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 phosphorous (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

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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.

Keywords: Total phosphorus; Available phosphorus; Phosphorus stock; Distribution; Yellow River Estuary

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 (Crunwald 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,

1 mobility and transformation of soil phosphorus in wetland soils play an important role
2 in impacting the eutrophication and ecological balance of wetlands. Therefore,
3 phosphorus dynamics has received considerable attention over the past years.

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

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

1 water quality and wetland ecosystem health in this region.

2 The primary objectives of this study included (1) investigating spatial and
3 seasonal distributions of total phosphorous (TP) and available phosphorus (AP)
4 contents along a sampling belt in a short-term flooding wetland of the Yellow River
5 Estuary; (2) analyzing the dynamic changes in total phosphorous stock (TPS) along
6 soil profiles in three sampling seasons and (3) revealing the relationships between soil
7 P and other selected soil properties.

9 **2. Materials and methods**

10 **2.1 Site description**

11 The Yellow River Estuary (YRE) is the most complete and youngest wetland
12 ecosystem in China's warm temperate zone and it is located in Dongying City,
13 Shandong Province of China (E 118°33' to 119°20', N 37°35' to 38°12') (Jiang et al.,
14 2013). It has the East Asian continental monsoon climate with an annual mean
15 temperature of 11.7 to 12.6°C. The annual mean evaporation is 1962.1 mm, and the
16 annual mean precipitation is 555.9 mm, most of which occur in July and August.
17 Since 2002, the flow-sediment regulation regime has been enforced in the period from
18 June to July every year. The dominant vegetations are *Phragmites australis*, *Tamarix*
19 *cheinensis* and *Suaeda salsa* in the study area (Bai et al., 2012).

21 **2.2 Soil collection and chemical analysis**

22 Five sampling sites (1-5) were selected from a short-term flooding wetland

1 which is located in the north bank along a sampling belt perpendicular to the Yellow
2 River in summer (August), autumn (November) of 2007 and spring (April) of 2008.
3 Plant zonation distribution is obvious and different dominant communities (i.e.,
4 *Phragmites australis*, *Tamarix cheinensis*- *Suaeda salsa* and *Suaeda salsa*) were
5 observed from Site 1 (nearby the Yellow River) to Site 5 (far away from the Yellow
6 River). Soil cores with three replicates were collected at a depth of 60 cm and
7 sectioned into 4 soil increments: 0–10 cm, 10–20 cm, 20–40 cm and 40–60 cm.
8 Another soil cores (100 cm³) were collected in each soil increment of each sampling
9 site in each sampling season for the determination of soil moisture and bulk density
10 (BD). All soil samples were brought to laboratory at once and stored at 4°C in a
11 refrigerator before analysis.

12 Total phosphorus (TP) and aluminum (Al) of the soil samples were analyzed by
13 inductively coupled plasma atomic absorption spectrometry (ICP-AAS) (Ye et al.,
14 2014). Available phosphorous (AP) was measured using the Olsen bicarbonate
15 extractable P method. Soil organic matter (SOM) was measured using dichromate
16 oxidation method (Nelson and Sommers, 1982), and soil pH values and salinity were
17 measured with a pH meter and a salinity meter (soil/water=1:5), respectively (Bai et
18 al., 2012). Soil moisture and BD were determined through drying soil at 105°C for 24
19 h in an oven. The physical and chemical properties of soil samples are listed in Table
20 1.

21

22 **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):

$$\text{TPS} = \text{BD}_i \times \text{TP}_i \times h / 100.$$

where TPS (g m^{-2}) is TP stock; BD_i (g cm^{-3}) is BD of soil layer i ; h (cm) is soil depth; TP_i (mg kg^{-1}) is 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 patterns of TP contents in the top 10 cm soils at each of five sampling sites in three sampling seasons were shown in Figure 1. There were different variations in TP levels along the sampling belt among 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

1 in each of three seasons. Generally, TP contents in five sampling sites were higher in
2 fall, followed by those in summer, whereas TP levels were lowest in spring.

