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Effects of Buffer Strip Widths on Retention Efficiency of Nutrients (N and P): A Case Study in the Taihu Lake, China

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ခန့်ကိုလှိုင်၊ တောအုပ်ကြီး
စီမံကိန်းနှင့်စာရင်းအင်းဌာန

စာတမ်းအကျဉ်း

Eutrophication သည် ရေချိုနှင့် ပင်လယ်ကမ်းရိုးတန်း ဂေဟာစနစ်များအတွက် အဓိကရေ အရည်အသွေးဆိုင်ရာ ပြဿနာတစ်ရပ် ဖြစ်လာပါသည်။ Riparian buffer strips (ကြားခံနယ် သစ်တော) သည် Agricultural Nonpoint source pollution (စိုက်ပျိုးရေးစွန့်ပစ် အညစ်အကြေးများ) ကို လျှော့ချရာတွင် runoff မှ pollutants (နုန်းအနည်အနှစ်၊ အာဟာရဓါတ်များနှင့် ပိုးသတ်ဆေး စသည်) ကို သစ်တော နယ်နမိတ်အစ၌ စစ်ထုတ်ခြင်း၊ စုပ်ယူခြင်းနှင့် တားဆီးခြင်းတို့ ဖြင့် ဖယ်ရှားရာ တွင် အကျိုးထိရောက်မှုရှိပါသည်။ ထို့ကြောင့် Eutrophication ဖြစ်ပွားနေသော အနီးဝန်းကျင်တွင် Riparian buffers များ တည်ထောင်ရန် လိုအပ်ပြီး ထိုနေရာဒေသနှင့် သင့်တော်ပြီး အကျိုးထိရောက်မည့် buffer width (ကြားခံအကျယ်)ကို သုတေသနပြု လေ့လာရန်မှာ လွန်စွာအရေးကြီးလှပါသည်။ သုတေသန တွေ့ရှိချက်များအရ Buffer strips၏ buffer width သည် နိုက်ထရိုဂျင်နှင့် ဖော့ဖရပ် levelsကို သိသာ ထင်ရှားစွာ လျော့နည်းစေကြောင်း တွေ့ရှိရပါသည်။ Riparian buffer strips width အကျယ် တိုးလာ သည်နှင့်အမျှ ဖော့ဖရပ်ဖယ်ရှားနိုင်မှု ပမာဏမှာ buffer strips အစအကျယ်တွင် တိုးမြှင့်လာပြီး နောက်ပိုင်း အကျယ်တွင် လျော့ကျသွားပါ သည်။ ၃၀မီတာအကျယ်widthရှိသော buffer strip သည် total dissolved phosphorus ၈၈%ကို တားဆီးစုပ်ယူပေးပြီး၊ total dissolved phosphorus အများဆုံးပါဝင်မှုပမာဏကို ၅မီတာ အကျယ် (၂.၇၅မီလီဂရမ်/ လီတာ)တွင် တွေ့ရှိရပါသည်။ Total phosphorus အမြင့်ဆုံးစုပ်ယူနိုင်စွမ်းကို ၅မီတာအကျယ် (၈၁%) ၌ တွေ့ရှိရပြီး ၄၀မီတာအကျယ် (၅.၉ မီလီဂရမ်/ လီတာ)သည် total phosphorus ပါဝင်မှုပမာဏ အများဆုံးကို ဖယ်ရှားပေးနိုင်ကြောင်း တွေ့ရှိရပါသည်။ Total nitrogen လျှော့ချနိုင်ရန်အတွက် အမြင့်ဆုံးဖယ်ရှား မှုကို ၁၅မီတာအကျယ် (၅၉%) ၌ တွေ့ရှိရပြီး total nitrogen ပါဝင်မှုပမာဏ အမြင့်ဆုံးကို ၄၀မီတာ အကျယ် (၁၉မီလီဂရမ်/ လီတာ)၌ စုပ်ယူနိုင်ကြောင်း လေ့လာတွေ့ရှိရပါသည်။ ၃၀မီတာအကျယ် (၈၅% နှင့် ၁.၅၄မီလီဂရမ်/ လီတာ)သည် ammonium nitrogen ဖယ်ရှားနိုင်စွမ်းနှင့် ပါဝင်မှုပမာဏ အမြင့်ဆုံးကို တားဆီး စုပ်ယူ ပေးနိုင်ကြောင်း တွေ့ရှိရပါသည်။ နိုက်ထရိုဂျင်နှင့် ဖော့ဖရပ် ဖယ်ရှားမှု နှုန်းများနှင့် မတူညီသော stand densities များအကြား သိသာထင်ရှားစွာ ခြားနားမှု မရှိကြောင်း တွေ့ရှိရပါသည်။

Effects of buffer strip widths on retention efficiency of nutrients (N and P): a Case study in the Taihu Lake, China

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Abstract

Eutrophication has become the overriding water quality issue for various freshwater and coastal marine ecosystems in the developing world. Riparian buffer strips (RBS) can mitigate ANPS pollution as they are effective in removing pollutants (sediment, nutrients, and pesticides etc.) from runoff by filtering, absorbing and intercepting them at field margins. Thus, it is needed to establish riparian buffers around eutrophic lakes and it is also critical to be able to dictate the minimum buffer width required for aquatic resource protection. According to this research, the width of buffer strips significantly reduced the phosphorus levels. With increasing of riparian buffer strips width, the removal rates of phosphorus increased first and decreased then. The buffer strip of 30 m width intercepts 88% of total dissolved phosphorus and highest total dissolved phosphorus concentration was identified at the width of 5 m (2.75 $mg.L^{-1}$) in runoff water. Maximum retention capacity of total phosphorus was recognized in 5 m width (81%) while 40 m width removed highest concentration of total phosphorus (5.9 mg.L-1). Highest removal rates to attenuate total nitrogen were measured at the width of 15 m (59%) and highest total nitrogen concentration was absorbed at 40 m width (19 $mg.L^{-1}$). Highest interception efficacy and concentration of ammonium nitrogen was found at 30 m (85% and 1.54 $mg.L^{-1}$) in runoff water in the riparian buffer zone. The removal rate of total dissolved phosphorus was higher in Poplar plantation with low stand density (400 stem per hectare) while total phosphorus reduction rate was higher in Ascendens plantation with medium stand density (1000 stem per hectare) respectively. Maximum retention efficiency of total nitrogen and ammonium nitrogen were observed in Ascendens plantation with low stand density (400 stem per hectare). There was no significant difference in terms of nitrogen and phosphorus removal rates between different stand densities of buffer strips.

