification in alkaline soils compared to the saline soil. Bai *et al.* [7] reported that nitrate nitrogen flux had significant correlations with both soil water diffusivity and soil moisture content in wetland soils. Lost and Landgraf *et al.* [8] demonstrated that the saturated hydraulic conductivity of soil and clay content had a great impact testified that coastal salt marshes are often nitrogen-limiting ecosystems [1, 9]. Therefore, a better understanding the influences of soil physical and chemical properties on nitrogen levels in coastal wetlands can contribute to protecting coastal wetland ecosystem health and improving the primary productivity in these wetlands.

Previous studies have focused on the correlation analysis and regression analysis to study the relationships between soil physical and chemical properties and soil nitrogen content in wetland soils [9]. However, simple correlation coefficients cannot properly reflect the correlations between variables as the linear correlation of two independent variables might be affected by other independent variables in multiple-variable response system [10]. In contrast, path analysis is a standardized multiple linear regression analysis which divides the correlation coefficients into direct and indirect effects through definite path coefficients among variables [10-12]. Bai *et al.* [13] investigated the relationships between urea activity and selected soil properties based on path analysis. However, few studies have been carried out on soil properties in relation to soil nitrogen using path analysis. Therefore, the primary objective of this study is to investigate the influence of soil properties on soil nitrogen in short-term flooding wetland of the Yellow River Delta using path analysis.

2. MATERIALS AND METHODS

2.1. Site Description

The Yellow River Delta is located in the city of Dongying, Shandong province of China (E 118°33' to

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119°20', N37°35'to 38°12'). It is the most complete and youngest wetland ecosystems in the warm temperate zone of China [9]. The study area has the East Asian continental monsoon climate with an annual mean temperature of 11.7 to 12.6 °C. The annual mean evaporation is 1962.1mm, and the annual mean precipitation is 555.9mm, most of which occur in July and August. Soil salinization in the region is serious (salt content ranging from 0.1 to 3‰) and the dominant vegetation is *Phragmites australis* and *Suaeda salsa* in this study area [9].

2.2. Soil Collection and Analysis

Soil samples were collected from wetlands located in the north bank perpendicular to the Yellow River. In total, 56 soil samples were sampled from this region. Another 100cm^3 soil core in each sampling site was also sampled for the determination of water content and soil bulk density (BD). All soil samples were immediately returned to laboratory. Some fresh soils were used to determine nitrate nitrogen (NO_3^- -N) concentration. All sub-samples were air-dried at room temperature for 3 weeks. Recognizable plant litters, coarse root materials and the stone were removed from the air-dried soil. All air-dried soils were ground using a pestle and mortar until all passed through a 0.18-mm nylon sieve, mixed well and stored in covered cardboard containers to determine other soil properties. Total nitrogen (TN) and total carbon (TC) was determined using an elemental analyzer (Vario EL, German). Total phosphorous (TP), total sulfur (TS) and total potassium (TK) were measured using an inductively coupled plasma-atomic emission spectrometry (ICP-AES). Available phosphorous (AP) was measured using the Olsen bicarbonate extractable P method. NO_3^- -N was determined on an automated flow injection analysis (AA3, Bran+Luebbe, Germany). Soil organic matter (SOM) was measured using dichromate oxidation. Soil pH and salinity were measured in the supernatant of 1:5 soil–water mixtures using a Hach pH meter (Hach Company, Loveland, CO, USA) and a salinity meter(VWR Scientific, WestChester, Pennsylvania, USA), respectively. Clay content was analyzed using a Laser Particle Size Analyzer (Microtrac Inc., USA).

2.3. Path Analysis

Path analysis is more precise compared with correlation and regression analyses. Multiple linear regression is used to determine the path coefficients in order to establish direct correlations and hypothesis relationships. Standardized partial regression coefficients in the regression analysis are direct path coefficient for the respective predictor variables. Each normal equation divides a simple correlation into direct and indirect effects. The detailed methodology of path analysis is described by Bai *et al.* [13].

3. RESULTS AND DISCUSSION

3.1. Correlation Analysis between TN and Selected Soil Physical and Chemical Properties

Table **1** shows the correlation coefficients between TN contents and selected soil physical and chemical properties. There were significant correlations among TN, TC, NO_3^--N, AP, TK, TS, and SOM (P <0.01). TP was significantly correlated with AP (P <0.01). The results indicated that nitrogen, sulfur, phosphorus, and potassium had close relations with soil organic matter. Strader [16] reported that soil inorganic nitrogen could impact soil nitrogen contents through influencing nitrogen transformation process as affected by the temperature, humidity and other environmental conditions. Nitrate nitrogen could be easily leached from the soil with less clay content. Snow [14] reported that more nitrogen would be leached in the sandy soil and the peat soil mixed sand compared to the peat soil. Vasslis [15] also found that the movement rate of nitrate nitrogen in the fine sand was higher than that in the sand loam. In addition, soil moisture content showed significant correlations with nitrate nitrogen and AP (P <0.05), and TP (P < 0.01) (Table **1**). The bulk density had significant negative correlation with TN and NO_3^--N (P < 0.05) and positive correlation with AP (P <0.01). AP and TS exhibited negative correlations with soil pH values (P <0.05). Therefore, AP was influenced by soil pH in rhizosphere, the assimilation of plant root, root secretion and microbial activities which were affected by the external environment.