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

11 **3.2 Profile distributions of AP and TP contents in three seasons**

12 Spatial and temporal distributions of TP, AP and AP: TP ratios along soil
13 profiles in the short-term flooding wetland are shown in Fig.3. The mean TP levels in
14 profile soils varied from 544.99 mg kg⁻¹ to 708.78 mg kg⁻¹ in these sampling sites and
15 were much higher in summer than that in fall and spring. Generally, TP contents in
16 profile soils exhibited a decreasing tendency from summer to the next spring. TP
17 contents increased to the maximum level from top soils to the 10-20cm soil depth and
18 then decreased with depth in summer and spring, whereas they showed a “decreasing
19 before increasing” tendency along soil profiles in fall. The mean AP levels generally
20 decreased along soil profiles in three sampling seasons, with lower AP levels at the
21 10-20cm soil depth in summer and in the 20-40cm soil depth in fall and next spring,
22 respectively. AP levels in profile soils increased slightly from summer to fall and

showed a decrease from fall to next spring. The AP:TP ratios exhibited similar profile distributions to AP in three seasons .

3.3 Spatial and seasonal dynamics of soil phosphorus stock

Total phosphorous stocks (TPS) along soil profiles in three sampling seasons were illustrated in Fig.4. TPS in the top 60 cm soils did not show significant differences among five sampling sites in spring and fall ($P > 0.05$). Comparatively, TPS ranged from 419.40 mg m⁻² to 578.45 g m⁻² and exhibited an increasing tendency from Site 1 to Site 5 (far away from the Yellow River) in summer except Site 2. Compared to spring, higher TPSs were observed in summer and fall at each of five sampling sites ($P < 0.05$). However, there were no significant differences in TPS between fall and summer ($P > 0.05$). Among different soil depths, the top 20cm soils contained higher TPSs than both the 20-40 cm soil depth and 40-60 cm soil depth and counted for approximately 50% of TPSs accumulated in the top 20cm soils. The mean TPSs increased before decreasing with depth and the maximum TPS appeared at the 10-20 cm soil depth in spring and at the 20-40 cm soil depth in summer, respectively (Fig.5). However, in fall, the mean TPSs showed a “decreasing before increasing” tendency along soil profiles, with the minimum value appearing at the 20-40 cm soil depth (Fig.5). Compared with spring, significant higher TPS were observed in each soil layer in fall and summer ($P < 0.05$). Generally, the mean TP stocks in the top 60 cm soils followed the order of summer (503.97g m⁻²) > fall (471.65 g m⁻²) > spring (350.22 g m⁻²).

3.4 Relationships between soil phosphorus and selected soil properties

The Pearson correlation coefficients among TP, AP, TPS and other selected soil properties were summarized in Table 2. As shown in Table 2, both TP and TPS had significant positive correlations with BD ($P < 0.05$), and significant negative correlations with soil pH values ($P < 0.05$). The significant correlations between TP and TPS were also observed ($P < 0.05$). Comparatively, AP was significantly negatively correlated with soil depth ($P < 0.05$). There were no significant correlations among AP, TP and Al ($P < 0.05$), whereas a significant correlation between TSP and Al was observed. Although salinity showed a negative correlation with TP, no significant correlations between AP, TPS and salinity were observed. Generally, SOM and moisture were not significantly correlated with soil P ($P > 0.05$).

4. Discussion

4.1 Spatial variability of TP and AP contents in surface soils

TP contents in three sampling seasons were higher than the national average level (500 mgkg^{-1}), which was mainly caused by high P contents in the sediments from the Yellow River (Chen et al., 2008). This is in agreement with the findings of Dun (2013) in the Yellow River Delta. The higher TP content had been detected in fall than spring (Fig.1), which might be associated with less P uptake by wetland plants and plant litter breakdown and return to surface soils in fall (Ye et al., 2014). Additionally, the freezing-thawing action might be another important reason for lower