Keywords: Buffer strip width, Nitrogen & Phosphorus, Remove rate, Riparian buffer strip, Soil depths, Stand density, Taihu Lake.

Effects of Buffer Strip Widths on Retention Efficiency of Nutrients (N and P): A Case Study in the Taihu Lake, China

1. Introduction

Eutrophication has become the overriding water quality issue for various freshwater and coastal marine ecosystems in the developing world (Howarth et al. 2002; Smith & Schindler 2009). It naturally takes place over geologic time (Carpenter 1981), but is escalated by human activities, for instance, overutilization of fertilizers, or sewage disposal (Chislock et al. 2013). As the global human population and food production rise, eutrophication has become a great concern that negatively influence on the environment, striking the micro-biome of aquatic ecosystems (Glibert et al. 2005). Anthropogenic activities from both point-sources (PS) and non-point sources (NPS) of pollution have encouraged the rate of eutrophication (Clark 2002). The growing human population has accelerated the magnitude of crop production, and the extent of other land-use changes in many regions has resulted in a rise of nutrient accumulation in many rivers and lakes with time (Heathwaite et al. 1996). Excessive amounts of nitrogen (N) and phosphorus (P) cause water contamination through blooming of blue-green algae (i.e. cyanobacteria), which is also called “cultural eutrophication” (Conley et al. 2009). It can lead to the alteration of oligotrophic water bodies to meso-trophic, eutrophic, and eventually hypertrophic, which is extremely toxic to most organisms (Dodds & Welch 2000).

In order to minimize non-point source pollution (NPS) impacts, the U.S. Department of Agriculture (USDA) prescribed the control strategies called best management practices (BMPs) for water quality improvement and soil conservation in forestry practices (Hickey & Doran 2004). To reduce nutrient runoff from adjacent land uses, a common technique is to preserve riparian buffers around the water resources. Riparian buffer is defined as a permanent vegetated zone adjacent to a water body for the intention of removing pollutants from surface runoff or groundwater (Borin et al. 2010). Riparian buffer strips (RBS) is one of BMPs that can mitigate ANPS pollution as they are effective in removing pollutants (sediment, nutrients, and pesticides etc.) from runoff by filtering, absorbing and intercepting them at field margins (Dosskey 2002; US National Research Council, 2002; Abu-Zreig et al. 2003; Bernhardt et al. 2005). Several studies shown that riparian buffer zones have been widely used to control ANPS pollution because it is biological prevention to attenuate eutrophication (Fischer & Fischenich 2000; Mitsch et al. 2001; Polyakov et al. 2005; Søvik & Syversen 2008). It also is a focus for the restoration and management of landscapes (Mankin et al. 2008). Forest buffer strips are well known to remarkably decrease sediments and nutrients exports from agricultural fields toward water bodies (Clausen et al. 2000; Aguiar et al. 2015). Nowadays, agricultural riparian buffer research has examined water flow through native forest buffers and grass filter strips (Barden et al. 2003). Several studies have shown that forest riparian buffers are very efficient in reducing nitrogen and phosphorus in agricultural surface runoff (Clausen et al. 2000; Aguiar et al. 2015).

Riparian buffers can preserve adjacent water bodies from detrimental human activities. Vital constituents to contemplate when designing buffer strips involve slope, site preparation, soil conditions, width, vegetation, placement, maintenance and monitoring

(USEPA. 2002). Factors which control the efficacy of riparian buffer zones can be classified into internal and external factors. External factors involve watershed area and gradient, stream channel morphology, soil mineralogy and texture, bedrock type and depth, and climate. Internal factors encompass slope and width of the buffer, type of vegetation, soil moisture content, organic content of soils, hydraulic conductivity, soil nutrient content and geochemistry (Correll 1996). Among them, one of the primary factors which manage the effectiveness of a buffer is its size. Buffers that are undersized can supply incapable protection for water bodies; however, over-sized buffers can eradicate land from production, which may result in economic losses (Castelle et al. 1994). Thus, it is critical to be able to dictate the minimum buffer width required for aquatic resource protection (Castelle et al. 1994). Nonetheless, there is no global optimum width for buffers because of the comprehensive variables controlling the efficiency of the riparian buffers (Liu et al. 2008). A riparian buffer of the suitable width can soundly impede soil erosion and reduce nutrients and chemical pollutants from surface runoff (Peterjohn & Correll 1984; Pinay & Decamps 1988; Liu et al. 2008). So, buffer width is the principal factor governing the effectiveness of nutrient deposition (Moon et al. 2013; Aguiar et al. 2015).

As riparian zones intercept run off from agricultural land, they also keep sediments and nutrients, foster vegetation uptake and transformation of nutrients, and breakdown pesticides. Sediments retention capacity is relied on the topographic slope and the density of plant cover (Naiman & Decamps 1997). The stand density influences the roughness of the soil surface and the soil structure, and also establishes the inter-relationship among the vegetation, which in turn affects the interception of nutrients such as nitrogen and phosphorus in the buffer zone. Vegetation with different forest densities has remarkable differences in the interception and absorption of nutrients and sediments in agricultural runoff water. Nevertheless, if the density of the stand is too dense, this would create fierce competition of vegetation on soil nutrients (Mao 2018).

2. Objectives

The overall objective of this research is to determine what factors influence nutrient reduction capacity of buffer strips based upon differences in buffer width and vegetation composition.

Specific objectives are as follows:

i. To examine the effect of buffer widths on the removal of nutrients
ii. To understand the effect of different stand densities in mitigating nutrient deposition

Hypotheses

H_1: Wider forest buffer strips remove more nutrients (total dissolved phosphorus, total phosphorus, total nitrogen, ammonium nitrogen) than narrow forest buffer strips.

