



Water quantity and quality changes from forested riparian buffer in Beijing

Kang Xu¹ · Lichun Mo² · Zhenming Zhang¹ · Mingxiang Zhang¹

Received: 4 January 2019 / Accepted: 16 July 2019 / Published online: 7 August 2019
© Springer-Verlag GmbH Germany, part of Springer Nature 2019

Abstract

As a transitional zone between aquatic and terrestrial ecosystems, the riparian buffer is an important control measure for non-point source pollution. The research presented here mainly discussed the interception efficiencies of different vegetation types for nitrogen and phosphorus pollution. The results showed that canopy, shrub, and grass interceptions basically accounted for about 80.0% of total interception, and therefore riparian buffer configurations should clearly distinguish three levels of vegetation types. (1) Canopy, shrub, grass, and litter interceptions of *Pinus tabuliformis* (YS) were the highest, up to about 71.1%. (2) *Platycladus orientalis* (CB) had the highest transportation and enrichment for the elements nitrogen (N) and phosphorus (P) throughout the process, which the value of TP decreased from 0.2 to 0.12 mg/L and the value of TN decreased from 5.0 to 2.5 mg/L. (3) The transportation of total phosphorus (TP) of the three tree species was higher than the transportation of total nitrogen (TN), showing that the enrichment of P was stronger than that of N. Thus, *Pinus tabuliformis* is the best configuration for rainfall interception, while *Platycladus orientalis* is the best configuration for N and P removals. Different forest configurations should also be considered to build a riparian buffer to remove nutrient in the future.

Keywords Riparian buffer · Hydrological processes · Nutrient transformation · Vegetation types

Introduction

In recent years, with population growth and ongoing social and economic development of cities, people's exploitation of natural resources and destruction of the environment have become increasingly critical. Water pollution also becomes an increasingly serious issue, being a serious threat to people's health and economic development. Non-point source pollution has become the most important source of water pollution in rivers and lakes (Quan and Yan 2002; Chen 2010; Shen 2010). For example, conversion to farmland, agricultural activities, grazing, and discharging industrial and domestic sewage around the river bank can all cause the deterioration of the

ecological environment of riparian areas (Jacobs and Gilliam 1985; Tian et al. 2010); moreover, rain or snowmelt runoff can carry non-point source pollutants into rivers, causing a change in the river or lake and reservoir water quality and eventually leading to increased eutrophication, diminished flood control capacity, and other disasters. Eutrophication by large inputs of nitrogen (N), phosphorous (P), and other nutrients occurs most commonly (Klapproth and Johnson 2000; Mankin et al. 2007).

Many studies have shown that a riparian buffer is an important control measure for non-point source pollution (Lowrance et al. 1988; Yan 1999; Jon et al. 2005), especially in watershed restoration aiming at reducing pollutants (Baker et al. 2007). In northeastern China, an excessive amount of fertilizers and pesticides is brought directly into the river by surface runoff, due to lack of riparian vegetation (Mi et al. 2015). Interception is defined as water that is temporarily intercepted and stored on vegetation surfaces (e.g., shrubs, grass, trees, and leaf litter) (Xiang et al. 2017). Thus, one way to reduce non-point source pollution is to utilize the natural purification services provided by the ecosystem (Yan et al. 2018). The water quality and stream habitat can be improved by riparian tree planting (Parkyn et al. 2005). With sediment accumulated, much nutrient load is retained and the discharge can be reduced by evaporation and transpiration.

Responsible editor: Kenneth Mei Yee Leung

✉ Zhenming Zhang
zhenmignzhang@bjfu.edu.cn

✉ Mingxiang Zhang
zhangmingxiang@bjfu.edu.cn

¹ School of Nature Conservation, Beijing Forestry University, Beijing 100083, China

² School of Economics & Management, Beijing Forestry University, Beijing 100083, China

The concentrations of total nitrogen (TN), total P (TP), and total suspended solids (TSS) are also found to be lower (Burchsted et al. 2010, Swanson et al. 2017). Moreover, many technical measures also have been taken (Wang et al. 2009; Wu 2011).

In the early 1980s, research started by United States Department of Agriculture (USDA) researchers in Tifton, Georgia (GA), showed that a riparian deciduous forest buffer can reduce the N content in the runoff by 68.0% (Wang et al. 2009). On the west coast of the Chesapeake Bay, Maryland (MD), scientists have found that riparian buffers can remove 89.0% of the N content (Peterjohn and Correll 1984). However, in terms of the removal of the element P, riparian buffers have less effect than sediment interception and N removal (Parsons et al. 1994).

Dillaha et al. (1989) showed that a 9-m-wide orchard–grass buffer can remove 89.0% of the P in the surface runoff; they also revealed that grass filter strips can only temporarily intercept P particles: once a storm comes, P will be lost. Zhang et al. (2009) found that 20–30 m of adjacent riparian zone can effectively reduce N, P, and other nutrients. Wang and Zhang (2006) analyzed the buffer sampling of Zhalong wetland and found that wetland buffer zones have a strong ability to remove N and P nutrients, and the removal efficiency for TN and TP reached 74.1% and 84.0%, respectively.

However, appropriate vegetation configuration may be also important to reduce the pollutants effectively. The purpose of this study was to determine the effects of a watershed forested riparian buffer system on the surface and subsurface transport of N and P. The basic hydrological and biogeochemical processes in three types of forest riparian buffers (*Quercus variabilis***Pinus tabulaeformis* (SP*YS), *Pinus tabulaeformis* (YS), and *Platycladus orientalis* (CB)) were explained. Thus, our study can provide theoretical and technical support for the reconstruction of different forest configuration riparian buffers of future water conservation areas.

Materials and methods

Study area

The study was conducted in Banchengzi basin, located on the northern Miyun Reservoir, Beijing, China, at 116° 55′–117° 2′ E and 40° 37′–40° 43′ N. This basin is entirely mountainous and its area is 66.18 km². There is a reservoir in this basin with a total storage capacity of 1.02 million m³. Banchengzi basin belongs to the warm temperate semi-humid continental monsoon climate, and the annual average temperature is 10.5 °C; the average annual rainfall reaches 669 mm, and is concentrated from June through August inclusively, which account for 75.0% of the annual rainfall. Banchengzi basin has rich

vegetation types, with *arborvitae* forest, *pine* forest, and *acacia* forest as the main vegetation types (Fig. 1).

