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Spatial and seasonal distributions of soil phosphorus in a short-term flooding wetland of the Yellow River Estuary, China

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ABSTRACT

Soil cores were collected at a depth of 60 cm along a sampling belt perpendicular to the Yellow River of the Yellow River Estuary and were collected in both summer and fall of 2007 and the spring of 2008 to investigate spatial and seasonal dynamics of soil phosphorus in a short-term flooding wetland. Our results showed that total phosphorus (TP) levels were lowest in spring, followed by those in summer and the maximum level was in fall along the sampling belt. Lower TP levels were observed at Site 3 in summer and fall, whereas the lowest TP levels appeared at Site 1 in spring. All available phosphorus (AP) levels were higher in fall than that in spring except for Site 4. However, in summer, AP contents showed a “decreasing before increasing” tendency along the sampling belt. TP contents in profile soils exhibited a decreasing tendency from summer to next spring, whereas AP levels increased slightly from summer to fall and decreased from fall to the next spring. TP contents increased and then decreased along soil profiles in summer and spring, whereas they showed a “decreasing before increasing” tendency in fall. The mean AP levels and AP: TP ratios generally decreased along soil profiles in three sampling seasons. TP stocks ranged from 419.40 mg m^{-2} to 578.45 mg m^{-2} and generally exhibited an increasing tendency from Site 1 to Site 5. Approximately 50% of TP stocks accumulated in the top 20 cm soils. Higher TP stocks in the top 60 cm soils were observed in summer and fall at each of five sampling sites than in spring ($p < 0.05$). Correlation analysis showed that Soil TP levels were significantly correlated with soil bulk density (BD) and salinity, and AP contents were significantly correlated with soil depth and pH values. TP stocks were significantly impacted by TP, BD and pH values.

1. Introduction

As an important nutrient element, soil phosphorus is often a limiting factor for wetlands since it can affect the productivity, structure and function of wetland ecosystems (Grunwald et al., 2006). In particular, soil available phosphorus (AP), a key source for plant phosphorus, is an important indicator for evaluating the capacity of soil phosphorus supply to plant growth (Sun et al., 2012). The distributions, mobility and transformation of soil phosphorus in wetland soils play an important role in impacting the eutrophication and ecological balance of wetlands. Therefore, phosphorus dynamics has received considerable attention over the past years.

Wetlands serve as buffers for phosphorus retention and release between uplands and adjacent aquatic systems (Reddy and Delaune, 2008). Hydrological fluctuations in wetlands can greatly impact the environmental behaviors of phosphorus in wetland soils by altering the reduction and oxidation conditions and microbial activities (Noe and Childers, 2007). Xia et al (2011) presented that the drying and rewetting events in wetlands could cause substantial release of phosphate by increasing water-soluble P in soil. Gao et al. (2010) presented that freshwater inputs elevated soil P levels in the degraded coastal wetlands. In addition, many environmental factors such as SOM (Yang et al., 2013), pH (Adhami et al., 2013), salinity (Hakanson and Eklund, 2010) and other soil properties in wetlands can also affect the dynamic change in phosphorus levels.

The Yellow River Estuary (YRE) of China is a young and newly-formed wetland with high ecological fragility (Zhang et al., 2011). With the development of local economy and the exploration of Shengli oilfield in this region, most coastal wetlands have been suffering from ecological degradation (Bi et al., 2011). The eutrophication of water bodies adjacent to the YRE is one of serious environmental problems, which is detrimentally affected by increasing nutrients (e.g., nitrogen and phosphorus) input to the YRE (Chen et al., 1991). Therefore, it is necessary to investigate spatial and seasonal distributions of soil phosphorus in estuarine wetland ecosystems to protect water quality and wetland ecosystem health in this region.