H_2: High stand density reduces more nutrients (total dissolved phosphorus, total phosphorus, total nitrogen, ammonium nitrogen) than low stand density.

3. Materials and Methods

3.1 Study Area

The research area is located in Shatang Village (31 ° 7'N ~ 31 ° 37'N, 119 ° 31'E ~ 120 ° 3'E), Zhoutie Town, Yixing City, Jiangsu Province, on the shores of Taihu (Figure 1). The climate of the study site is classified as subtropical monsoon with high rainfall. The dominant wind is southeast wind, the frost-free period is 239 d, the annual average temperature is 15.7 ℃, the annual sunshine hours are 1924.2 h, the winter is cold and dry, prevalent in the northwest wind, rainfall is concentrated in the spring and summer with an annual rainfall of 1,177 mm. The soil within the buffer strip was classified as a heavy loam with a uniform soil quality and a soil bulk density of 1.38 g/cm^3 (Meng et al. 2016).

Figure 1. Map of the Taihu Lake; Study area

3.2 Layout of Experiment Plots

At the end of 2013, a total of eight plots with a size of 20 m × 40 m were set up in the study area. The plots were arranged in parallel and perpendicular to the surface runoff with a slope ratio of 1: 250 (Figure 2).

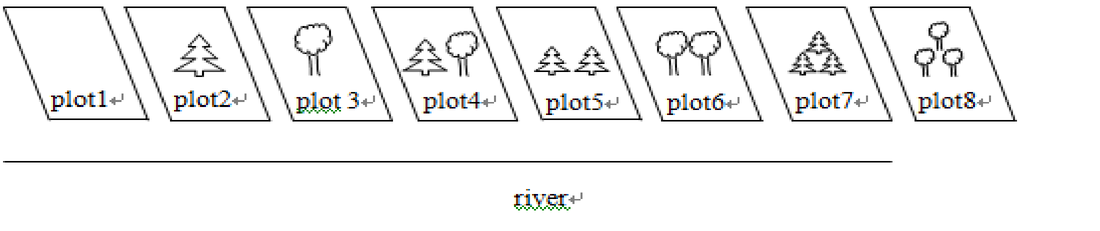

Figure 2. Sketch map of sample plots

In each plot, four widths of 5m, 15m, 30m, and 40m were set along the runoff direction (Figure 2). At each width, PVC leaching pipes (0-20 cm above ground, 60 cm underground, and 2 mm thick) were embedded parallel to Taihu Lake, two in each group, with depths of 0-20 cm, 20-40 cm and 40-60 cm, respectively. The interval distance between two adjacent leaching tubes was 1 m, and the interval between adjacent groups of leaching tubes was 4 m (see in Figure 3). The weather stations were also set up in the plots 1, 3, 4, and 8 to measure meteorological data.

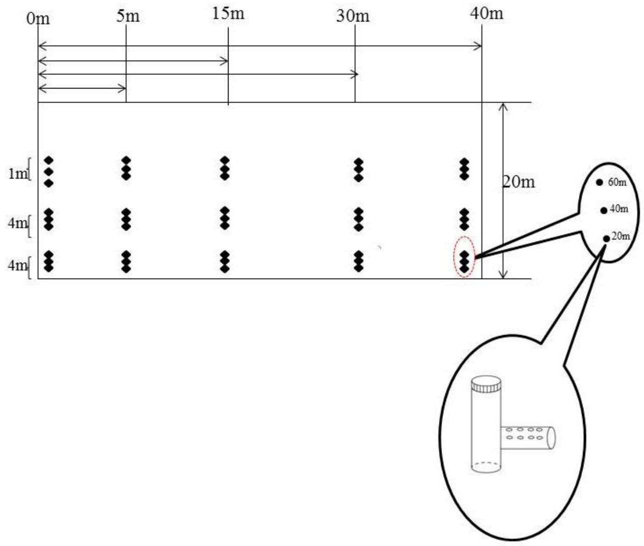

Figure 3. Setting of sample plots

3.3 Studied Plantations

This study was conducted using a split plot in a randomized complete block design. Different types of 5-year old plantations, including control plot, poplar plantation (*Poplar Nanlin 95*), Ascendens plantation (*Ascendens mucronatum*) and mixed plantation of poplar and Ascendens with different plant density (400/hm^2, 3000/hm^2, and 3000/hm^2) were planted as shown in Table 1. Among these plots, multispecies herbaceous plants were allowed to naturally grow. The main understory herbaceous species were *Glycine soja*, *Solidago canadensis*, *Phragmites australis*, *Alternanthera philoxeroides*, *Artemisia lavandulifolia* and predominant families were Fabaceae, Asteraceae, Poaceae, Amaranthaceae, Polygonaceae.

Table 1. Allocation of vegetation in the experiment plots

Sampling settings	**Sample site 1**	**Sample site 2**	**Sample site 3**	**Sample site 4**	**Sample site 5**	**Sample site 6**	**Sample site 7**	**Sample site 8**
Plant configuration	No tree (Control)	Ascendens	Poplar	Poplar × Ascendens	Ascendens	Poplar	Ascendens	Poplar
Plant density (trees/hm^2)	—	400	400	1000	1000	1000	1600	1600

3.4 Herbs Sample Collection and Biomass Measurement

Field experiments were conducted under natural rainfall in two different seasons (summer and autumn); 17th of July and 24th of October, 2018 . For the first time in summer, herbaceous species samples were collected on 12th of July, 2018. Herb samples were gathered again in autumn 29th of October. Area of 1.0 m^2 (1 m × 1 m) from each sample plot herbaceous species were harvested using quadrats, totaling 24 samples from eight sample plots and weighed to estimate fresh yield (Ameen et al. 2018). Samples were then taken back to the laboratory within one day. Fresh biomass of herbaceous species weight was measured. After that, herbs samples were oven-dried until a constant weight was achieved in order to determine its water content and biomass. After four days, all herbs samples were removed from the oven, and then dry biomass weight were calculated.