Methods

Sampling was collected during summer in 2014. Ensuring that the sample's nutrient content did not change, thus, the samplings were collected the next day after the rainfall events. The amount of rainfall, throughfall, stemflow, runoff, and subsurface flow of each rainfall was measured. Samples of the rainfall, throughfall, stemflow, runoff, and subsurface flow were collected and brought back to the laboratory. There, the relationship of rainfall, runoff, and water quality as affected by different plant types was analyzed, providing a reference for further study of N transfer.

Throughfall

Three rain barrels with a bunghole diameter of 26 cm were placed uniformly along the diagonal of each of the four 10 × 10-m typical forest plots. After rainfall, the barrels were used to measure the volume of the throughfall collected in the barrels. Rain volume divided by the collection area of the rain barrel is the throughfall of the measuring area; then the average value of three measuring areas is taken as the throughfall of the forest. Thus, the formula of the throughfall is as follows:

$$TF = \sum T_i / \sum A_i$$

where TF is the throughfall (mm), T_i is the collected rainfall volume (mm³), and A_i is the collection area of the rain barrel (mm²).

Stemflow

Three standard trees were selected whose trunk diameter class was representative in the four 10 × 10-m typical forests plots, respectively, and then the rubber tube which was wound on the trunk was employed to measure stemflow. Firstly, prominent parts of the trunk bark were smoothed with a paring knife to prevent puncturing of the rubber tube. Simultaneously, the degree of fit of the rubber tube and the tree bark was increased in order to make the measurement more accurate. Then the rubber tube (1.5 m in length, 3.0 cm in diameter) was cut open and twined around the trunk from a 1.3-m height to the trunk's base. The rubber tube was affixed on the trunk with small nails, sealing the pores with a thin rubber skin to prevent water leaking. The collection bucket was connected to the rubber tube at the trunk base in order to collect stemflow. After every rainfall, the rain volume collected in the collection bucket was measured with a graduated cylinder. The measured rain volume divided by the

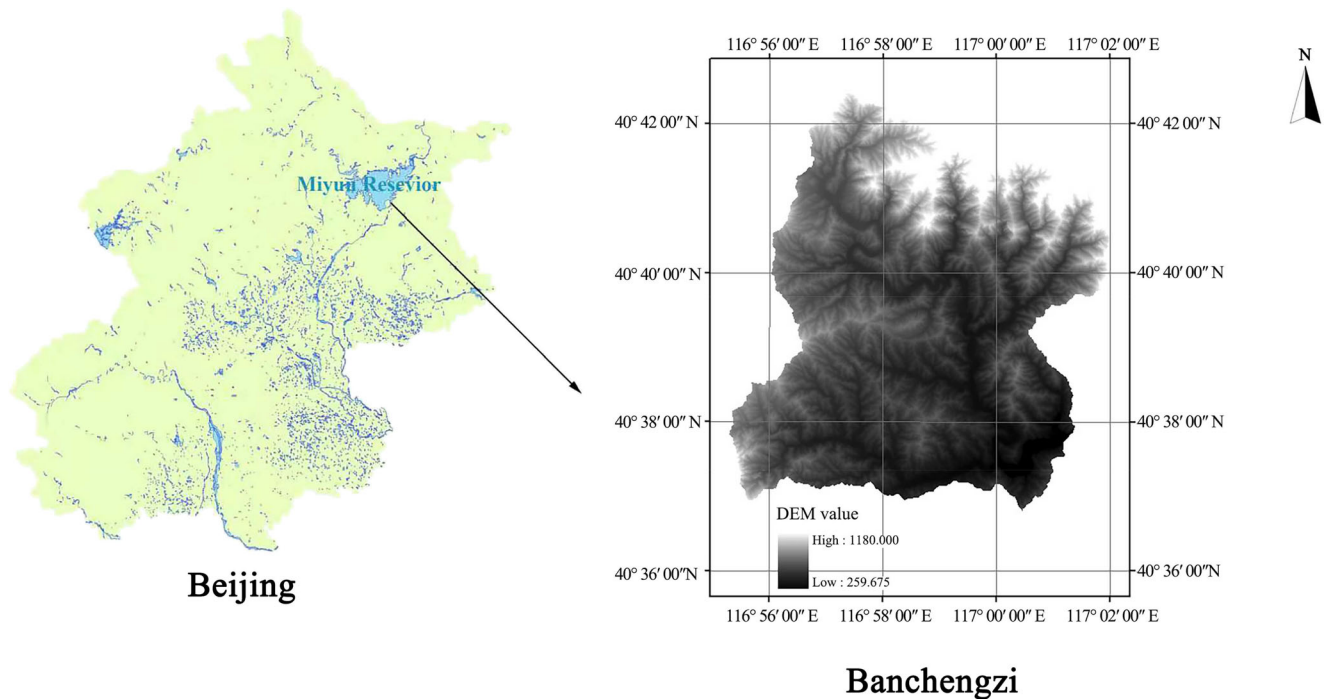


Fig. 1 Study area and the locations of the sampling sites

standard tree’s canopy area is the stemflow of the standard tree. Therefore, the formula of the stemflow is as follows:

$$SF = \frac{1}{M} \sum_{i=1}^n \frac{SF_n}{K_n} M_n$$

where SF is the stemflow (mm), SF_n is the stemflow of each different diameter class (mm), M is the number of trees per unit area, M_n is the number of trees per diameter class, n is the number of diameter classes, and K_n is the average projection area of the canopy in each different diameter class (cm^2).

Canopy interception

Canopy interception is a calculated value, and according to the principle of the water balance, the formula for canopy interception is as follows:

$$I = P - P' - G$$

where I is the canopy interception (mm), P is the rainfall (mm), P' is the throughfall (mm), and G is the stemflow (mm).

Shrub interception

In order to study the rain interception characteristics of the forest’s vertical hierarchy, additional shrub interception observations were made as follows: understory shrubs were dug up and planted in plastic buckets, then a ring-shaped rainwater harvesting device was made and

placed at the base of the small shrub’s roots. A rain gauge connected to the water outlet automatically recorded rainfall interception. The setup is shown schematically in the diagrams of Figs. 2 and 3.

