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Soil nutrient concentration and distribution at riverbanks undergoing different land management practices: Implications for riverbank management

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Abstract. Riverbanks are important boundaries for the nutrient cycling between lands and freshwaters. This research aimed to explore effects of different land management methods on the soil nutrient concentration and distribution at riverbanks. Soils from the reed-covered riverbanks of middle Yangtze River were studied, including the soils respectively undergoing systematic agriculture (gathering young tender shoots, reaping reed straws, and burning residual straws), fires and no disturbances. Results showed that the agricultural activities sharply decreased the contents of soil organic matter (SOM), N, P and K in subsurface soils but less decreased the surface SOM, N and K contents, whereas phosphorus were evidently decreased at both surface and subsurface layers. In contrast, the single application of fires caused a marked increase of SOM, N, P and K contents in both surface and subsurface soils but had little impacts on soil nutrient distributions. Soils under all the three conditions showed a relative increase of soil nutrients at riverbank foot. This comparative study indicated that the different or even contrary effects of riverbank management practices on soil nutrient statuses should be carefully taken into account when assessing the ecological effects of management practices.

1. Introduction

Riverbanks are important ecotones between aquatic and terrestrial ecosystems. The nutrient inputs from riverbank soils have been considered as an important nutrient source of freshwater ecosystems [1] and play a vital role in the nutrient cycle and eutrophication of water bodies [2]. However, it is notable that riverbanks are often suffering from various management practices for human benefits. Soil nutrients have been taken as an important part when assessing the ecological effects of those varied riverbank management methods or when evaluating the efficiency of riverbank restorations [3]. Understanding the nutrient status of riverbank soils under different land management practices can provide meaningful insights for riverbank restoration and management.

Changes of soil properties are always accompanied with land use change. Studies have attempted to connect soil nutrient stocks and forms with land management [4]. Most of these studies were focused on large-scale landscapes. Studies on the influences of land management on the nutrient inputs into rivers were carried out at a watershed scale [5], but the freshwater–land transition zones were often seen as homogeneous transport passages. More recently, the importance of resources

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movement across ecosystems has being increasingly recognized [2]. The heterogeneity and complexity of management practices imposed on riverbanks are worthy of careful consideration.

Recent studies reveal that riverbanks represent a considerable nutrient source rather than a nutrient pool [1], and the nutrient inputs from riverbank soils into rivers were considered as an unneglectable contributor of aquatic eutrophication [6, 7]. Nutrients in riverbank soils are transferred into rivers not only by the way of surface flow but by ways of subsurface flow [8] and riverbank erosion [1, 9], and an obviously higher phosphorus concentration in suspended sediments and bed sediments than in soils were observed [7, 10]. Studies have also attempted to connect the nutrient dynamics of riverbank soils with hydrogeomorphological attributes such as geomorphic patterns [8], riverbank erosion [1, 9], sedimentation [6], and hydrologic connectivity [11]. Notably, the close relation of land use with water quality and aquatic ecological processes [10] requires a better understanding of the nutrient status in riverbank soils within a human-activity-related context. Studies have evaluated the role of riverbanks in the nutrients reduction [12] and examined the validity of riparian zone restorations [3], yet knowledge about the differences in the soil nutrients at riverbanks similar in land cover but undergoing different management practices is limited. More care should be taken on restoration practices in consideration of the potential eco-obstacles resulted from riparian restoration [6, 7]. Riverbank soils have been used as a management tool to mitigate the nutrient inputs into rivers, but the reduction efficiency is not necessarily creditable [8]. As researchers have pointed out [6], conservation and restoration of floodplain ecosystems often suffer from a deficient knowledge on the basic information in soils. Improper riverbank management methods would produce unpredictable ecological consequences such as aggravating nutrient inputs [9].

Therefore, an evaluation of the soil nutrient status under different land management practices is needed for sustainable riverbank management and restoration. We consider the nutrient concentration and distribution in riverbank soils would be a tangible variable as a response to riverbank management practices. Using the reed-covered riverbanks of middle Yangtze River under different land management practices as an example, we aimed (1) to investigate the soil organic matter, nitrogen, phosphorus and potassium contents and pH value at these riverbanks, (2) and to evaluate the nutrient status of the riverbank soils having similar vegetation cover but suffering from different management practices.