3.5 Water Samples Collection and Processing

In summer of 15th of August, 2018, fertilizer (15%N, 15%P_2O_5 and 15%K_2O) was applied to the fields at a rate of 10 kg per sample unit on all sample plots one week to a rainfall event. The leachate water from each tube were collected after two weeks (9th of September) rainfall event following fertilizer application. At different sampling plots, water samples were collected at 20 cm, 40 cm and 60 cm respectively. Three samples were collected from each point, producing 36 samples from each sample plot, totaling 288 samples from the 8 sample plots were studied. For summer, 5m, 15m, 30m, 40m widths with three different depths were measured. Then, the leached water was pumped into a 150 mL plastic bottle and returned to the laboratory where it was stored at -4 ~ 0 ℃ until further anlaysis (Meng et al. 2016). Runoff samples were analyzed for concentrations of Total Dissolved Phosphorus (TDP), Total Phosphorus (TP), Total Nitrogen (TN) and Ammonium Nitrogen (NH_4-N) in accordance with national environmental protection standard of People's Republic of China (Table 2). Samples for analysis of soluble forms of N and P were filtered through a Whatman No. 1 filter paper for determining ammonium (NH_4–N) concentrations. Total N and P concentrations were determined from the unfiltered portion of samples (Blanco-Canqui et al. 2004). Analysis of N and P were conducted using a UV-2550 Spectrophotometer. The laboratory experiments were finsihed on 26th of September.

In autumn of 12th of October, 2018, fertilizer was applied in the field as the same method mentioned above in summer. On 29th of October, 2018, water samples were collected at 5m, 15m, 30m and 40m widths. Laboratory experiments were carried out the same method described above and on 28th of November, 2018, laboratory works for autumn were done.

Table 2. The index and determination method

Sample name	Analysis index	Test methods
Water Sample	Total Phosphorus (TP)	Ammonium molybdate spectrophotometry
	Soluble Total Phosphorus (TDP)	Molybdenum antimony anti-ultraviolet spectrophotometry
	Total Nitrogen (TN)	Alkaline potassium persulfate digestion UV spectrophotometry
	Ammonia Nitrogen (NH_4 - N)	Nessler's reagent spectrophotometry

The surface runoff retention efficiency in (%) R for N and P analysis in buffer zone was calculated according to Zhang et al. (2010):

$$R = (C_0 - C_i)/(C_0) \times 100\%$$

where C_0 = N and P concentration in runoff water at the beginning of the buffer strip (mg/L^{-1})

C_i = N and P concentration in surface runoff water at different sampling points of buffer strip (mg/L^{-1})

i = Buffer with different widths (i = 5, 15, 30 and 40) (m)

4. Data Analysis

To compare the performance of different treatments in removing the studied pollutants, a data base was created in Microsoft Excel 2010. Also, comparison of means was conducted using SPSS software Version 20. Threshold level of significance is set up at $p = 0.05$.

In this study, the mean removal efficiency and mean concentrations of nutrients (total dissolved phosphorus, total phosphorus, total nitrogen, ammonium nitrogen) were used. One-Way ANOVA test was carried out to determine the effects of the buffer widths on nutrient removal rates. Least significant difference (LSD) tests were performed to determine differences at $p < 0.05$ in buffer treatments for all variables.

Pearson's correlation coefficients were also used in order to determine the strengths between variables (removal efficiency with buffer strip width, stand density, vegetation cover, soil depth and season).

5. Results

H_1: Wider forest buffer strips remove more nutrients (total dissolved phosphorus, total phosphorus, total nitrogen, ammonium nitrogen) than narrow forest filter strips.

Retention efficiency of total dissolved phosphorus of buffer strip widths

The results indicated that the minimum retention efficiency of total dissolved phosphorus in runoff water was found at 0 m width followed by 40 m width. Unlike the widths of 0 m and 40 m, all the other widths (5 m, 15 m and 30 m) had the more efficient capacity to reduce total dissolved phosphorus with the rate of 84%, 86% and 88% respectively (Figure 4). Highest retention capacity to mitigate total dissolved phosphorus was seen at the width of 30 m in runoff water in the riparian buffer zone.

Concentration of total dissolved phosphorus in buffer strip widths

The results showed that maximum concentration of total dissolved phosphorus in runoff water was found at the 5 m buffer width with the rate of 2.75 mg.L^{-1}, followed by 30 m in 1.82 mg.L^{-1}, 15 m in 1.0 mg.L^{-1}, while 40 m width has minimum total dissolved phosphorus concentration that is 0.13 mg.L^{-1} (Figure 4). Unlike the widths of 5 m, 15 m, 30 m and 40 m, 0 m width had more efficient capacity to reduce total dissolved phosphorus with the concentration of 4.27 mg.L^{-1}. Highest total dissolved phosphorus concentration in runoff water was seen at the width of 5 m in runoff water in the riparian buffer zone.