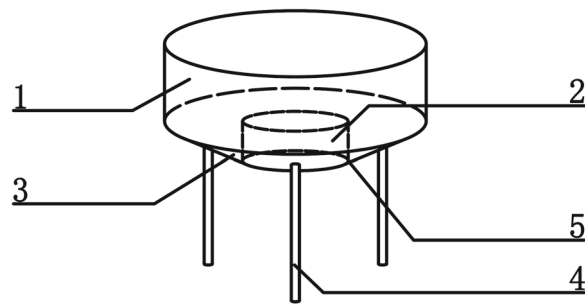
Grass interception

To complete the assessment of the rainfall interception characteristics of the forest’s vertical hierarchy, additional grass interception observations were also set up. In a selected plot of grassland in the forest, a steel ring was positioned on the ground in the understory herbaceous vegetation, and was then hammered into the soil layer until the steel ring was at level with the ground surface. The steel ring was dug out with a shovel and placed on a steel ring base. The removed sample of herbal layer was then placed in an adjustable frame, the three parts of which all had connection screws with which their height could be adjusted to correspond with the slope of the soil in the selected plot, ensuring the herbal layer’s natural position. The sampled undisturbed herbal layer was placed on the collector and the automatic recording rain gauge was connected outside the collector; thus, the rainfall could be recorded and the dynamic process of its interception could be observed. A schematic diagram is given in Figs. 4 and 5.

Litter interception

Observation of rainfall interception by leaf litter employed the same equipment as that used for the observation of

Fig. 2 Schematic diagram of shrub interception collector



1: the outer thin-walled, 2: inner thin-walled, 3: harvesting funnel, 4: water holes, 5: frame

interception by grass in this research, taking the original and undisturbed forest litter and placing it in the rainwater harvesting device. For the specific methods of operation, the reader is referred to the schematic diagram of grass interception observation (Figs. 4 and 5).

Nutrient monitoring

The study area was the Banchengzi Basin, which was on the rural area in Beijing. Crop and forest lands were the primary land types here. Thus, the increase nitrogen, phosphorous, and pesticide concentrations in nearby river water were through agricultural activities (Xiang et al. 2016). Based on the measurement data and using

the corresponding statistical analysis method, we analyze and discuss the transportation of nutrients such as $\text{PO}_4^{3-}\text{-P}$, TP, $\text{NO}_3^- \text{N}$, and TN under different plant types in forested riparian buffer, in order to assess their efficiency of interception and transportation of N and P. Water quality indicators measured in this study are $\text{PO}_4^{3-}\text{-P}$, TP, $\text{NO}_3^- \text{N}$, and TN, which were all measured by reference to national standards. The method of $\text{PO}_4^{3-}\text{-P}$ and TP is Molybdate spectrophotometry (GB 11893-89) (Environmental Protection Agency of China 1989a, b), which has been widely used to determine phosphorus for fresh water, with a detection limit of 0.01 mg/L. According to the standard curve and spectrophotometer to get the value. The method of $\text{NO}_3^- \text{N}$ is UV

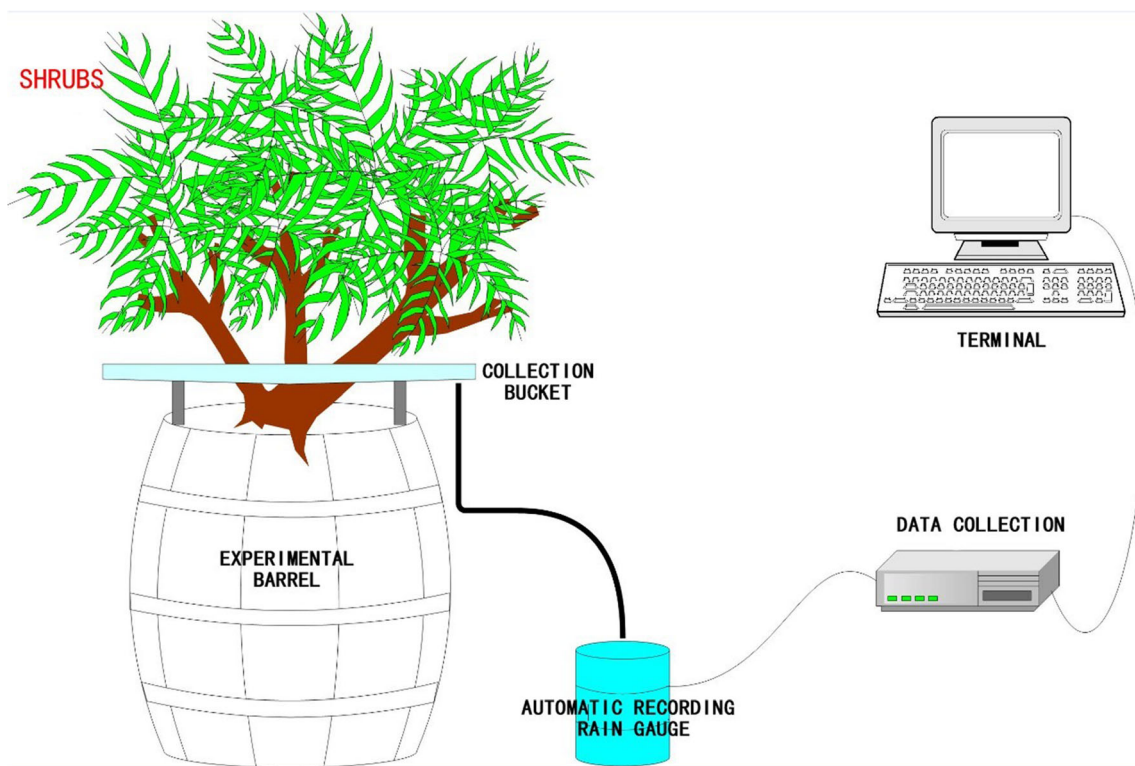
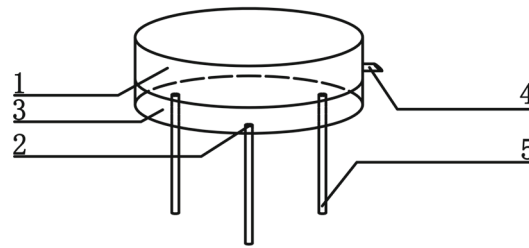


Fig. 3 Schematic diagram of shrub interception observation

Fig. 4 Schematic diagram of herb and litter interception collector



1: outer diameter thin-walled, 2: connection screws, 3: steel ring base, 4: water hole, 5: frame

spectrophotometry (HJ/T 346-2007) (State Environmental Protection Administration of China 2007), and the method of TN is alkaline potassium persulfate digestion ultraviolet spectrophotometry (GB 11894-89) (Environmental Protection Agency of China 1989a, b).