2. Study area and method

Yangtze River, the world's third largest river in the world and the largest river in China, is an important ecological and economic corridor of China. Its middle reach ranges from Yichang to Hukou (figure 1). The floodplains along the middle Yangtze River are utilized at a high level of intensity for agriculture. The sloping riverbank lands are commonly covered by reeds (*Phragmites australis*), which is a perennial and tall herbaceous plant.

Three typical locations of the reed-covered riverbanks along the middle Yangtze River (figure 1) were selected to represent three different statuses of land management: the Soils with Systemic Agricultural activities, SSA; the Soils with Single application of Fires, SSF; and the Soils with No Disturbances, SND. The SND soils were used as a control for understanding the soil nutrient status after the application of management methods. The contents and distributions of soil nutrients in the SSA and SSF soils were compared with those in the SND soils, and the significance of difference were statistically tested.

The slopes of these three riverbanks for study have a length of about 130 m at a gradient of about 4.5-5.6%. The floodplains adjacent to these riverbanks are used as farmland for planting oilseed rape or wheat. At the SSA riverbanks, in spring, local people gather the young tender shoots, which is a widely-used vegetable in China; in autumn, people reap the reed straw for paper making and burn the residual straws in situ. These sequential agricultural activities have been imposed on SSA riverbanks over six decades since the land development in 1950s, but there are no other cultivation activities such as fertilization, spraying pesticides or ploughing. The SSF riverbanks are always adjacent to farming lands, and the annually burning of reeds at autumn is just a supplementary method for the cultivations in the adjacent farm lands. The SND riverbanks are not suffering from any direct disturbances.

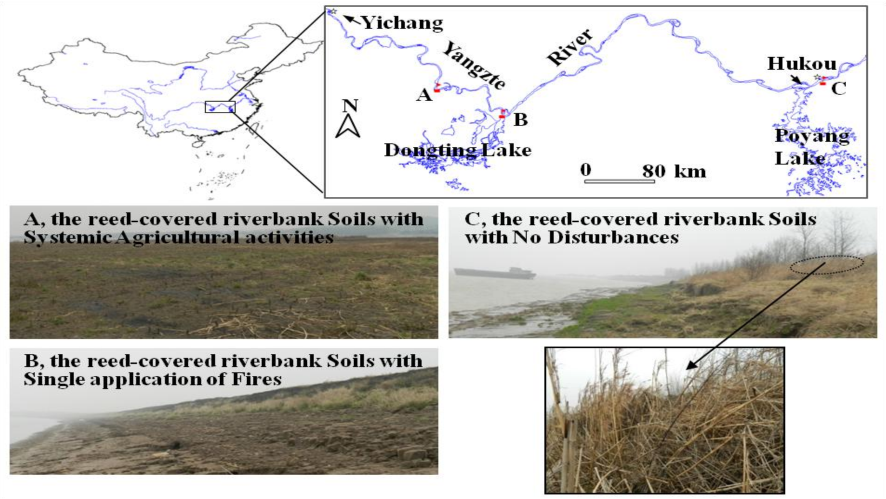

Figure 1. Study area and the three locations for soils sampling.

Soil sampling was carried out in early spring, and there had been about ten days without rains before sampling. At each location, we selected three sampling transects at 5-m intervals, and set seven sampling points at equidistant intervals along each transect, covering the gradient from the top to the bottom of the riverbank. A total of 126 soil samples at depths 0–10 cm and 10–20 cm were collected.