Salinity was significantly correlated with SOM (P <0.05) and TS (P <0.01), and clay contents were closely linked to TS. Soil bulk density had a significant correlation with soil pH (P <0.01), and both of them showed significantly negative correlations with soil water content (P <0.01). Yao *et al.* [16, 17] pointed out that soil bulk density and salt content could be affected by the soil parent material, soil formation, climate and biological processes in the study area, of which groundwater was the dominant factor influencing the spatial distribution of salt in soil. Clay content was significant correlated with TK content (P <0.01). Soil pH could affect soil organic matter and nitrogen absorption or release by changing microbial activities [9] because microorganism activities could be inhibited under the

Table 1: Correlation Coefficient Matrix Among Soil TN and Soil Properties

	TN	TC	NO_3^--N	TP	AP	TK	TS	SOM	WC	DB	pH	Salinity	Clay
TN	1.000	0.869**	0.732**	-0.020	0.639**	0.620**	0.534**	0.804**	0.228	-0.317*	0.005	0.122	0.091
TC		1.000	0.578**	0.154	0.791**	0.724**	0.650**	0.779**	-0.010	-0.045	-0.142	0.240	0.170
NO_3^--N			1.000	-0.227	0.358**	0.417**	0.404**	0.576**	0.270*	-0.299*	-0.088	0.191	0.127
TP				1.000	0.277*	0.214	0.031	0.062	-0.429**	0.352**	-0.048	0.080	-0.087
AP					1.000	0.504**	0.532**	0.636**	-0.328*	0.259	-0.269*	0.209	0.041
TK						1.000	0.543**	0.628**	0.100	-0.135	-0.093	0.257	0.071
TS							1.000	0.555**	0.049	0.023	-0.304*	0.579**	0.318*
SOM								1.000	0.131	-0.190	-0.140	0.270*	0.120
WC									1.000	-0.904**	0.562**	0.005	0.138
DB										1.000	-0.581**	0.091	-0.081
pH											1.000	-0.411**	0.036
Salinity												1.000	0.090
Clay													1.000

*Significant correlation at the level of $P<0.05$; **Significant correlation at the level of $P<0.01$

acid or alkaline conditions [18]. Some literatures demonstrated that mineral nitrogen content was obviously lower in alkaline soils compared to saline soils and the mineralized nitrogen decreased with increasing alkaline degree and pH value. Additionally, nitrogen mineralization rate increased with increasing degree of salinization, whereas nitrification rate was higher in alkaline soils.

3.2. Path Analysis between Soil Nitrogen Contents and other Soil Properties

3.2.1. Standardization of Multivariate Regression Equation and Variance Test

The standardized multivariate regression equation (1) could be obtained through analyzing soil total nitrogen and other soil physical and chemical properties of soil in the north bank of the Yellow River. The standardized parameters in the equation are the direct path coefficients. The multiple determination coefficient (R^2) was 0.903 and the modified multiple determining coefficient was 0.876 (F=33.476,sig =0.000,P <0.001). Therefore, it was significant for the relationships between TN and other soil properties using path analysis.

$$\begin{aligned} TN' &= 0.590TC' + 0.246NO_3^- - N' + 0.005TP' + 0.044AP' \\ &-0.081TK' + 0.070TS' + 0.188SOM' - 0.039WC' - 0.238DB' \\ &+0.002pH' - 0.116Salinity' - 0.084Clay' \end{aligned} \quad (1)$$

3.3.2. Path Analysis

In the regression equation, each independent variable can cause the change in the dependent variables through direct or indirect effects among other related independent variables. The direct and indirect effects of soil physical and chemical properties on nitrogen can be identified by dividing the correlation coefficient into direct and indirect correlation coefficients. As shown in Table **2**, the larger direct path coefficient for nitrogen was TC (0.590), NO_3^--N (0.246) and soil organic matter (0.188). Total carbon showed lager indirect effect on TN through NO_3^--N and soil organic matter with a large the coefficient of determination. This indicates that TC had higher direct and indirect effects on soil nitrogen through influencing the inorganic and organic nitrogen. Besides, bulk density and salinity exhibited higher negative direct effects on TN with respective negative direct path coefficient of -0.238 and -0.116, whereas they had lower indirect effects. This implied that bulk density and salinity had a direct inhibiting effect on TN. AP, TK and TN and TS showed strong indirect effects and lower direct effects on TN. TC, NO_3^--N and SOM had larger indirect path coefficients, indicating that P, K, S mainly had indirect effects on TN through their interactions or through TC, NO_3^--N and SOM.