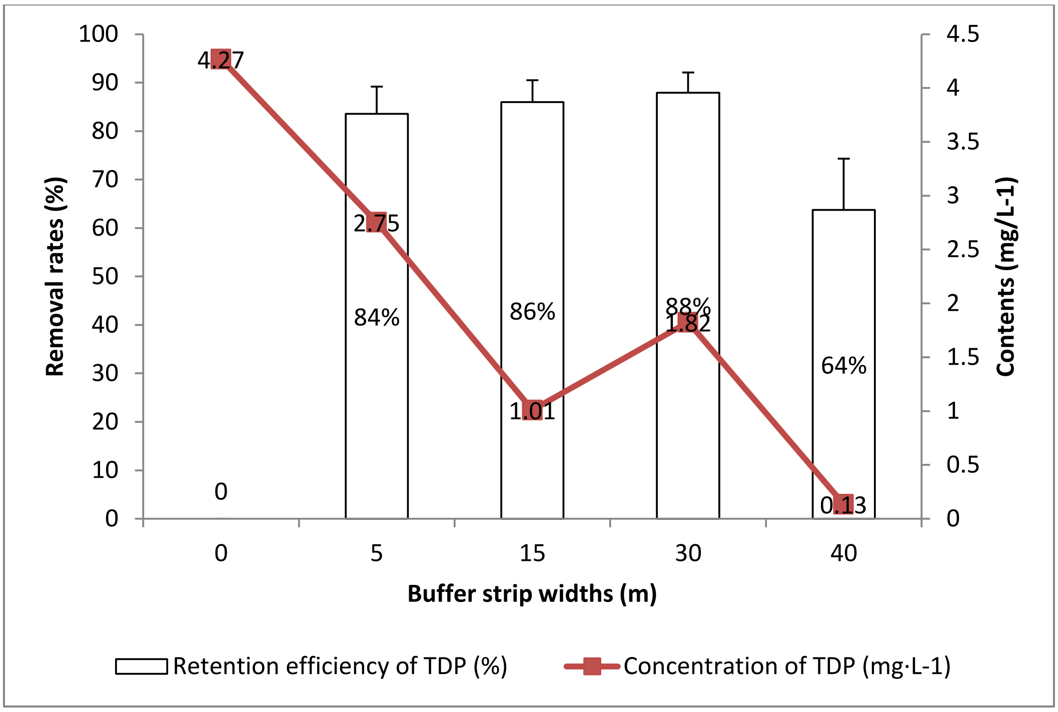

Figure 4. Total dissolved phosphorus interception effects of runoff water by different buffer widths in riparian buffer strips

Retention efficiency of total phosphorus of buffer strip widths

The results expressed that minimum retention efficiency of total phosphorus in runoff water was observed at 0 m width followed by 40 m width. The buffer strip widths (5 m, 15 m and 30 m) have the ability to mitigate total phosphorus with more or less the similar rate, while the nearest width to the lake (40 m) in the riparian zone is not able to effectively contribute to reduction of total phosphorus (Figure 5). Unlike the widths of 0 m and 40 m, all the other widths (5 m, 15 m and 30 m) had more efficient capacity to reduce total phosphorus with the percentage of 81%, 77% and 78% respectively. Highest retention capacity to alleviate total phosphorus was detected at the width of 5 m in runoff water.

Concentration of total phosphorus in buffer strip widths

The results showed that the minimum concentration of total phosphorus was observed at 5 m, 15 m, 30 m widths (1.89 mg.L^{-1}, 2.6 mg.L^{-1}, 1.1 mg.L^{-1},) respectively(Figure 5). Unlike the widths of 5 m, 15 m, 30 m, 40 m width was more effective to reduce total phosphorus with the concentration of 5.9 mg.L^{-1}. Highest total phosphorus concentration was found at the width of 40 m in runoff water in the riparian buffer zone.

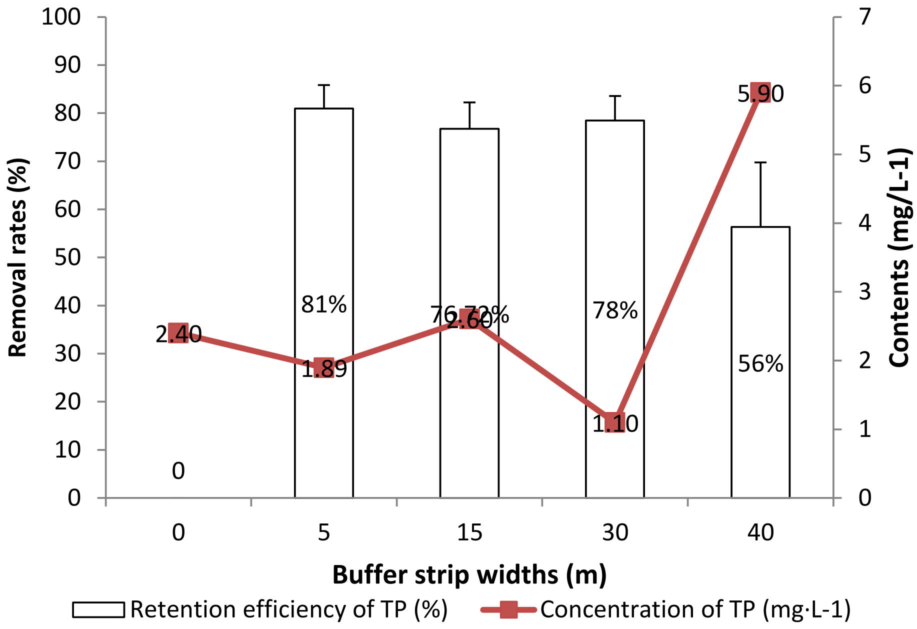

Figure 5. Total phosphorus interception effects of runoff water by different buffer widths in riparian buffer strips

Retention efficiency of total nitrogen of buffer strip widths

The results indicated that minimum retention efficiency of total nitrogen was discovered at 0 m width followed by 40 m width. Unlike the widths of 0 m and 40 m, all the other widths (5 m, 15 m and 30 m) had more efficient capacity to decrease total nitrogen with the percentage of 52%, 59% and 54% respectively (Figure 6). Highest retention capacity to attenuate total nitrogen was recognized at the width of 15 m in runoff water in the riparian buffer zone.

Concentration of total nitrogen in buffer strip widths

The results expressed that the minimum concentration of total nitrogen in runoff water was discovered at 0 m, 5 m, 15 m and 30 m widths (4.83 mg.L^{-1}, 4.16 mg.L^{-1}, 4.63 mg.L^{-1}, 19 mg.L^{-1}) respectively. Unlike the widths of 0 m, 5 m, 15 m and 30 m, 40 m width was more efficient for removing total nitrogen concentration (18.63 mg.L^{-1}) (Figure 6). Highest total nitrogen concentration in runoff water was noticed at the width of 40 m buffer strip.