Analysis methods for soil pH and nutrient content followed the related Chinese national standards. Specifically, soil pH was determined by using a glass electrode in a 1 mol/L potassium chloride solution, in accordance with the NY/T 1377-2007 standard published by Ministry of Agriculture of the People's Republic of China. Determination of soil organic matter content (SOM, g/kg) was based on the standard NY/T 121.6-2006, using the potassium dichromate volumetric method. In the soil alkali-hydrolyzable nitrogen content (N) determination based on the Chinese standard LY/T 1229-1999, the air-dried soils were hydrolyzed with 1.8 mol/L sodium hydroxide solution; the alkali-hydrolyzable nitrogen was led in a boric acid receiving solution of 20 g/L; the receiving solution was titrated using hydrochloric acid; then the alkali-hydrolyzable nitrogen content in the soil sample was calculated. The soil available phosphorus content (P) was measured based on the Chinese standard HJ 704-2014 using the sodium hydrogen carbonate solution-Mo-Sb anti spectrophotometric method. Contents of available potassium (K) in soil samples were determined with ammonium acetate extraction using flame photometer, according to the Chinese standard NY/T 889-2004.

3. Results

3.1. The nutrient levels of riverbank soils under different land management practices

The average and variation of soil nutrient contents along the riverbank slope are shown in table 1. At soil surface layer (0–10 cm), the SOM contents in the SSA and SSF soils were higher than that in the SND soils; the nitrogen content was highest in the SSF soils followed by the SND soils; the SSA soils was remarkably lower in available P content than the SSF and SND soils; and the available K content was highest in the SSF soils followed by SND soils. At soil subsurface layer (10–20 cm), the SOM, N, P and K contents in the SSA soils were evidently less than those in the SSF and SND soils, and the SSF soils had the highest nutrient contents. Although all the riverbank soils had higher contents of soil nutrients in the surface layer than in the subsurface layer, the difference of soil nutrient contents between the surface and the subsurface layers was largest in the SSA soils and was smallest in the SND soils.

Table 1. The soil nutrient contents in the riverbank soils undergoing different land management practices.

Riverbank soils		SOM /g.kg^{-1}		N /mg.kg^{-1}		P /mg.kg^{-1}		K /mg.kg^{-1}		pH	
		Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
0–10cm	SSA	13.85	5.58	56.98	27.84	6.74	1.80	61.17	22.03	8.55	0.09
	SSF	14.58	3.22	77.99	15.88	19.10	8.96	99.85	54.41	8.18	0.17
	SND	11.84	4.46	61.27	17.00	21.26	7.38	63.35	31.67	8.48	0.06
10–20cm	SSA	10.51	2.49	43.56	10.21	4.19	1.35	31.15	11.54	8.62	0.07
	SSF	13.49	3.10	69.96	13.93	21.41	8.04	74.28	19.52	8.27	0.16
	SND	11.16	2.61	64.24	19.62	15.13	5.29	55.38	35.01	8.48	0.05

Note: SOM, Soil Organic Matter; N, alkali-hydrolyzable Nitrogen; P, available Phosphorus; K, available potassium; Avg, average of soil nutrient contents; SD, the standard deviation of soil nutrient contents along soil transect; SSA, the Soils with Systemic Agricultural activities; SSF, the Soils with Single application of Fires; SND, the Soils with No Disturbances.

All soils especially the SSA soils showed that the variation of soil nutrient contents along the riverbank slope was larger at the surface layer than at the subsurface layer (table 1). Specifically, surface SOM and N concentrations exhibited a larger degree of variation along the SSA soil transect than along the SSF and SND soil transects. In contrary, the variations of subsurface SOM and N contents along the SSA soil transect were smaller. The soil P and K contents at either surface or subsurface layer had the smallest variations along the SSA soil transect.

3.2. Soil nutrient distribution along the riverbank slopes under different land management practices

The distribution of soil N contents was generally similar to that of SOM contents (figure 2). Along the riverbank slope in downward direction, there was a decreasing trend of SOM and N contents especially for the SSF and SND soils. It is noteworthy that a marked increase of SOM and N contents at the riverbank foot was observed, and that the SOM and N contents at the SSA riverbank foot were obviously lower than those at the SSF and SND riverbank foots.