The primary objectives of this study included (1) investigating spatial and seasonal distributions of total phosphorous (TP) and available phosphorus (AP) contents along a sampling belt in a short-term flooding wetland of the Yellow River Estuary; (2) analyzing the dynamic changes in total phosphorous stock (TPS) along soil profiles in three

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sampling seasons and (3) revealing the relationships between soil P and other selected soil properties.

2. Materials and methods

2.1. Site description

The Yellow River Estuary (YRE) is the most complete and youngest wetland ecosystem in China's warm temperate zone and it is located in Dongying City, Shandong Province of China (E 118°33′ to119°20′, N37°35′ to 38°12′) (Jiang et al., 2013). It has the East Asian continental monsoon climate with an annual mean temperature of 11.7 to 12.6 °C. The annual mean evaporation is 1962.1 mm, and the annual mean precipitation is 555.9 mm, most of which occur in July and August. Since 2002, the flow-sediment regulation regime has been enforced in the period from June to July every year. The dominant vegetations are *Phragmites australis*, *Tamarix cheinensis* and *Suaeda salsa* in the study area (Bai et al., 2012).

2.2. Soil collection and chemical analysis

Five sampling sites (1–5) were selected from a short-term flooding wetland which is located in the north bank along a sampling belt perpendicular to the Yellow River in summer (August) and autumn (November) of 2007 and spring (April) of 2008. Plant zonation distribution is obvious and different dominant communities (i.e., *P. australis*, *T. cheinensis*, and *Suaeda salsa*) were observed from Site 1 (nearby the Yellow River) to Site 5 (far away from the Yellow River). Soil cores with three replicates were collected at a depth of 60 cm and sectioned into 4 soil increments: 0–10 cm, 10–20 cm, 20–40 cm and 40–60 cm. Another soil cores (100 cm^3) were collected in each soil increment of each sampling site in each sampling season for the determination of soil moisture and bulk density (BD). All soil samples were brought to laboratory at once and stored at 4 °C in a refrigerator before analysis.

Total phosphorus (TP) and aluminum (Al) of the soil samples were analyzed by inductively coupled plasma atomic absorption spectrometry (ICP-AAS) (Ye et al., 2014). Available phosphorous (AP) was measured using the Olsen bicarbonate extractable P method. Soil organic matter (SOM) was measured using dichromate oxidation method (Nelson and Sommers, 1982), and soil pH values and salinity were measured with a pH meter and a salinity meter (soil/water = 1:5), respectively (Bai et al., 2012). Soil moisture and BD were determined through drying soil at 105 °C for 24 h in an oven. The physical and chemical properties of soil samples are listed in Table 1.

2.3. TP stock

Total phosphorus stock (TPS) at certain soil layer of each sampling site in each sampling season was calculated by (Tong et al., 2010; Ye et al., 2014):

$$TPS = BD_i \times Tp_i \times h/100.$$

where *TPS* (g m^{-2}) is the TP stock; BD_i (g cm^{-3}) is the BD of soil layer i; h (cm) is the soil depth; TP_i (mg kg^{-1}) is the TP content at soil layer i ($i = 1, 2, 3$, and 4).

2.4. Statistical analysis and graphing

One-way ANOVA analysis was used to test the differences of total phosphorous stocks among three sampling seasons and among different soil depth increments, and differences were considered to be significant if $p < 0.05$. Pearson correlation analysis was selected to analyze the relationships between soil P and other selected soil properties. Statistical analysis was conducted using SPSS 18.0 software package, and graphs were performed using Origin 8.0 and Surfer 10.0 software packages.

3. Results

3.1. Spatial and temporal variabilities of TP and AP contents in surface soils

Spatial distribution patters of TP contents in the top 10 cm soils at each of five sampling sites in three sampling seasons are shown in Fig. 1. There were different variations in TP levels along the sampling belt among the three seasons. TP exhibited the lowest level in spring among the three sampling seasons. Lower TP levels were observed at Site 3 in summer and fall, whereas the lowest TP levels appeared at Site 1 in spring. Compared to other sampling sites, soils at Site 5 exhibited higher TP levels in each of three seasons. Generally, TP contents in five sampling sites were higher in fall, followed by those in summer, whereas TP levels were lowest in spring.