Data analysis

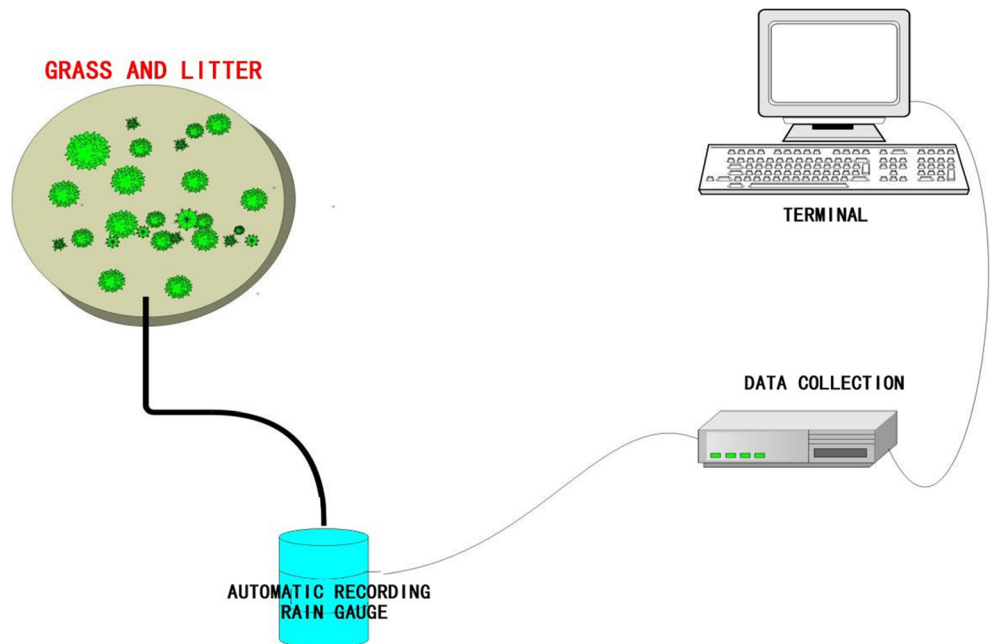
Differences in the measured hydrological processes of the different tree species, i.e., in canopy interception, stemflow, shrub, grass, and litter interceptions, were analyzed statistically and plotted in charts using software such as Sigmaplot 11.0 and SPSS 18.0. In addition, the amounts of various nutrients involved in nutrient transportation in the different hydrological processes were analyzed, and formulae describing these changes were derived. Simultaneously, a theoretical analysis is provided, which supports the different plant type configurations in the forested riparian buffer.

Results

Hydrological processes

There were three types of vegetation such as *Quercus variabilis***Pinus tabuliformis* (SP*YS), *Pinus tabuliformis* (YS), and *Platycladus orientalis* (CB) in this experiment. The hydrological processes in the buffer zone are canopy interception, stemflow, shrub interception, grass interception, litter interception, runoff, and subsurface flow. The data analysis showed that canopy interception was the most important process; SP*YS had the highest canopy interception, and CB had the lowest. Stemflow rates of these three types of forest were similar and all relatively low. The rate of YS was higher than that of SP*YS and CB. The shrub interception rates of these three types were also similar and the rate of YS was higher than that of SP*YS and CB. Grass interception had the lowest interception rate in all three forest types and CB was higher than that of SP*YS and YS. Litter interception was relatively high. YS had the highest litter interception rate, and CB had the lowest. The runoff the subsurface flow showed the

Fig. 5 Schematic diagram of interception observation for herb and litter



low rates. CB had the highest runoff but the lowest subsurface flow while SP*YS had the lowest runoff but the highest subsurface flow (Fig. 6).

Nutrient transportation processes

PO_4^{3-} content in rainfall of three types of species was approximately 0.03 mg/L. After canopy interception, the PO_4^{3-} content measured in the throughfall is improved in all configurations. At this stage, the PO_4^{3-} content of YS is enriched fastest, and the changes in stemflow also fit well with this. Subsequently, the PO_4^{3-} content measured in runoff improves significantly, with SP*YS having the highest content. The changes in PO_4^{3-} content in subsurface flow are opposite because here the PO_4^{3-} content is significantly reduced by absorption and chemical reactions involving microorganisms inside the soil. The PO_4^{3-} contents of the three types of vegetation all improve compared with the beginning PO_4^{3-} content in rainfall outside the forest, and SP*YS has the largest improvement. This shows that PO_4^{3-} is not absorbed well in the rain process, instead, it rises. The sum of the PO_4^{3-} content of surface runoff and subsurface flow shows that SP*YS has the most obvious change (Fig. 7).

The TP content in rainfall in the three types of forest was approximately 0.06 mg/L. As for the PO_4^{3-} , the TP contents measured in throughfall in the three forest types all improved, but the TP content of SP*YS enriches fastest at this stage; the TP content measured in stemflow is basically the same as in throughfall. Through the runoff, the TP content is increased significantly, but the TP content in subsurface flow declined, as did PO_4^{3-} , which SP*YS reduced the least, and the data of TP content in subsurface flow of three vegetation types are

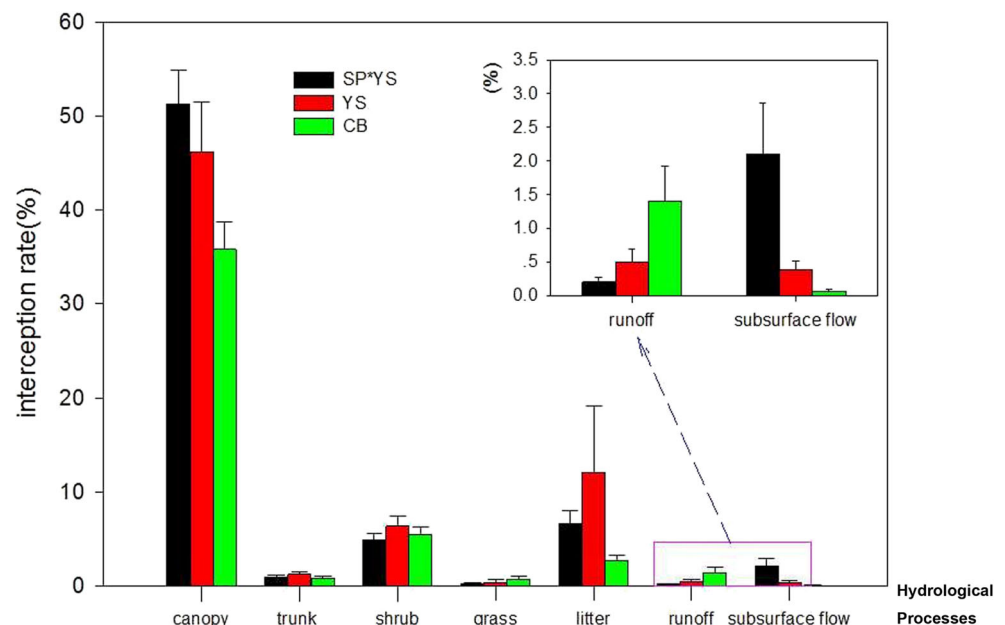
similar. This also confirms that the element P is enriched significantly in the whole rainfall process.