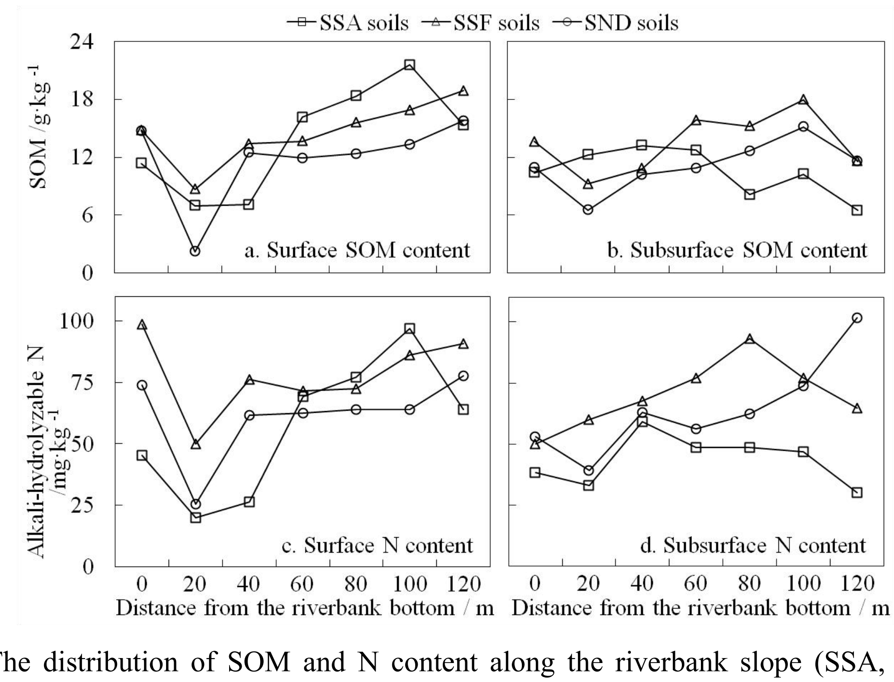

Figure 2. The distribution of SOM and N content along the riverbank slope (SSA, the Soils with Systemic Agricultural activities; SSF, the Soils with Single application of Fires; SND, the Soils with No Disturbances).

In either the SSF or SND soils, the nutrient distribution patterns at surface and subsurface layers were similar. In contrast, the surface and subsurface layers of SSA soils presented different nutrient distribution patterns, and the subsurface SOM and N contents varied little along the riverbank slope.

Both the surface and subsurface P contents in the SSA soils varied little along the riverbank slope, and the vertical difference of P contents was small (figure 3). Contrary, a more complex distribution pattern of P contents along the SSF and SND soil transects were observed. At the middle part of SSF and SND transects the soil P content decreased along the riverbank slope in downward direction. But there were an obvious increasing trend of P content at the bottom part and a decreasing trend of P content at the top part. Similar to SOM and N, the P content in all the soils obviously increased at the riverbank foot.

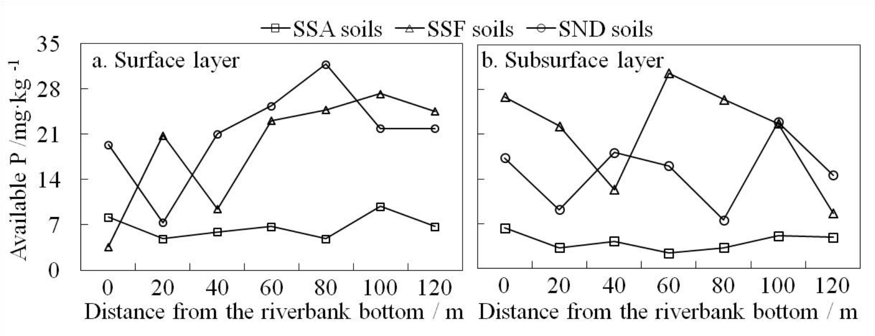

Figure 3. The distribution of soil available P content along the riverbank slope (SSA, the Soils with Systemic Agricultural activities; SSF, the Soils with Single application of Fires; SND, the Soils with No Disturbances).

Along the riverbank slope in downward direction, on the whole, the surface K contents in all the soils presented a decreasing trend except an increase of K content occurring at the riverbank foot (figure 4). In the SSF and SND soils, the distribution patterns of surface and subsurface K contents were similar. But the K contents in the SSA soils had different distribution patterns at the surface and subsurface layers, and the subsurface K contents varied little along the riverbank slope.