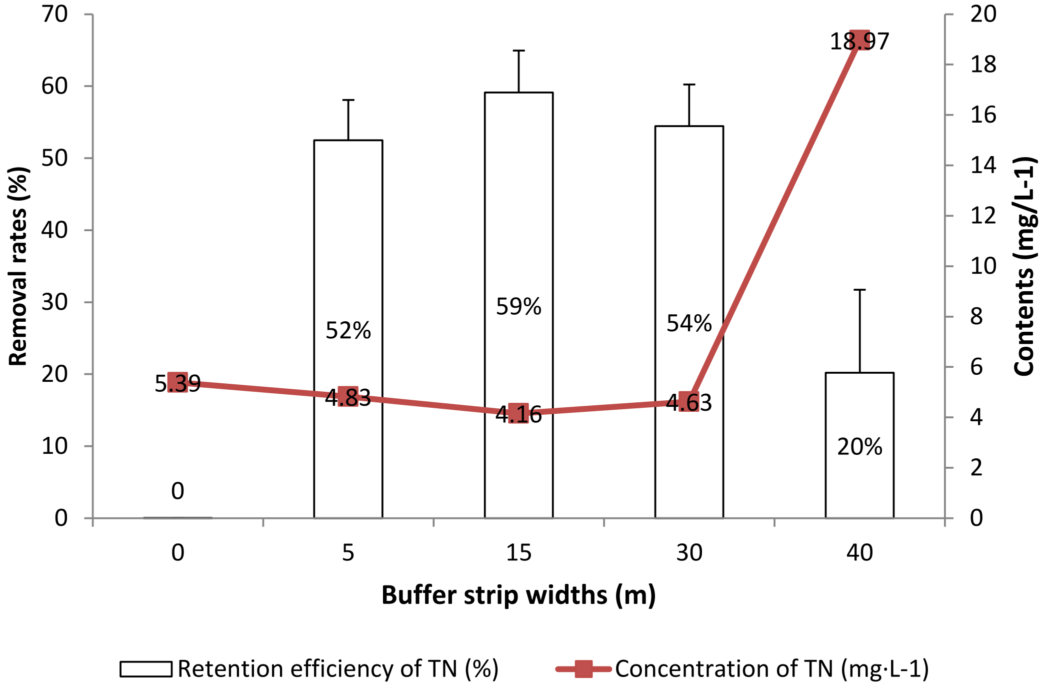

Figure 6. Total nitrogen interception effects of runoff water by different buffer widths in riparian buffer strips

Retention efficiency of ammonium nitrogen of buffer strip widths

The results indicated that the minimum retention efficiency of ammonium nitrogen was learnt at 0 m width followed by 40 m width. Unlike the widths of 0 m and 40 m, all the other widths (5 m, 15 m and 30 m) had the more efficient capacity to remove ammonium nitrogen with the percentage of 82%, 81% and 85% respectively (Figure 7). Highest retention capacity to reduce ammonium nitrogen was identified at the width of 30 m in runoff water in the riparian buffer zone.

Concentration of ammonium nitrogen in buffer strip widths

The results expressed that the minimum concentration of ammonium nitrogen in runoff water was learnt at 5 m width followed by 15 m and 40 m widths. Unlike the widths of 5 m, 15 m and 40 m, all the other widths (0 m and 30 m) was more effectual to reduce ammonium nitrogen with the concentration of 3.37 $mg.L^{-1}$ and 1.54 $mg.L^{-1}$ (Figure 7). Maximum concentration to reduce ammonium nitrogen was identified at the width of 30 m in runoff water in the riparian buffer zone.

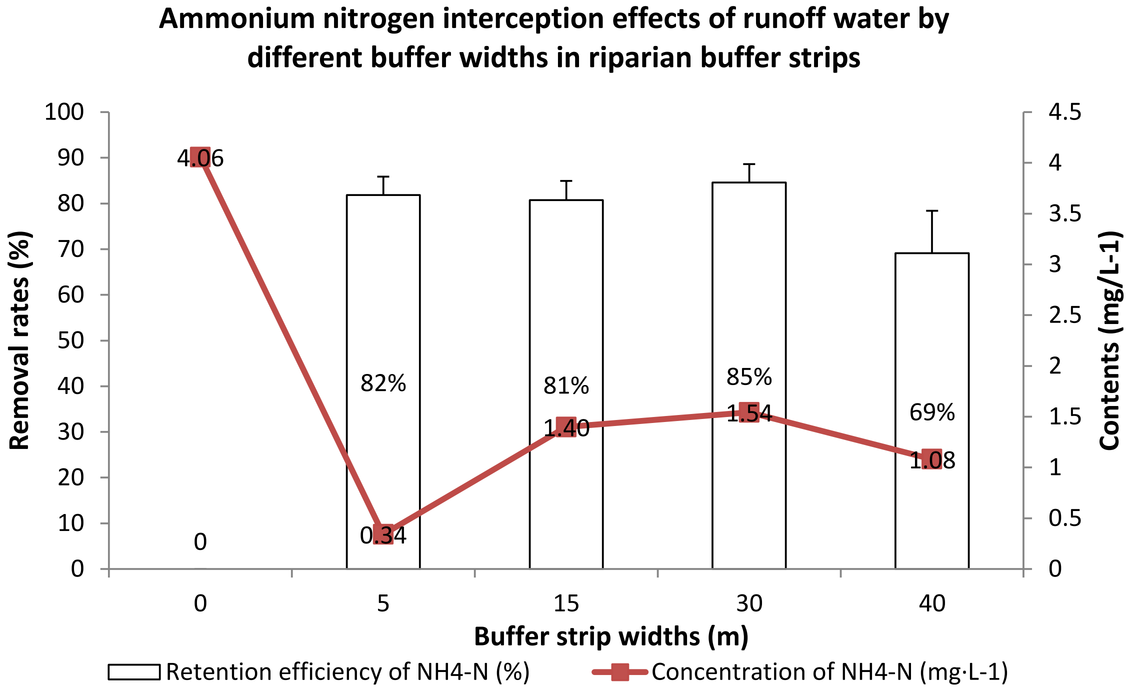

Figure 7. Ammonium nitrogen interception effects of runoff water by different buffer widths in riparian buffer strips

H_2: High stand density reduces more nutrients (total dissolved phosphorus, total phosphorus, total nitrogen, ammonium nitrogen) than low stand density.

Retention efficiency of total dissolved phosphorus of stand density

The analyzed results of descriptive statistics however showed that the lowest removal efficiency percentage (58%) of total dissolved phosphorus in runoff water was found in stand density of 1000 stem per hectare. Highest removal efficiency percentage (73%) of total dissolved phosphorus in runoff water in riparian buffer zone was noticed in Poplar forest with stand density of 400 stem per hectare (Figure 8).