1 TP levels in spring since organic phosphorous mineralization and dissolved organic
2 phosphorous and inorganic phosphorous losses in surface flow can be greatly
3 promoted (Fitzhugh et al., 2001; Shanley and Chalmers, 1999). Although wetland
4 plants could assimilate more P in summer due to rapid plant growth, P flux from
5 water during the duration of flooding in summer could contribute to elevating TP
6 level. Risser (1990) reported that water was always considered as a source of nutrients
7 in terrestrial/ aquatic ecotones. Meanwhile, the flow-sediment regulation in the late
8 June and the early July could also bring rich P to wetland soils, because most P from
9 the croplands in the upstream of the Yellow River Delta could be absorbed and
10 carried to wetlands. As TP and AP in surface soils could be more easily leached or
11 mobilized by surface runoff (Gudimov et al., 2011), lower TP and AP levels were
12 observed at Sites 1 in summer. AP levels in surface soils of five sampling sites
13 increased from summer to fall, which was associated with organic phosphorus
14 mineralization and less plant uptake in fall. Moreover, the drying and re-wetting
15 condition controlled by the flow-sediment regulation could increase the mineralization
16 of organic matter (Chepwony et al., 2001) and thus elevate AP levels in fall. The
17 highest AP levels at Site 4 in fall and spring was closely related to phosphorus
18 exchanges between tidal salt water and adjacent wetland soils in the surface soil
19 (White et al., 2006) and less P uptake by *Suaeda salsa* (Site 4) compared to
20 *Phragmites australis* (Sites 1 and 2) and *Tamarix cheinensis* (Sites 3 and 5)(Zhao,
21 2010). Additionally , high salinity and moisture at Site 4 could contribute to P
22 mineralization (Neo et al., 2013) and improve the bioavailability of phosphorus in soil

by enhancing the activation of the hardly soluble phosphorus in soil (Liu et al., 2002).

4.2 Soil P distribution along soil profiles in three seasons

The accumulative peak of TP at 10-20 cm soil depth in summer and spring might be closely related to phosphate and dissolved organic phosphorous which were leached from surface soils (Hesketh and Brookes, 2000; Zhou et al., 2013). However, lower TP contents in deeper soils were associated with plant root uptake because soil P can be accumulated in top soils through plant litters (Jobbagy and Jackson, 2001). The roots of *Phragmites australis* and *Tamarix cheinensis* could reach a depth of 60 cm in soil profiles and assimilate soil P from deeper soils, leading to a decrease in total P in deeper soils in fall. Zhang et al. (2009) also observed the highest P absorption amount of wetland plants in estuarine wetlands (e.g., *Phragmites australis*) in fall. TP contents decreased gradually from summer to next spring , indicating that the flow-sediment regulation might be an important P source to this wetland. Moreover, available P contents could be easily assimilated by wetland plants, resulting in a small proportion of TP contents (Fig.3). Meanwhile, AP move upwards through plant litter decomposition and return, bringing about an accumulation in top soil layer (Jobbagy and Jackson, 2001). Generally, the AP/TP ratios for all soil samples were below the threshold of P load (2%) for P bioavailability (Xiao et al., 2012) in all three seasons in this study, suggesting that the transformation rate from TP to AP was relatively low, and AP supply for plant growth was deficient.

Higher TP stocks in summer and fall were observed compared to spring (Fig.5).

1 This was associated with the P input from the flow-sediment regulation in July (Bai et
2 al., 2012) and plant litter input in fall (Jobbagy and Jackson, 2001). Wei et al. (2011)
3 observed higher fluxes of sediment (6.63×10^7 t), particulate phosphorous (3.42×10^4 t)
4 and particulate bioavailable phosphorous (8.30×10^3 t), accounting for approximately
5 80% of their total yearly fluxes in the Yellow River downstream during the
6 flow-sediment regulation. Yao et al. (2009) also reported a higher phosphate level in
7 the downstream water during the period of the flow-sediment regulation compared to
8 other studied periods. In contrast, the organic P mineralization and plant uptake could
9 contribute to less soil P accumulation in spring. Meanwhile, compared to summer and
10 fall, lower BD in spring (Table 1) due to various soil moisture would take
11 responsibility for lower TP stocks. Although the top 20 cm contained higher TP
12 stocks in the whole soil profiles, however, the higher contribution (approximately
13 50%) of TP stocks in deeper soil layers below 20 cm could not be ignored.