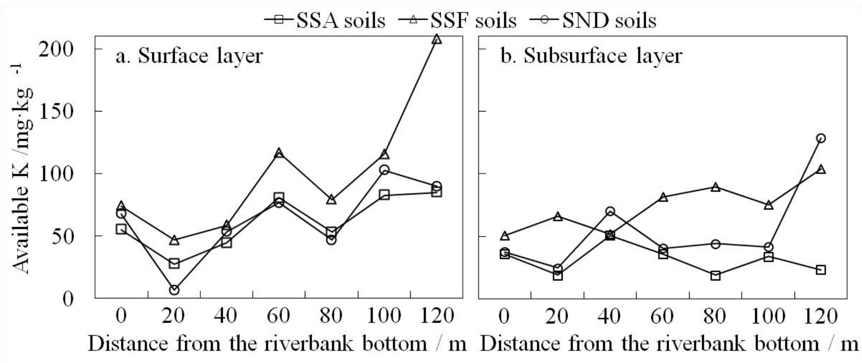

Figure 4. The distribution of soil available K content along the riverbank slope (SSA, the Soils with Systemic Agricultural activities; SSF, the Soils with Single application of Fires; SND, the Soils with No Disturbances)

3.3. The pH of riverbank soils under different land management practices

Table 1 and figure 5 show that either at surface or subsurface layer, the soil pH value was the highest in the SSA soils, lower in the SND soils, and lowest in the SSF soils. The average pH value of the surface SSA soils was 8.55 (range: 8.43–8.70), and the average pH values in the surface SND and SSF soils were respectively 8.48 (range: 8.43–8.57) and 8.18 (range: 7.92–8.42). At subsurface layer, the average pH values of the SSA, SND and SSF soils were 8.62 (range: 8.54–8.72), 8.48 (range: 8.43–8.56), and 8.27 (range: 8.06–8.53). All soils showed a higher pH value at the subsurface layer than at the surface layer (figure 5), and the vertical difference of soil pH was largest in the SSF soils. Both SSA and SND soils showed an increasing trend of soil pH value along the downward riverbank slope, while a clear decreasing trend of pH value was observed in the SSF soils.

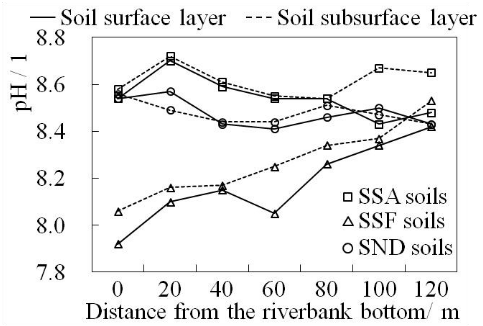

Figure 5. The distribution of soil pH along the riverbank slope (SSA, the Soils with Systemic Agricultural activities; SSF, the Soils with Single application of Fires; SND, the Soils with No Disturbances).

4. Discussions

4.1. Impacts of riverbank management practices on the nutrient levels in riverbank soils

The comparison between the SSA and SND soils indicates that the agricultural activities imposed on the reed-covered riverbank have led to the significant decrease of subsurface soil nutrient contents (table 2). The subsurface N, P and K contents in the SSA soils were significant lower than those in the SND soils ($p < 0.05$, table 2). Notably, the agricultural activities have resulted in the significant decrease of soil P contents at either surface or subsurface layer ($p < 0.05$). Impacts of agricultural activities on the SOM, N and K contents in surface soil layer were not significant.

Table 2. The nonparametric-test statistical significance of the differences in soil nutrient content and pH between the riverbank soils undergoing different land management practices.