Retention efficiency of total phosphorus of stand density

The analyzed results of descriptive statistics however indicated that the lowest removal efficiency percentage (50%) of total phosphorus was seen in stand density of 1600 stem per hectare. Highest removal efficiency percentage (61%) of total phosphorus in runoff water in riparian buffer zone was seen in Ascendens forest with stand density of 1000 stem per hectare (Figure 8).

Retention efficiency of total nitrogen of stand density

The analyzed results of descriptive statistics however expressed that the lowest removal efficiency percentage (37%) of total nitrogen was observed in stand density of 1600 stem per hectare. Highest removal efficiency percentage (43%) of total nitrogen in runoff water in riparian buffer zone was found in Ascendens forest with stand density of 400 stem per hectare (Figure 8).

Retention efficiency of ammonium nitrogen of stand density

The analyzed results of descriptive statistics however showed that the lowest removal efficiency percentage (59%) of ammonium nitrogen was discovered in stand density of 1000 stem per hectare. Highest removal efficiency percentage (68%) of ammonium nitrogen in runoff water in riparian buffer zone was observed in Ascendens forest with stand density of 400 stem per hectare (Figure 8).

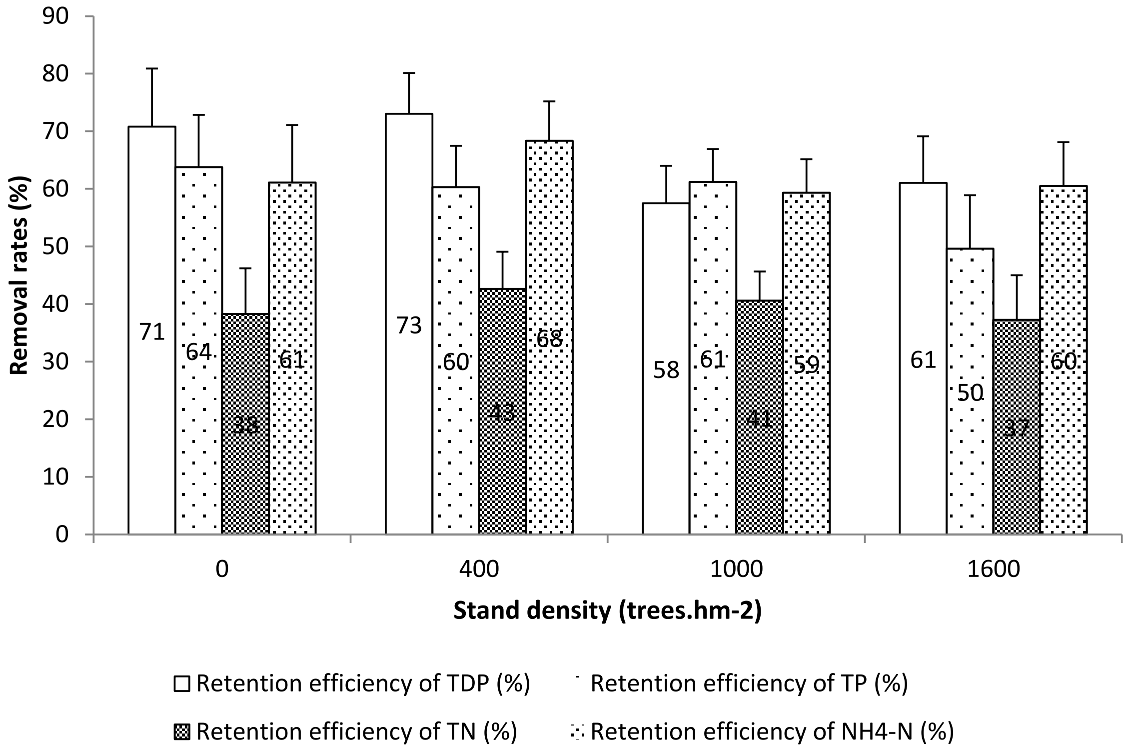

Figure 8. Nutrients interception effects of runoff water by different stand densities in riparian buffer strips

Pearson's correlation coefficients between dependent variable (removal efficiency) and independent variables (buffer strip width, stand density, vegetation cover, soil depth and season)

It was observed that retention efficiency of total dissolved phosphorus (r = 0.588**), total phosphorus (r = 0.521**), total nitrogen (r = 0.375**) and ammonium nitrogen (r = 0.624**) in runoff water were positively correlated with buffer strip widths (m) (Table 3). The strength of "r" is only at the substantial or moderate level ($0.304 < r < 0.632$, $p < 0.001$) and not very strong, but statistically acceptable.

It was also shown that retention efficiency of total dissolved phosphorus (r = 0.156), total phosphorus (r = 0.081), total nitrogen (r = 0.263**) and ammonium nitrogen (r = 0.101) were positively correlated with soil depth (cm) (Table 3). The strength of "r" is relatively at low level.

It was found that retention efficiency of total dissolved phosphorus, total phosphorus, total nitrogen and ammonium nitrogen were more or less negatively correlated with stand density, vegetation cover, season (see in Table 3).

Table 3. Pearson's correlation coefficients between removal efficiency (dependent variable) and buffer strip width, stand density, vegetation cover, soil depth and season (independent variables)

Variables	Retention efficiency of TDP (%)	Retention efficiency of TP (%)	Retention efficiency of TN (%)	Retention efficiency of NH_4-N (%)
Buffer strip width (m)	0.588**	0.521**	0.375**	0.624**
Stand density (trees/hm^2)	-0.119	-0.093	-0.023	-0.045
Vegetation cover	-0.097	-0.081	0.081	-0.060
Season	-0.257**	-0.223	-0.466**	-0.200*
Soil depth (cm)	0.156	0.081	0.263**	0.101

* $p < 0.05$, ** $p < 0.01$

6. Discussion

H_1: Wider forest buffer strips remove more nutrients (total dissolved phosphorus, total phosphorus, total nitrogen, ammonium nitrogen) than narrow forest buffer strips.