The $\text{NO}_3^- \text{N}$ content in rainfall in the three types of forest was approximately 1.45 mg/L. After canopy interception, the $\text{NO}_3^- \text{N}$ content measured in throughfall was reduced in all cases, the decline in CB and YS being big, but the decline in SP*YS being relatively small. The stemflow showed that the $\text{NO}_3^- \text{N}$ content for the three forest types is almost identical, approximately 1.5 mg/L. The runoff showed an improvement of the $\text{NO}_3^- \text{N}$ content in all three vegetation types, but the magnitudes of change are different. Compared with the rainfall, the increasing proportion in CB is most significant, and the rate of increase in SP*YS is lowest. The subsurface flow shows a decreased $\text{NO}_3^- \text{N}$ content in the three forest types compared with the runoff, and the $\text{NO}_3^- \text{N}$ content of the three vegetation types becomes similar. Thus, it can be concluded that the impact of microorganisms from the ground surface and the soil layer on the $\text{NO}_3^- \text{N}$ content is large.

As for TN, the content in rainfall in the three vegetation types was approximately 2.75 mg/L. After canopy interception, the throughfall shows a reduced TN content for YS and CB, but the TN content in SP*YS improves. As for stemflow, the TN content in SP*YS is lower than in YS or CB, YS being highest. The analysis of runoff showed that the TN content in CB is highest, and is lowest in SP*YS. The subsurface flow shows that the TN content in all three types of forest decreases, and is basically the same.

Overall, CB has the maximum transfer ratio and the most obvious enrichment for N and P in the process. Therefore, if practical transportation and absorption of these elements are considered, CB forest is the best choice to plant in riparian buffer zones. Besides, the transfer ratio of TP is higher than

Fig. 6 Hydrological processes



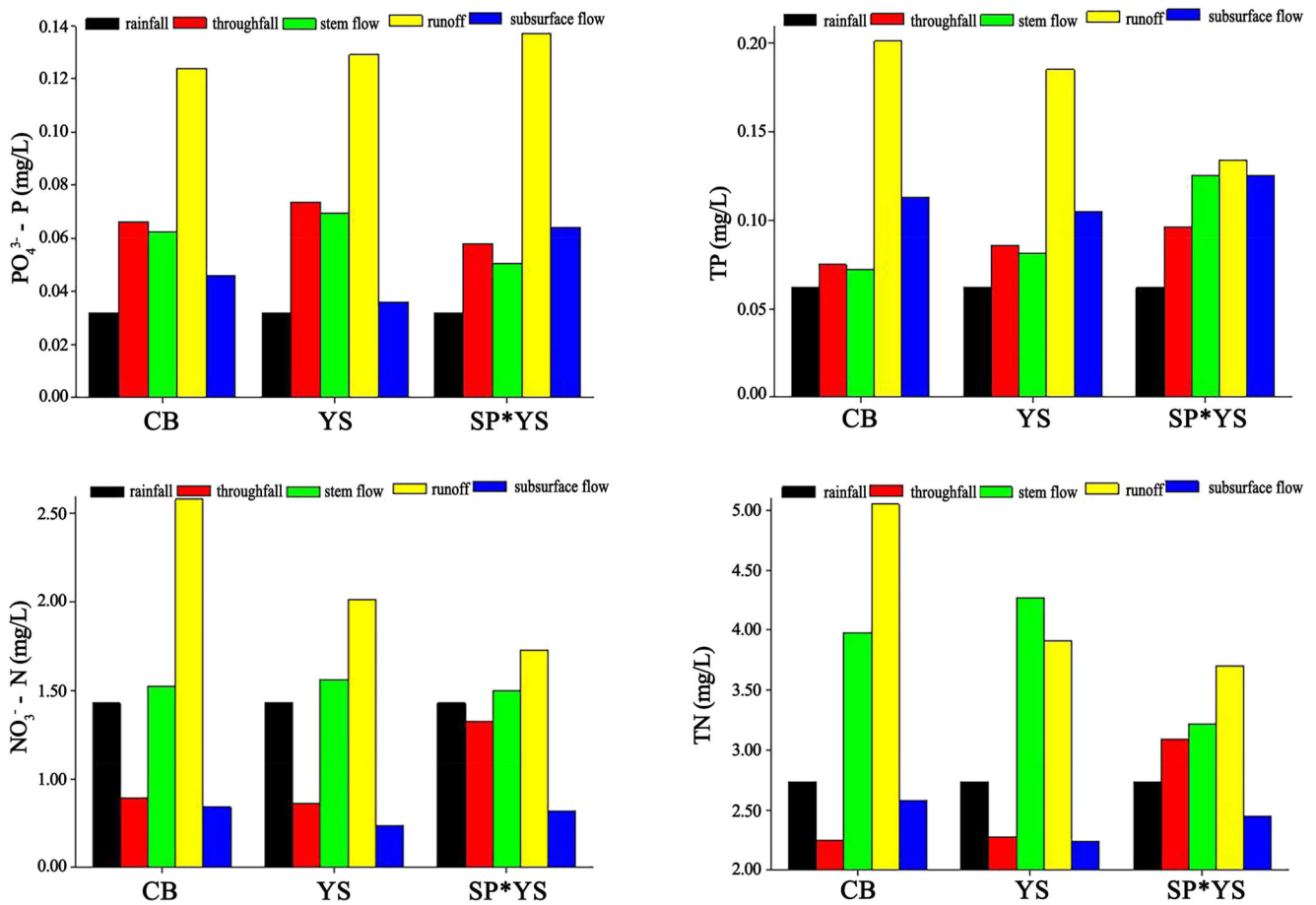


Fig. 7 Nutrient transportation processes

that of TN for the three vegetation types, which shows that the enrichment of P is stronger than that of N.

