Riparian soil physicochemical properties and correlation with soil organic carbon of an inflowing river of Taihu Lake

Jin Qian\textsuperscript{a,b}, Jingjing Liu\textsuperscript{a,b}, Peifang Wang\textsuperscript{a,b}, Chao Wang\textsuperscript{a,b}, Kun Li\textsuperscript{a,b}, Mengmeng Shen\textsuperscript{a,b}

\textsuperscript{a} Key Laboratory of Integrated Regulation and Resources Development on Shallow Lakes, Ministry of Education, Hohai University, Nanjing, People’s Republic of China, 210098
\textsuperscript{b} College of Environment, Hohai University, Nanjing, People’s Republic of China, 210098

The corresponding author’s e-mail address: hhuqi@hhu.edu.cn

Abstract. Profile method and the classic measurement method were used to analyse the vertical distribution of riparian soil physicochemical properties of an inflowing river (Yincungang River) of Taihu Lake. The results showed that the soil physicochemical properties distribution of the riparian zones with three different vegetation communities were showed a similar regular change tendency with the increase of soil depth. But the maximum of soil organic carbon (SOC), total nitrogen (TN) and total phosphorus (TP) were occurred in the riparian zone with \textit{Arundo donax} community, and the maximum of soil bulk density (BD) and pH value were occurred in the riparian zone with \textit{phragmites australis} community. Besides, there was significant positive correlation between SOC and TN, TP, BD, while the opposite result was observed for pH.

1 Introduction
Soil organic carbon (SOC) pool, as one of the most important carbon stocks on the earth, plays a key role in the global carbon cycle. Globally, about 1500 ~2000 Pg SOC is stored in the upper 100 cm of the soil\textsuperscript{[9]}\textsuperscript{[15]}. Riparian zone is the interface between land and a river or stream\textsuperscript{[12]}. Riparian SOC is strongly influenced by soil structures, soil properties, aquatic plants root depth, effective water retention capacity and soil biological diversity \textsuperscript{[3]}\textsuperscript{[6]}\textsuperscript{[21]}. Soil nitrogen (N), phosphorus (P), pH value, bulk density (BD) and other soil physicochemical characteristics indexes in accurately reflect the functional variability of riparian ecosystem, and it is important to determine the change of soil element in riparian ecosystem, which has a significant effect on the response of soil C cycle \textsuperscript{[18]}. Analyzing the relationship between SOC and N, P, pH values and BD in riparian zone, can let us understand the condition of soil fertility of riparian zone, the composition of soil organic matter and the condition of soil quality as well as the supply ability of nutrients \textsuperscript{[18]}\textsuperscript{[23]}. The interactions between the cycle of soil N and P with the soil carbon cycle affect the distribution of SOC and then affect the environmental effects of riparian zone. Wang et al. \textsuperscript{[23]} studied the distribution characteristics of soil carbon and nitrogen in different Riparian zone of Yangze River estuary and Zhang et al. \textsuperscript{[28]} studied the pattern and causes of soil carbon distribution in riparian zone in arid desert area. However, the relationship between soil carbon characteristics and soil physicochemical properties of riparian zone in Taihu Lake Basin has not been reported. Yingcungang
River is one of the main inflowing rivers of Taihu Lake, China. Yingcungang riparian zone is an important part of the ecological system of riparian zone in Taihu Area [25]. *Phragmites australis, Arundo donax, Canna indica* is the zonal typical aquatic plants in the region. This study was designed to examine the distribution characteristics of SOC in Yingcungang riparian zone with different vegetation types, analysis the correlation between SOC and soil physicochemical properties. The objectives of this study were to explore the distribution pattern of riparian soil physicochemical properties and the response of SOC to soil physicochemical properties of an inflowing river of Taihu Lake.

2 Materials and methods

2.1 Study sites

The study area, located in Yingcungang riparian zone, is characterized as the subtropical monsoon climate with a mean annual temperature of 15.7°C, the mean annual rainfall is approximately 1177 mm. The area was mainly used for agricultural production and the main crops were rice, wheat., soybean and so on. Near the river bank, emergent plants was dominated by *Phragmites australis, Arundo donax, Canna indica* and other aquatic plants [14][25].

2.2 Soil sampling design and field work

The sample sites were located at latitude 31° 27’ N and longitude 119° 59’ E. Soil samples were collected from three regions growing *phragmites australis, Arundo donax* and *Canna indica* in the riparian zone, respectively in June 2016.. We choose two blocks (10 m×10 m) in every region and recorded the slope, coverage and average height aquatic of the plants (Table 1). By the S-shaped sampling strategy, each group has three parallels.