14

15 **4.3 Effects of environmental factors on soil P**

16 Soil P levels were mainly affected by environmental factors including SOM (Yang et
17 al., 2013), pH (Adhami et al., 2013), salinity (Hakanson and Eklund, 2010) and other
18 properties. In this study, the significant positive correlations among TP, TPS and BD
19 (Table 2) could be explained by the fact that soil P in wetlands often existed in
20 stable chemical properties (Qu et al., 2010) and soil P levels were mainly affected by
21 soil parent materials in wetlands (Ding et al., 2009). Meanwhile, higher BD could
22 reduce air permeability and water holding capacity, which would affect soil

P transformation. The significant negative correlations between AP, TPS and pH value were observed since pH value was an important factor influencing phosphorus release (Sun et al., 2006). Gustafsson et al. (2012) presented that the rise of pH would weaken the P adsorption in soil under alkaline conditions ($\text{pH} > 7$). Additionally, higher salinity would exert negative effects on TP levels in wetland soils (Liu et al., 2012). TPS were significantly positively correlated with Al ($P < 0.01$), because high P retention in soil was mainly attributed to the active Al in organic and mineral fractions (Satti et al., 2007; Igwe et al., 2010). AP decreased significantly with soil depth (Fig. 3 and Table 2), which was in agreement with the finding of Ye et al. (2013). AP usually concentrated the surface soil layer and transferred vertically due to eluviations. In this procedure, AP in aqueous phase could be absorbed in the inner soil layer in a small amount, thus the absorption amount of AP in the soil decreased with increasing soil depth (Hu et al., 2010). Furthermore, the degradation and decomposition of plant residues by soil microbial communities also contribute a lot to the profile pattern of soil AP (Zhang et al., 2012). Although soil P contents in some literatures were reported to associated with SOM (Vincent et al., 2010; Fekri et al., 2011; Camargo et al., 2013), no significant correlation was observed between them in this study.

5. Conclusions

Spatial and seasonal dynamics of soil phosphorus were investigated in a short-term flooding wetland of Yellow River Estuary. Generally, higher spatial and temporal variabilities in soil P levels were observed in this wetland. Soil P levels were

1 higher in fall than in summer and spring in surface soils. Lower soil P contents
2 appeared at these sampling sites (e.g., Sites 1 and 2) nearby the Yellow River,
3 whereas higher soil P levels occurred at those sampling sites (e.g., Site 4) far away
4 from the Yellow River. Soil P mainly accumulated in the top 20 cm soils and P stocks
5 in the whole soil profiles were higher in summer and fall compared to spring.
6 Although soil P levels were higher than the national average level, the AP contents
7 were lower, indicating a deficient AP supply for plant growth. Therefore, further
8 studies on P transformation of different fractionations in estuarine wetlands are still
9 need in order to improve soil P supply for plant growth and thus to improve wetland
10 productivity and ecological functions. Meanwhile, it is very important to investigate
11 labile P dynamics, P carrying capacity and the adsorption-release processes of P in
12 coastal wetlands to protect water quality of the Yellow River Estuary. Soil pH values
13 and salinity should be paid more attention in the soil quality management of coastal
14 wetlands because they were significantly correlated with soil P levels.

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21 22 **Conflicts of interest**

23 The authors declare no conflict of interest.

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Table

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.

Table 2. Pearson correlation coefficients among soil P and selected soil properties										
	Moisture	BD	SOM	Salinity	pH	Al	TP	AP	TPS	Depth
TP	0.204	0.601*	-0.442	-0.641*	-0.397	0.482	1.000	0.231	0.855**	-0.076
AP	0.438	0.424	0.495	-0.141	-0.585*	0.483	0.231	1.000	0.400	-0.066*
TPS	0.087	0.925**	-0.426	-0.562	-0.721**	0.693*	0.855**	0.400	1.000	0.220

*Significant correlation at P<0.05(2-tailed).

**Significant correlation at P<0.01(2-tailed).

Fig.1 Horizontal distributions of TP contents in top 10cm soils in three seasons

Figure

Fig.2 Horizontal distributions of AP contents in top 10cm soils in three seasons

Fig. 3 Profile distributions of TP, AP, and AP/TP ratios in wetland soils in three sampling seasons

Figure

Fig.4 TP stocks in 60cm depth in each sampling site in three seasons.

a,b,c Different letters represent significant differences in TP stocks between different sampling seasons.

Fig.5 Profile distribution of TP stocks in 60cm depth in three seasons.

a,b,c Different letters represent significant differences in TP stocks between different soil layers.