Discussion

The riparian buffer is an important part of the riparian ecosystem that can transform and intercept non-point source pollutants effectively through hydrological and nutrient processes (Tang et al. 2012). This study had revealed the hydrological and nutrient processes in the riparian buffer. It has shown that, starting from the rainfall outside the forest, riparian buffers will intercept the rainfall effectively and are able to intercept and transform N, P, and other nutrients in the rain through a series of hydrological processes such as canopy interception, throughfall, stemflow, shrub interception, grass interception, litter interception, and runoff. Many studies have shown that riparian buffers, such as grass riparian buffer and forest riparian buffer, can intercept N effectively (Lowrance et al. 1984; Cooper 1990). Delgado and Periago (1995) and Heathwaite et al. (1998) have shown that grass riparian buffer has a good effect on non-point source pollution control, and the average removal rates of TN and TP are 70.0–95.0% and 70.0–98.0%,

respectively. Dabney (1995) found that establishing rational grass or forest riparian buffers between farmland and water can greatly reduce the content of N and P in the water.

Interception rate

Riparian vegetative buffer is used to intercept groundwater flow and surface runoff to reduce nutrient and other organic pollutants (Lin et al. 2002). The present study shows that a riparian buffer can intercept rainfall effectively, and even more effective than other kinds of plants such as mountain plants. Afforestation may lead to the decrease of annual runoff, but the role of vegetation characteristics on runoff generation is still controversial (Liu et al. 2019). And a study in Southeastern Brazil showed a positive relationship between base flow/runoff and the increases in riparian vegetation (Alvarenga et al. 2017). Both biotic and abiotic factors such as leaf morphology which is related to the differences in leaf area and litter thickness may impact interception. And crown interception storage for needle species is 1.8 and 1.2 times larger than that of broadleaf species (Xiang et al. 2017). Thus, two types of species configurations may contribute to the difference in the interception.

A comparative analysis of interception rate between the riparian buffer and other kinds of plants was made in this study (Table 1). As for YS forest, the interception rate sum of canopy interception and stemflow in this study (48.5%) is higher than those of Taihang Mountain (Hebei, China) (18.9%) (Qian et al. 2012), Jiufeng Mountain (Beijing, China) (31.0%) (Li et al. 2013), Western Mountain (Beijing, China) (39.6%) (Wu et al. 2013), Sierra Madre Oriental Mountain (Nuevo León, Mexico) (19.8%) (Silva and Rodríguez 2001), and the Loess Plateau (Gansu, China) (23.5%) (Fang et al. 2013). As for CB forest, the interception rate sum of canopy interception and stemflow in this study (38.5%) is higher than those of Taihang Mountain (Hebei, China) (24.5%) (Pang 2010), Jiufeng Mountain (Beijing, China) (28.3%) (Li et al. 2013), and Miyun protection forest (Beijing, China) (34.4%) (Zhou and Yang 2008). As for SP*YS forest, the interception rate sum of canopy interception and stemflow in this study (54.4%) is also higher than those of Western Mountain (Beijing, China) (38.1%) (Wu et al. 2013), Sierra Madre Oriental Mountain (Nuevo León, Mexico) (23.0%) (Silva and Rodríguez 2001), and Western Mountain (Beijing, China) (30.2%) (Li et al. 2006a, b) (Table 1). The difference may be because of the different geographical position. For instance, the Taihang mountains are more south than our study and the annual precipitation is higher. And the slope of the study field could also cause the difference (Qian et al. 2012).

Canopy, shrub, and grass interception basically accounts for about 80.0% of total interception, and therefore, riparian buffer configuration should clearly distinguish three levels of vegetation. From the point of view of interception by different

forest types (high interception is superior), canopy, shrub, grass, and litter interception rate of YS forest is highest, totaling up to about 71.1%, when the SP*YS forest is 66.8% and the CB forest is 48.0%. And in YS forest, the canopy, shrub, grass, and litter interception rate is 48.5%, 6.8%, 0.9%, 14.9%, respectively (Table 2).

Similarly with this study, for the vegetation of a typical small black-water river watershed in its upstream part, Liu (2013) conducted field observations and manual experiments of the rainfall interception characteristics. The space simulation results of each vegetation rainfall interception in the 2012 growing season show that the average interception rate of Qinghai spruce forest is 44.6%, the average interception rate of shrub is 49.1%, and the average interception rate of mountain meadow in grazed and ungrazed plots is 11.0–16.9% and 16.2–22.1%, respectively. Because of the different study area and different tree species, the research data has much difference from this study, but this research also proves that canopy, shrub, and grass interceptions are really high, which is consistent with our study.

Transportation ratio

Riparian vegetation is necessary to achieve habitat improvement goals as the shade and cover provided by vegetation will result in appreciable benefits in nutrient reduction and sediment (Parkyn et al. 2005). And the nutrient removal effectiveness of riparian buffers is variable because of the different forms of nutrient, slopes, flow pathways, and soils (Parkyn et al. 2005). Li et al. (2006a, b) used two kinds of mixed plant

Table 1 Statistical summary of the Interception rate

Location	Interception rate of YS		Interception rate of CB		Interception rate of SP*YS		References
	Canopy interception	Stemflow	Canopy interception	Stemflow	Canopy interception	Stemflow	
Miyun Reservoir, Beijing, China	46.2%	2.3%	36.6%	1.9%	52.2%	2.2%	This study
Taihang Mountain, Hebei, China	18.9%	3.5%	13.3%	8.9%	–	–	Qian et al. (2012)
Jiufeng Mountain, Beijing, China	29.5%	1.5%	26.2%	2.1%	–	–	Li et al. (2013)
Western Mountain, Beijing, China	32.6%	7.1%	–	–	27.9%	10.2%	Wu et al. (2013)
Sierra Madre Oriental Mountain, Nuevo León, Mexico	19.2%	0.6%	–	–	23.0%	0.1%	Silva and Rodríguez (2001)
The Loess Plateau, Gansu, China	22.4%	1.1%	–	–	–	–	Fang et al. (2013)
Miyun protection forest, Beijing, China	–	–	30.6%	3.9%	–	–	Zhou and Yang (2008)
Western Mountain, Beijing, China	–	–	–	–	26.9%	3.2%	Li et al. (2006a, b)