Three soil samples (0–15, 15-30, 30-45cm) were collected in each sample site. To avoid compaction and degeneration, the soil samples were put into hard aluminum boxes and transported to laboratory for the following analyses.

| Plant type              | Slope | Average Height (cm) | Taproot Length (cm) | Diameter (cm) | Coverage (%) |
|-------------------------|-------|---------------------|---------------------|---------------|--------------|
| Phragmites australis    | South | 258.7               | 43.7                | 2.6           | 95           |
|                         | North | 102.8               | 39.2                | 1.7           | 75           |
| Arundo donax            | South | 285.3               | 37.5                | 3.1           | 97           |
|                         | North | 258.8               | 35.8                | 2.7           | 80           |
| Canna indica            | South | 102.1               | 21.3                | 2.1           | 95           |
|                         | North | 65.9                | 14.5                | 1.4           | 75           |

2.3 Laboratory procedures

Each soil sample was weighed for bulk density determination, then passed through an 8-mm mesh sieve by gently breaking soils along natural fracture planes [4]. Soil was digested using H_2SO_4–HClO_4 and TP was measured by the spectrophotometric method with a continuous flow automated analyzer at 700 nm [1]. SOC was measured using acid dichromate wet oxidation as described by Nelson and Sommers [13], TN was tested with potassium persulfate oxidation [2]. A soil sub-sample was air-dried and pH was measured on a 1:2.5 soil–water suspension [11].

[25]
2.4 Statistical analysis

All statistical calculations were performed with Office excel 2013 and SPSS 19.0, indicating the relationship between SOC and soil physicochemical properties in Riparian Yingcungang. To analyze the significant relationship between SOC and physicochemical properties (BD, pH value, TN and TP), one-way analysis of variance (ANOVA) was used with post hoc test (Duncan’s test, with a critical significance level of 0.05). Levene’s test was also used for determining equality of variances.

3 Results and Discussion

3.1 Distribution pattern of soil physicochemical properties

The soil physicochemical properties of the riparian zones with three plant communities were changed regularly with the increase of soil depth (Table 2). SOC, TP and TN decreased with the increase of soil depth, but BD and pH value decreased after an increase along with the increasing of soil depth. Overall, with the increase of soil depth, soil acidity enhanced, soil nutrient contents reduced, the soil became tight. The results were in accordance with the findings of Kong et al. [8].

As illustrated in Table 2, the maximum of SOC, TN and TP was occurred in Arundo donax community, and the maximum of BD and pH value was occurred in Phragmites australis community. The results showed that the differences of physicochemical properties of soil in riparian zone are closely related to vegetation community composition. The characteristic factors of the physicochemical properties of soils are mainly affected by root exudates [8][23]. The differences of decomposition speed, decomposition quantity, and chemical composition of the decomposition products caused by the exudates composition, led to the differences of soil physicochemical properties of the riparian zone with three different vegetation communities.

Table 2 Soil properties in different soil layers in Riparian zone

| Vegetation type  | Depth (cm) | SOC (g kg⁻¹) | TN (mg g⁻¹) | TP (mg kg⁻¹) | BD (g cm⁻³) | pH value |
|------------------|------------|--------------|--------------|--------------|-------------|----------|
| Phragmites australis | 0-15       | 11.24±0.42   | 343.86±17.82 | 420.09±4.61  | 1.35±0.10   | 7.22±0.20 |
|                   | 15-30      | 8.76±0.24    | 341.19±11.27 | 402.81±5.79  | 1.66±0.06   | 7.81±0.16 |
|                   | 30-45      | 9.44±0.27    | 513.23±14.64 | 398.73±7.82  | 1.45±0.11   | 7.44±0.06 |
| Mean              |            | 9.81±0.31    | 399.43±14.58 | 407.21±9.11  | 1.48±0.09   | 7.79±0.14 |
| Arundo donax      | 0-15       | 17.37±0.62   | 1324.82±31.87| 504.75±5.64  | 1.36±0.04   | 5.14±0.03 |
|                   | 15-30      | 15.84±0.73   | 1048.41±26.84| 507.64±3.64  | 1.39±0.01   | 5.60±0.02 |
|                   | 30-45      | 15.32±0.45   | 899.11±18.36 | 498.76±6.84  | 1.30±0.06   | 4.76±0.02 |
| Mean              |            | 16.17±0.60   | 1090.78±25.69| 503.72±5.37  | 1.35±0.04   | 5.16±0.03 |
| Canna indica      | 0-15       | 11.80±0.48   | 803.63±22.67 | 433.11±3.72  | 1.32±0.06   | 6.17±0.14 |
|                   | 15-30      | 8.52±0.32    | 884.82±9.74  | 427.43±7.65  | 1.46±0.02   | 5.95±0.07 |
|                   | 30-45      | 7.65±0.36    | 1009.55±13.26| 403.83±4.86  | 0.98±0.06   | 5.87±0.04 |
| Mean              |            | 9.32±0.58    | 899.33±15.22 | 421.46±5.41  | 1.23±0.05   | 6.01±0.08 |