Paired samples		SOM	N	P	K	pH
SSA-SND	0–10 cm [a]	0.310 [b]	0.612 [c]	0.018 [c, *]	0.612 [c]	0.046 [b, *]
	10–20 cm [a]	0.735 c	0.018 [c, *]	0.018 [c, *]	0.018 [c, *]	0.018 [b, *]
	0–20 cm [a]	0.612 [b]	0.063 [c]	0.018 [c, *]	0.063 [c]	0.018 [b, *]
	VD [d]	0.048 [*]	0.040 [*]	0.024 [*]	0.655	0.847
SSF-SND [e]	0–10 cm [a]	0.018 [b, *]	0.018 [b, *]	0.398 [c]	0.018 [b, *]	0.018 [c, *]
	10–20 cm [a]	0.028 [b, *]	0.310 [b]	0.063 [b]	0.128 [b]	0.034 [c, *]
	0–20 cm [a]	0.018 [b, *]	0.018 [b, *]	0.310 [b]	0.028 [b, *]	0.028 [c, *]
	VD [d]	0.565	0.405	0.798	0.949	0.046 [*]
SSA-SSF	0–10 cm [a]	0.612 [c]	0.128 [c]	0.028 [c, *]	0.018 [c, *]	0.018 [b,*]
	10–20 cm [a]	0.063 [c]	0.018 [c, *]	0.018 [c, *]	0.018 [c, *]	0.018 [b, *]
	0–20 cm [a]	0.043 [c, *]	0.018 [c, *]	0.018 [c, *]	0.018 [c, *]	0.018 [b, *]
	VD [d]	0.035 [*]	0.201	0.038 [*]	0.949	0.275

[a] The Wilcoxon two-sample test is used (2-tailed).
[b] Based on positive ranks.
[c] Based on negative ranks.
[d] *VD* is the vertical difference of soil nutrient content and pH between the surface and subsurface layers, and the Mann-Whitney two-sample test is used (2-tailed).
[e] SSA, the Soils with Systemic Agricultural activities; SSF, the Soils with Single application of Fires; SND, the Soils with No Disturbances.
'*', Significant at p=0.05 level.

In contrast, the single application of fires has remarkably increased the soil nutrient content at the reed-covered riverbanks. At the depth 0–20 cm, the SOM, N and K contents in the SSF soils were significant higher than those in the SND soils ($p < 0.05$, table 2). Specifically, the increases in surface SOM, N and K contents and subsurface SOM content were significant at $p = 0.05$ level. The subsurface SSF soils had higher contents of N, P and K than the subsurface SND soils, but the difference was not statistically significant.

Furthermore, there are evident differences in soil nutrient content between the riverbank soils suffering from fires and the soils impacted by agricultural activities. At 0–20 cm soil layer, the SSF soils had significantly higher contents of SOM, N, P and K than the SSA soils ($p < 0.05$, table 2).

For the SSA soils, the marked decrease in subsurface nutrient contents as well as the decrease in surface P content is connected with the annual reaping of reeds, which means the direct removal of soil nutrient source. The unnoticeable change in the SOM, N and K contents in surface SSA soils is an integrated result of the soil-nutrient source removal and the accelerated nutrient-transformation rate by fires.

The black carbon produced by fires may play an important role in the increase of SOM content in SSA and SSF soils. Studies have reported that black carbons can strongly influence the organic carbon dynamics in soils [12]. The effect of fires on soil nitrogen status is complex. Some studies have demonstrated that fires can decrease the nitrogen content in forest soils because of the poor quality litter produced by incomplete burning [13], but others claimed that fires can increase the soil N availability [14]. In contrast to trees, reeds are easy burned and the unburned litter is of much lower quantity, and more organic carbon and nitrogen are released. The higher SOM and N contents in the SSF soils in this study indicated that fires can accelerate the releasing of carbon and nitrogen. It has long been recognized that agricultural activities reduce the phosphorus content of soils [15], while fires are generally considered to benefit the accumulation of available phosphorus in soils [16].

On the whole, agricultural activities can lead to a remarkable decrease of nutrient contents in the subsurface riverbank soils, and have a stronger impact on mineral nutrients (P and K) than on the SOM and N. Fires can sharply increase the nutrient contents especially the mineral nutrient content in soils.