Table 2 Interception rate of each species

3-year average rainfall 14.05 (mm)	SP*YS	YS	CB
Canopy interception	52.2%	46.2%	36.6%
Stemflow	2.2%	2.3%	1.9%
Shrubs interception	4.5%	6.8%	5.2%
Grass interception	0.8%	0.9%	1.2%
Litter interception	7.2%	14.9%	3.2%
Runoff	0.2%	0.5%	1.4%
Subsurface flow	2.2%	0.5%	0.1%

bands (vetiver grass + submerged plants; hydrophytic plants + cattail + reeds) to study a polluted river, and also compared them with a blank band without vegetation. The results show that mixed plants bands are better than the blank band without vegetation in the transportation effect for pollutants. Vetiver grass + submerged plants have the best effect; over the whole process, the transportation ratios for COD, NH₄⁺-N, and TP are 43.5%, 71.1% and 69.3%, respectively. Zhang (2013) studied the removal effect by different riparian plant buffers in Beijing Chaobai River basin of surface runoff N and P pollutants at different pollutant concentrations. In terms of the order of their removal effect for pollutants, the grass buffer riparian vegetation band is best, followed by grass and shrub buffer, shrub buffer, and finally the comparison buffer.

Here, the same comparison method was used to compare the transportation rate for N and P nutrient elements of CB forest, YS forest, and SP*YS forest. Overall, the order of the effect for N and P transportation is as follows: CB > SP*YS > YS. CB has the highest transportation and enrichment for N and P throughout the process. The transportation ratios for PO₄³⁻-P, TP, NO₃⁻-N, and TN of CB are 81.2%, 80.3%, 58.3%, and 64.2%, respectively (Table 3). However, in the

present study, the difference between SP*YS and YS is insignificant. The reason may be that the study design did not include multiple sets of parallel experiments, which should be done in future experiments to improve the accuracy of the results.

In conclusion, this paper also found that the transportation for TP of the three tree species is higher than that for TN, showing that the enrichment of P is stronger than that of N. According to the results of this study, different forest configurations can be considered to build riparian buffer to remove different kinds of nutrients in the future.

Conclusion

Riparian buffers can intercept the rainfall effectively through a series of hydrological processes and transform N, P, and other nutrients in the rain, thereby reducing the pollution of river water. Canopy, shrub, and grass interception basically accounts for about 80.0% of total interception; therefore, riparian buffer configuration should clearly distinguish three levels of vegetation types. On the one hand, canopy, shrub, grass, and litter interception rate of YS forest is highest, totalling up to about 71.1%; thus, YS is the best configuration considering only the amount intercepted. On the other hand, CB has the highest transportation and enrichment of N and P throughout the process, and the transportation ratios for PO₄³⁻-P, TP, NO₃⁻-N, and TN of CB are 81.2%, 80.3%, 58.3%, and 64.2%, respectively; therefore, CB is the best configuration considering the transportation of N and P. Overall, the transportation of TP of the three tree species is higher than the transportation of TN, which shows that the enrichment of P is stronger than that of N.

Table 3 Nutrient gathering and transference in riparian buffer strips

Nutrient types	Vegetation	Rainfall (mg/L)	Runoff + subsurface flow (mg/L)	Enrichment (mg/L)	Transformation ratio (%)
PO ₄ ³⁻ -P	CB	0.032	0.170	0.138	81.2
	YS	0.032	0.165	0.133	80.6
	SP*YS	0.032	0.201	0.169	84.1
TP	CB	0.062	0.314	0.252	80.3
	YS	0.062	0.290	0.228	78.6
	SP*YS	0.062	0.259	0.197	76.1
NO ₃ ⁻ -N	CB	1.428	3.420	1.992	58.3
	YS	1.428	2.750	1.322	48.1
	SP*YS	1.428	2.547	1.119	43.9
TN	CB	2.734	7.630	4.896	64.2
	YS	2.734	6.150	3.416	55.5
	SP*YS	2.734	6.150	3.416	55.5

Funding information This research was supported by the Natural Science Foundation of China (41771547).