3.2 Relationship between soil nutrients and SOC

There was a significant positive logarithmic correlation between soil TN and SOC (R²=0.8608, P<0.01, n=24) in the riparian zone. The result was similar to the finding obtained by Kong et al. [8] and Knoepp et al. [7] (Fig.1). SOC had a great influence on soil TN. The appropriate ratio of C/N was beneficial to the nutrient release and the increase of available nitrogen during the decomposition of microorganism on organic matter. To some extent, the amount of SOC was determined by the soil TN
As an important nutrient element in soil, phosphorus was closely related to SOC. The decomposition of SOC can promote the release of phosphorus and the increase of phosphorus can contribute to the accumulation of organic carbon in soil. There was a significant positive correlation in logarithmic function ($R^2=0.7101$, $P<0.01$, $n=24$) between TP and SOC (Fig.2). This was in accordance with the results of Qiu K L et al. [16].

3.3 Correlation between BD, pH value and SOC

Fig.3 showed a significant positive power function correlation between BD and SOC in the study area ($R^2=0.6374$, $P<0.01$, $n=24$). The results showed that the higher BD was, the higher the content of SOC was. The main reason of this phenomenon was that the increase of SOC content resulted in the increase of soil carbon density, soil bulk density [16][27].
Fig.3 Relationship between BD and SOC in riparian soil
It was generally showed a negative correlation between soil pH value and SOC. Some research suggested that it was not meaning for the relationship between pH and SOC if pH value was not defined in certainty range [22]. In the study area, the soil is weak acidity (Table 2), and it showed linear negative correlation between pH and SOC ($R^2=0.4182$, $P<0.01$, $n=24$) (Fig.3). This was in accordance with the findings of Li S J et al. [10] and it showed that pH can affect the type and activity of soil microorganisms, further to mineralization of SOC. The lower the soil pH value was, the faster the mineralization rate of soil and the lower the SOC content would be.

Fig.4 Relationship between pH value and SOC in riparian soil

4 Conclusion
Firstly, the soil physicochemical properties distribution of the riparian zones with three different vegetation communities in the Yincungang River were showed a similar regular change tendency with the increase of soil depth. With the increasing of soil depth, soil nutrient content reduced, the soil becomes tight, and soil acidity increased gradually. Secondly, the obvious differences of soil physicochemical properties existed in the riparian zone with three different plant communities. The maximum of SOC, TN and TP was occurred in the riparian zone with Arundo donax community, and the maximum of BD and pH value was occurred in the riparian zone with phragmites australis community. Finally, it was showed that there was significant positive correlation between SOC and TN, TP, and BD, while the opposite result was observed for pH.

Acknowledgements
We acknowledge the National Natural Science Foundation of China (No. 51379062), the National Key Plan for Research and Development of China (No. 2016YFC0401703), the Key Program of National Natural Science Foundation of China (No. 41430751), the National Natural Science Foundation of China (No. 51579073), the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD) for funding this research.

References
[1] Bao, S.D.,. Soil and agricultural chemistry analysis. third ed. Agriculture Press, Beijing,2008 .(In Chinese)
[2] Bremner, J.M., 1996. Nitrogen-total. In: Sparks, D.L. (Ed.), Methods of Soil Analysis.Part 3. Chemical Methods, No. 5. ASA and SSSA, Madison, WI, pp. 1085–1121.
[3] Capon, S.J., Chambers, L.E., Mac Nally, R., Naiman, R.J., Davies, P., Marshall, N., Pittock, J., Reid, M., Capon, T., Douglas, M., Catford, J., Baldwin, D.S., Stewardson, M., Roberts, J., Parsons, M., Williams, S.E., 2013. Riparian ecosystems in the 21st century: hotspots for climate change adaptation. Ecosystems 16, 359–381.
[4] Cheng, X., Luo, Y., Xu, X., Sherry, R., Zhang, Q., 2011. Soil organic matter dynamics in a North
America tallgrass prairie after 9 yr of experimental warming. Biogeosciences 8, 1487–1498.

[5] Chimel D S. Terrestrial ecosystems and the carbon cycle. Global Change Biology, 1995, 1(1): 77-91. (In Chinese)

[6] Feller, C., Beare, M.H., 1997. Physical control of soil organic matter dynamics in the tropics. Geoderma, 79, 69–116.