4.2. Impacts of riverbank management practices on the pH value of riverbank soils

Agricultural activities can result in a higher soil pH value, which may be associated with the burning of residual straws (figure 5 and table 2). The single application of fires, however, has resulted in a significant decrease of soil pH value ($p < 0.05$, table 2) and has created a different distribution pattern of soil pH along the riverbank slope. This may be in connection with the uneven burning of reeds across the riverbanks. Different from the prescribed burning of residual straws, burning reeds at the wild-reeds covered riverbanks is just a supplementary method for the cultivation at the adjacent farm land. And the burning severity decreases with the distance from the riverbank top. Therefore, the soil pH decreases along the riverbank slope at the downward direction. Additionally, the relatively higher content of SOM favors the lowering of soil pH.

4.3. Impacts of riverbank management practices on the soil nutrient distribution along the riverbank slope

As shown in figures 2–4, the soil nutrient distribution pattern along riverbank slope was quite similar between the soils with single application of fires (SSF) and the soils with no disturbances (SND), and it means that the single application of fires has little impacts on the soil nutrient distribution at riverbanks. Along the riverbank slope in downward direction, the nutrient content in both SSF and SND soils decrease on the whole, and the distribution patterns at surface and subsurface layers differ little. But there is a marked increase of soil nutrient content at the riverbank foot, implying that the nutrient accumulation at riverbank foot should be carefully taken into account when assessing the filtration effects of riverbanks.

In contrast, the agricultural activities showed remarkable influences on soil nutrient distribution. Specifically, the subsurface nutrient content in the SSA soils vary little along the riverbank slope, and the vertical differences of SOM and N contents were significantly larger in the SSA soils than in the SND soils ($p < 0.05$, table 2). That is, agricultural activities have resulted in the relative enrichment of soil nutrients at the soil surface layer, and variations of both surface and subsurface P contents along the SSA riverbank slope are evidently smaller. Additionally, the soil nutrient contents at the SSA riverbank foot were lower than those at the SND riverbank foot.

4.4. The potential impacts of riverbank management practices on the nutrient inputs into the river

The comparison between the SND and SSF soils has shown that fires have caused a remarkable increase of SOM, N, P and K contents in riverbank soils. Furthermore, the soil nutrient content increase at riverbank foot was larger for the SSF soils than for the SND soils. That is, the SSF soils have a higher accumulation of soil nutrients at riverbank foot. The single application of fires can accelerate the soil nutrients cycling at riverbanks and potentially increase the nutrient inputs into the river.

Although there was no significant difference in surface SOM, N and K contents between the SSA and SND soils, the subsurface N and K contents were remarkably lower in the SSA soils. Notably, both the surface and subsurface P contents were much lower in the SSA soils than in the SND soils. Furthermore, the increase of soil nutrient contents at the SSA riverbank foot was fainter. It can be seen that the agricultural activities may decrease the nutrient inputs (especially N, P and K) into the river. Additionally, the agricultural activities have enhanced the relative enrichment of soil nutrient at the surface layer and would make the surface soil be the major passage for the nutrient inputs into the river.

5. Conclusions

This study at the reed-covered riverbanks of the middle Yangtze River indicates that different management practices have significant and different impacts on the concentration and distribution of soil nutrients. The subsurface SOM, N, and K contents were decreased in the riverbank soils with systemic agriculture, but the surface SOM, N, and K contents were less decreased. The agricultural practices applied to the studied riverbanks evidently decreased the P contents at both surface and subsurface layers. Soil nutrient distribution was also affected by these agricultural practices, that is, the vertical and horizontal variations of soil nutrient contents were enlarged. In addition, soil alkalinity was increased in the soils with systemic agriculture. In contrast to the agricultural practices, the single application of fires evidently increased contents of SOM, N, P and K, and the soil pH level, but impacted little on the soil nutrient distribution. In all the studied circumstances, there is a generally decreasing trend in soil nutrient content toward the river except a relative increase at riverbank foot.

These results indicate that the agricultural activities – gathering young tender shoots, reaping mature reeds, and burning residual straws – potentially decrease the nutrient inputs (especially P and K) into the river waters, whereas fires might largely increase the nutrient inputs into the river. The agricultural practices with a moderate degree of disturbance may be a management method providing ecological and economic benefits for the reed-covered riverbanks of middle Yangtze River, but fires are not advisable.

Acknowledgments

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