References

- Alvarenga LA, Mello CRD, Colombo A, Cuartas LA (2017) Hydrologic impacts due to the changes in riparian buffer in a headwater watershed. *Cerne* 23:95–102
- Baker ME, Weller DE, Jordan TE (2007) Effects of stream map resolution on measures of riparian buffer distribution and nutrient retention potential. *Landsc Ecol* 22:973–992
- Burchsted D, Daniels M, Thorson R, Vokoun J (2010) The river discontinuum: applying beaver modifications to baseline conditions for restoration of forested headwaters. *Bioscience* 60:908–922
- Chen Y (2010) Research on evaluation and controlling measure system of agriculture non-point source pollution in Shaanxi Province. *Northwest Agric For Univ* 6–8
- Cooper AB (1990) Nitrate depletion in the riparian zone and stream channel of a small headwater catchment. *Hydrobiologia* 202:13–26
- Dabney LD (1995) Depositional patterns of sediment trapped by grass filter strips during simulated. *Trans Am Soc Agric Eng* 38: 1719–1729
- Delgado AN, Periago EL (1995) Vegetated filter strips for wastewater purification: a review. *Bioresour Technol* 5:113–122
- Dillaha TA, Reneau RB, Mostaghimi S, Lee D (1989) Vegetative filterstrips for agricultural nonpoint source pollution control. *Trans Am Soc Agric Eng* 32:513–519
- Environmental Protection Agency of China (1989a) GB 11893–89 water quality-determination of total phosphorus-ammonium molybdate spectrophotometric method. China Standard Press, Beijing
- Environmental Protection Agency of China (1989b) GB 11894–89 water quality-determination of total nitrogen-alkaline potassium persulfate digestion-UV spectrophotometric method. China Standard Press, Beijing
- Fang SM, Zhao CY, Jian SQ, Yu K (2013) Canopy interception of *Pinus tabulaeformis* plantation on Longzhong loess plateau, Northwest China: characteristics and simulation. *Chin J Appl Ecol* 24: 1509–1516
- Heathwaite AL, Griffiths P, Parkinson RJ (1998) Nitrogen and phosphorus in runoff from grassland with buffer strips following application of fertilizers and manures. *Soil Use Manag* 14:142–148
- Jacobs TC, Gilliam JW (1985) Riparian losses of nitrate from agricultural drainage waters. *J Environ Qual* 14:472–478
- Jon ES, Karl WJ, James JZ (2005) Nutrient attenuation in agro forestry surface runoff by riparian buffer zones in southern Illinois. *Agrofor Syst* 64:169–180
- Klapproth JC, Johnson JE (2000) Understanding the science behind riparian forest buffers: effects on water quality. *Va Coop Ext* 1–19
- Li JY, Zhai HB, Wei XX (2006a) Rainfall and its redistribution of *Pinus tabulaeformis* and *Quercus variabilis* mixed forests. *J Beijing For Univ* 28:154–157
- Li RH, Guan YT, He M, Hu HY, Jiang ZP (2006b) Pilot-scale study on riparian mixed plant zones treating polluted river water. *Environ Sci* 27:651–654
- Li XF, Chen LH, Yu XX, Zhang Y (2013) Intercept characteristics of typical forest in Beijing severe storm. *Agric Sci Guangdong* 18: 172–173
- Lin CY, Chou WC, Lin WT (2002) Modeling the width and placement of riparian vegetated buffer strips: a case study on the Chi-Jia-Wang Stream, Taiwan. *J Environ Manag* 66:269–280
- Liu YY (2013) Characteristics of rainfall interception of vegetations in typical small watershed of black river upstream. Master Thesis Lanzhou Univ.
- Liu J, Engel BA, Wang Y, Wu Y, Zhang Z, Zhang M (2019) Runoff response to soil moisture and micro-topographic structure on the plot scale. *Sci Rep* 9:2532
- Lowrance R, Todd R, Fall J, Hendrickson O, Leonard R, Asmussen L (1984) Riparian forests as nutrient filters in agricultural watersheds. *Bioscience* 34:374–377
- Lowrance R, McIntyre S, Lane C (1988) Erosion and deposition in a field/forest system estimated cesium-137 activity. *J Soil Water Conserv* 43:195–199
- Mankin KR, Ngandu DM, Barden CJ, Hutchinson SL, Geyer WA (2007) Grass-shrub riparian buffer removal of sediment, phosphorus, and nitrogen from simulated runoff. *J Am Water Resour Assoc* 43:1108–1116
- Mi Y, He C, Bian H, Cai Y, Sheng L, Ma L (2015) Ecological engineering restoration of a non-point source polluted river in northern China. *Ecol Eng* 76:142–150
- Pang XB (2010) Rainfall interception capacity of regetation in Taihang mountinares. *J Hebei For Sci Technol* 4:1–8
- Parkyn SM, Davies-Colley RJ, Cooper AB, Stroud MJ (2005) Predictions of stream nutrient and sediment yield changes following restoration of forested riparian buffers. *Ecol Eng* 24:551–558
- Parsons JE, Gilliam JW, Munoz-Carpena R, Daniels RB, Dillaha TA (1994) Nutrient and sediment removal by grass and riparian buffers. *Am Soc Agric Eng* 147–154
- Peterjohn WT, Correll DL (1984) Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. *Ecology* 65: 1466–1475
- Qian JP, Wang RD, Bai J, Zhang GY (2012) Canopy rainfall interception of different planted forests in Taihang mountainous region. *Bull Soil Water Conserv*
- Quan WM, Yan LJ (2002) Effects of agricultural non-point source pollution on eutrophication of water body and its control measure. *Acta Ecol Sin* 22:291–299
- Shen YN (2010) Modeling about non-point source pollution and quantity control for it within watershed. *Zhejiang Univ* 12
- Silva IC, Rodríguez HG (2001) Interception loss, throughfall and stemflow chemistry in pine and oak forests in northeastern Mexico. *Tree Physiol* 21:1009–1013
- State Environmental Protection Administration of China (2007) HJ/T 346–2007 water quality-determination of nitrate-nitrogen-ultraviolet spectrophotometry. China Environmental Science Press, Beijing
- Swanson S, Kozlowski D, Hall R, Heggem D, Lin J (2017) Riparian proper functioning condition assessment to improve watershed management for water quality. *J Soil Water Conserv* 72:168–182
- Tang JX, Sun LX, Sun TX, Zhang LH (2012) Research advances on retaining and transformation of N and P and ecological restoration of riparian buffer zone. *Ecol Environ Sci* 21:1514–1520
- Tian S, Luo W, Jia Z, Butalia RS (2010) Temporal variation of over-bank flooding of Wei River and its impact on a riparian wetland in Xi'an. *China Hydrol Process* 24:1296–1307
- Wang L, Zhang GX (2006) Removal of nitrogen and phosphorus in riparian buffer zone of wetland. *J Agro-Environ Sci* 25:649–652
- Wang XY, Zhang YF, Yang O (2009) Cost-effectiveness evaluation and preferring of non-point source pollution control management measures. *Ecol Environ Sci* 18:540–548
- Wu JQ (2011) Different slope buffer zone stagnated runoff and pollutant removal quantitative. *J Soil Water Conserv* 22:112–117
- Wu WQ, Li P, Sun XY, Yu X (2013) Distribution traits of precipitation of *Pinus tabulaeformis*, *Quercus variabilis* and mixed forest of West Mountains in Beijing. *J Northeast For Univ* 9:26–29
- Xiang C, Weiqi Z, Steward P et al (2016) Spatial-temporal variations of water quality and its relationship to land use and land cover in Beijing, China. *Int J Environ Res Publ Health* 13(5):449

- Xiang L, Xiao Q, Niu J, Dymond S, Mcpherson EG, Doorn NV, XinxiaoYu, Xie B, Zhang K, Jiao L (2017): Rainfall interception by tree crown and leaf litter:an interactive process. *Hydrol Process* 31
- Yan WJ (1999) Transformation and runoff losses of nitrogen and phosphorus in paddy wetlands. *J Appl Ecol* 10:312–316
- Yan Y, Guan Q, Wang M, Su X, Wu G, Chiang P, Cao W (2018) Assessment of nitrogen reduction by constructed wetland based on InVEST: a case study of the Jiulong River Watershed, China. *Mar Pollut Bull* 133:349–356
- Zhang GF (2013) The effects of riparian vegetation buffer zones on nitrogen and phosphorus reduction in Chaobai River upstream. *Chin Agric Sci Bull* 29:189–194
- Zhang P, Zhang XD, Huang LL, Liu WG, Zhu WS, Tang SQ (2009) Interception effect of surface runoff on different width *Bambusa rigida* Keng riparian buffer strips. *J Soil Water Conserv* 23:23–27
- Zhou BS, Yang XB (2008) Study on simulation of canopy interception in *Platycladus orientalis* and *Quercus* mixed woodland. *J Hebei For Sci Technol* 6:12–15

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.