Changes in soil TN content are often coupled with soil organic matter [9], thus their spatial distributions showed certain similarities [19]. In this study, there is no correlation between SOM and P. However, Zhang *et al.* [20] found significant correlations among OC, TN and TP and all of them showed negative correlations with soil bulk density. Li [21] also presented that SOM had significant correlations with TP and AP. Path

Table 2: Direct and Indirect Path Coefficients Among TN and Soil Properties

	Indirect effect												Direct effect Pyi	r
	TC	NO_3^--N	TP	AP	TK	TS	SOM	WC	DB	pH	Salinity	Clay		
TC		0.142	0.001	0.035	-0.059	0.045	0.146	0.000	0.011	0.000	-0.028	-0.014	0.590	0.869
NO_3^--N	0.341		-0.001	0.016	-0.034	0.028	0.108	-0.011	0.071	0.000	-0.022	-0.011	0.246	0.732
TP	0.091	-0.056		0.012	-0.017	0.002	0.012	0.017	-0.084	0.000	-0.009	0.007	0.005	-0.020
AP	0.467	0.088	0.001		-0.041	0.037	0.120	0.013	-0.062	-0.001	-0.024	-0.003	0.044	0.639
TK	0.427	0.103	0.001	0.022		0.038	0.118	-0.004	0.032	0.000	-0.030	-0.006	-0.081	0.620
TS	0.383	0.099	0.000	0.023	-0.044		0.104	-0.002	-0.005	-0.001	-0.067	-0.027	0.070	0.534
SOM	0.460	0.142	0.000	0.028	-0.051	0.039		-0.005	0.045	0.000	-0.031	-0.010	0.188	0.804
WC	-0.006	0.067	-0.002	-0.014	-0.008	0.003	0.025		0.215	0.001	-0.001	-0.012	-0.039	0.228
DB	-0.026	-0.074	0.002	0.011	0.011	0.002	-0.036	0.035		-0.001	-0.011	0.007	-0.238	-0.317
pH	-0.084	-0.022	0.000	-0.012	0.008	-0.021	-0.026	-0.022	0.138		0.048	-0.003	0.002	0.005
Salinity	0.142	0.047	0.000	0.009	-0.021	0.041	0.051	0.000	-0.022	-0.001		-0.008	-0.116	0.122
Clay	0.100	0.031	0.000	0.002	-0.006	0.022	0.023	-0.005	0.019	0.000	-0.010		-0.084	0.091

Table 3: The Coefficient of Determination of Path Coefficients Among TN and Soil Properties

	TC	NO_3^--N	TP	AP	TK	TS	SOM	WC	DB	pH	Salinity	Clay
TC	0.348	0.168	0.001	0.041	-0.069	0.054	0.173	0.000	0.013	0.000	-0.033	-0.017
NO_3^--N		0.061	-0.001	0.008	-0.017	0.014	0.053	-0.005	0.035	0.000	-0.011	-0.005
TP			0.000	0.000	0.000	0.000	0.000	0.000	-0.001	0.000	0.000	0.000
AP				0.002	-0.004	0.003	0.011	0.001	-0.005	0.000	-0.002	0.000
TK					0.007	-0.006	-0.019	0.001	-0.005	0.000	0.005	0.001
TS						0.005	0.015	0.000	-0.001	0.000	-0.009	-0.004
SOM							0.035	-0.002	0.017	0.000	-0.012	-0.004
WC								0.002	-0.017	0.000	0.000	0.001
DB									0.057	0.001	0.005	-0.003
pH										0.000	0.000	0.000
Salinity											0.013	0.002
Clay												0.007

network should approach to a closed system as far as possible, that is, all the factors reflecting the variable Y should be included in the system, which could be identified using the multivariate coefficient of determination (R^2) (Table **3**). Biological system can not be completely closed, but R^2 should be within the range from 0.9 to 1 for a practical system [22]. The path coefficients in this equation is $R^2 = 0.903$ (Table **3**), indicating that path analysis was relatively reasonable.

4. CONCLUSIONS

Our studies exhibited that soil total nitrogen was significantly correlated with TC, NO_3^--N, AP, TK, TS and soil organic matter. TC, NO_3^--N, and soil organic matter showed higher direct and indirect positive effects to TN, whereas bulk density and salinity had a higher negative effect. AP, TK and TS indirectly affect TN through TC. These findings indicate that soil organic matter and TC, NO_3^--N can contribute to nitrogen accumulation, whereas bulk density and salinity can decrease nitrogen levels. Therefore, it is very important to control bulk density and salinity to improve nitrogen level in N-limiting coastal ecosystems.

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