As shown in Fig. 2, similar variations in AP levels in fall and spring were observed. The followed order of AP contents in top 10 cm soils was Site 4 > Site 5 > Site 3 > Sites 2 and 1. All AP contents were higher in fall than in spring except for Site 4. However, in summer, AP contents showed a "decreasing before increasing" tendency along the sampling belt and higher AP levels appeared at Sites 5 and 2, which was similar to the TP distribution. Generally, AP contents were low and only accounted for 0.22%~4.78% of the TP contents.

Table 1
Physical and chemical characteristics of the sampled soils.

Soil depth (cm)	Moisture (%)	BD (g/cm^3)	SOM (‰)	Salinity (‰)	pH	TN (g/kg)	TC (g/kg)	Al (g/kg)
Summer								
0–10	20.32 ± 3.34	1.43 ± 0.06	4.41 ± 2.35	0.07 ± 0.07	6.50 ± 0.30	0.15 ± 0.09	13.63 ± 2.75	44.35 ± 8.92
10–20	19.76 ± 2.29	1.41 ± 0.09	3.21 ± 1.46	0.14 ± 0.14	6.45 ± 0.26	0.09 ± 0.05	11.90 ± 1.91	46.24 ± 7.67
20–40	18.84 ± 1.36	1.54 ± 0.04	3.31 ± 1.98	0.15 ± 0.15	6.23 ± 0.45	0.11 ± 0.10	13.19 ± 3.93	48.04 ± 9.13
40–60	19.42 ± 2.12	1.52 ± 0.11	2.79 ± 1.61	0.11 ± 0.11	6.63 ± 0.34	0.08 ± 0.09	11.28 ± 2.93	44.26 ± 8.83
Fall								
0–10	22.09 ± 3.15	1.47 ± 0.11	7.72 ± 3.24	0.90 ± 0.58	6.25 ± 0.15	0.31 ± 0.17	17.08 ± 4.46	50.39 ± 7.18
10–20	18.32 ± 1.99	1.51 ± 0.10	4.82 ± 1.98	0.07 ± 0.44	6.33 ± 0.20	0.15 ± 0.10	13.59 ± 2.99	43.13 ± 9.29
20–40	18.91 ± 1.83	1.46 ± 0.05	3.00 ± 1.25	0.60 ± 0.31	6.34 ± 0.27	0.08 ± 0.05	11.87 ± 2.85	45.44 ± 0.24
40–60	20.09 ± 1.76	1.52 ± 0.11	4.22 ± 2.03	0.80 ± 0.49	6.32 ± 0.25	0.15 ± 0.10	14.83 ± 3.87	54.25 ± 10.56
Spring								
0–10	18.99 ± 2.23	1.17 ± 0.14	6.72 ± 3.87	0.66 ± 0.59	6.58 ± 0.33	0.34 ± 0.14	15.40 ± 3.87	41.44 ± 16.77
10–20	19.21 ± 1.98	1.19 ± 0.05	4.29 ± 3.17	0.72 ± 0.63	6.80 ± 0.14	0.18 ± 0.13	13.68 ± 4.50	42.60 ± 6.86
20–40	19.33 ± 1.92	1.20 ± 0.04	4.46 ± 3.50	0.70 ± 0.59	6.82 ± 0.13	0.12 ± 0.06	11.57 ± 2.24	34.15 ± 4.30
40–60	20.62 ± 4.47	1.16 ± 0.1	5.50 ± 3.33	0.84 ± 0.68	6.66 ± 0.26	0.17 ± 0.07	13.46 ± 3.39	39.45 ± 14.01

SOM, soil organic matter; BD, bulk density; TN, total nitrogen; C:P, carbon–phosphorus ratio; AP, available phosphorus; TP, total phosphorus.