[7] Knoepp JD, Clinton BD. Riparian zones in southern Appalachian headwater catchments: Carbon and nitrogen responses to forest cutting. Forest Ecology and Management, 2009, 258(10): 202–20293.

[8] Kong Tao, Zhang De-sheng, Kou Yong-ping, et al. Soil Organic Carbon, Total Nitrogen and Total Phosphorus Distribution of Typical Vegetation Riparian Zones in Upper Reaches of Hun River. Soils, 2014, 46(5): 793 – 798. (In Chinese)

[9] Lal, R., 2004. Soil carbon sequestration impacts on global climate change and food security. Science 304, 1623–1627.

[10] Li S J, Qiu L P, Zhang X C. Mineralization of soil organic carbon and its relations with soil physical and chemical properties on the Loess Plateau. Acta Ecologica, 2010, 30(5): 1217-1226. (In Chinese)

[11] Lu, R., 2000. Analysis of Soil Agrochemistry. Chinese Agricultural Science and Technology Press, Beijing.

[12] Mander, U., Kuusemets, V., Krista, L., Lõhmus, K., Mauring, T., 1997. Efficiency and dimensioning of riparian buffer zones in agricultural catchments. Ecol. Eng. 8: 299-324.

[13] Nelson, D.W., Sommers, L.E., 1996. Total carbon, organic carbon and organic matter. In: Sparks, D.L. (Ed.), Methods of Soil Analysis. Part 3. Chemical Methods, No. 5. ASA and SSSA, Madison, WI, pp. 961–1010.

[14] Niu Yong, Yu Hui, Niu Yuan, et al. Pollution of Nutrients and Heavy Metals in Sediments from Yin Cun Gang River of Lake Taihu Basin, China. Agricultural journal of environmental science, 2015. 34(8):1557-1562. (In Chinese)

[15] Post W M, Emanuel W R, Zinke P J et al. Soil carbon pools and life zones. Nature, 1982, 298: 156-159.

[16] Qiu K L, Chen W D, Peng P H, et al. Analysis on correlation between soil organic carbon and other factors in Neijiang Section of Tuojiang River Basin. Research of Soil and Water Conservation, 2013, 20(3): 28-31. (In Chinese)

[17] Raven J A, Handley L L, Andrews M. Global aspects of C/N interactions determining plant-environment interactions[J]. Journal of Experimental Botany, 2004, 55(394):11-25.

[18] Robin Hale, Paul Reich, Tom Daniel, et al. Scales that matter: guiding effective monitoring of soil properties in restored riparian zones. Geoderma 228–229 (2014) 173–181.

[19] Schlesinger W H. Carbon storage in the calishe of arid soils: a case study from Arizona. Soil Science, 1982, 133: 247-255.

[20] Susan, S., 2007. Cambridge University Press, Cambridge.

[21] Thomson, J.R., Bond, N.R., Cunningham, S.C., Metzeling, L., Reich, P., Thompson, R.M., Mally, R., 2012. The influences of climatic variation and vegetation on stream biota: lessons from the Big Dry in southeastern Australia. Glob. Chang. Biol. 18, 1582–1596.

[22] Wang Q K, Wang S L, Feng Z W, et al. Active soil organic matter and its relationship with soil quality. Acta Ecologica, 2005, 25(3): 513-519. (In Chinese)

[23] Wang Zhi et al. Distribution Characteristics of Soil Carbon and Nitrogen in Different Riparian Zone in Chongming Island. Journal of Anhui Agri. Sci. 2013, 41(22):9266-9269. (In Chinese)

[24] Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J., Dokken, D.J., 2000. Land use, land-use change and forestry. IPCC Special Report. Cambridge University Press, Cambridge, UK.

[25] Yang Xiao-ying, Luo Xing-zhang, Zheng Zheng, et al. Explore the spatial and temporal patterns of water pollution in the Yincungang canal of the Lake Taihu Basin, China. Environmental
Science, 2012, 33(9): 3051-3056. (In Chinese)

[26] Yu S, Chen W, He X Y, et al. Soil physical and chemical properties in four types riparian forests around Dahuofang Reservoir. Journal of Northeast Forestry University, 2015, 43(3): 87-89. (In Chinese)

[27] Zhang Xue-ni, Lv Guang-hui, Gong lu, et al. Pattern and Causes of Soil Carbon Distribution in Riparian Zone in Arid Desert Area. Chinese Journal of Soil Science, 2013, Vol.44, No.6. (In Chinese)

[28] Zhang Y, Qin J H, Zhao Y C, et al. Change of soil physical and chemical properties, organic carbon and nutrients of different soil profile on different forest in Binggou of Heihe Basin. Journal of Soil and Water Conservation, 2013, 17(2): 126-130.