Retention efficiency of total dissolved phosphorus of buffer strip widths

There are relationships between retention efficiency of total dissolved phosphorus and buffer strip widths. The result showed that maximum retention capacity to alleviate total dissolved phosphorus in runoff water was observed at 30 m width in the riparian buffer strip. It means that the closest distance (30 m) to the lake is the most optimal width in terms of nutrient mitigation of total dissolved phosphorus. This is in line with Castelle et al. (1994) who recommended that the minimum buffer width should be between 15-30 m for the purpose of preserving rivers and wetlands. Likewise, Zhang et al. (2010) found that under appropriate slope conditions (≈ 10%); 30 m buff er width reduced more than 85% of all the studied pollutants (sediment, pesticides, nitrogen, and phosphorus). Peterjohn & Correll (1984) proved that 19 m buffer width could reduce 58.1% of dissolved phosphorus. Mao (2018) also stated that interception capacity of total dissolved phosphorus in runoff water in 15 m width was 62.74%, and also mentioned that initial phosphorus content in runoff water was steadily reduced as roots of the vegetation directly absorbed and used phosphorus. At this time, the roots of the vegetation were stimulated to produce various phosphorus-related enzymes to promote the release of phosphorus in the soil (Sheng et al. 2010). If the wider the buffer width, the closer to the Taihu Lake and the higher the groundwater level, which may govern the soil properties and material conversion process at 30-40 m width.

Retention efficiency of total phosphorus of buffer strip widths

Total phosphorus in the buffer zone was positively correlated with the change of width, and the correlation between these two variables was significant. The results expressed that optimum width of the buffer strip for retention capacity of total phosphorus in runoff water was at 5 m width. This is in line with results of Zhang et al. (2010) who noted that 5-10 m buffer width would increase the retention efficacy of phosphorus by about 20% and trees were more effectual in removing more phosphorus than grasses. Likewise, Lee (1999) found that 16.3 m wide warm-season grass/woody buffer removed 91% of total phosphorus in runoff. This maximum retention capacity is explained by high infiltration rates and uptake of deep rooted plants. Lee et al. (2000) also evaluated the capacity of different species of riparian vegetation for nutrient retention. They observed that woody vegetation with 20 m width had a good efficiency for reducing pollutants, with removal rate of 65%. Groffman et al. (2002) noted that plant roots can effectively intercept and absorb pollutants in the soil. Woody soils contain higher organic matter content than soils with grass and shrubs and therefore riparian woody vegetation was efficacious in reducing phosphorus and nitrogen concentrations. Zhu et al. (2016) found that removal rates of total phosphorus were 50% at 5 m and 70% at 30 m, and maximum phosphorus reduction rates occurred in the poplar buffer zone at 40 m with 72%-78%. Their results presented that plant absorption and soil adsorption can efficiently remove total phosphorus in runoff water.

On the other hand, Aguiar et al. (2015) assessed different widths of riparian buffer zones (12, 24, 36, 48 and 60 m) with different vegetation composition (woody, shrubs or grasses) with no-till farming systems in Brazil. They found that retention capacity is mainly controlled by buffer zone width and vegetation type. Effective removals of phosphorus in woody buffers were 36% in 12 m, 92% in 36 m and 100% in 60 m respectively. Chang et al. (2009) estimated the effectiveness of riparian buffer strips using cost-benefit analyses in Feitsui watershed in Northern Taiwan. They noted that the trapping efficiency of suspended solid (SS), total phosphorus and total nitrogen were 50%, 32.7% and 9.8% respectively in 30-50 m buffer strip width with a slope of 5%. They suggested that phosphorus loadings (high nutrient) were found to be most cost effective for that study area. Mao (2018) also pointed out that the optimum width of the total phosphorus retained by the buffer zone was 30 m. Because if phosphorus in runoff water enters the buffer zone, it is easy to organize insoluble phosphate with charged cations, and phosphate is simply adsorbed by soil minerals or maintained by soil microorganisms. Peterjohn & Correll (1984) also found that strip with 19 m width can remove 73.7% of total phosphorus.

Retention efficiency of total nitrogen of buffer strip widths

There are associations between removal efficiency of total nitrogen and buffer strip widths. In this study, retention rates of total nitrogen in runoff water were 52%, 59%, 54%, and 20% in 5 m, 15 m, 30 m and 40 m wide buffer strips respectively. Maximum retention capacity of total nitrogen was recognized at the width of 15 m. At 15 m, it was able to capture about 54% of total nitrogen in runoff water, which is similar to Cooper's (1990) finding that greatest nitrate depletion happened in 15 m wide riparian zone of stream channel of a small New Zealand headwater stream. My results support Peterjohn & Correll (1984) who observed that significant nitrate reduction took place in 17 m riparian zone of agricultural watershed in Maryland. Likewise, Zhang et al. (2010) also reported that removal efficacy of nitrogen was about 91% to 100% in a 20 m buffer. They also found that trees were more effective in removing more phosphorus than grasses. The study results are consistent with Correll (1984) who discovered that most of the nitrogen concentrations decreased in the uphill first 19 m of a 50 m riparian zone. This is also similar with Bu et al. (2017) findings that groundwater nitrate concentrations decreased by 67.5% to 88% within the 15 m poplar-grass riparian buffers in Taihu Lake through the year. Nitrate was reduced more efficiently in spring and summer than in autumn and winter as vegetation uptake and denitrification rates were higher in the growing season due to higher level of groundwater table and soil temperature. Lee (1999) found that 16.3 m wide warm-season grass/woody buffer reduced 94% of total nitrogen and 85% of nitrate nitrogen in agricultural runoff. This nutrient retention was due to by a combination of chemical, biological and physical processes including deposition of nitrogen and phosphorus with sediment material and infiltration of runoff water into the soil profile and filtration of suspended solids by plants.

Haycock & Pinay (1993) also presented that maximum nitrate retention was found within the first 5 m of poplar and grass riparian buffer strips along the Leach River in southern England. Maurizio &Elisa (2002) studied a buffer composed of a 5 m wide grass strip and a 1 m wide row of trees in a private farm in Northeast Italy, with maize and wheat cultivated in the neighboring field. They found that 6 m width buffers were very effective in reducing NO_3-N concentrations. Clausen et al. (2000) reported that most nitrate nitrogen concentrations (52%) decreased within a 2.5 m of restored riparian buffer in northeast Connecticut. They observed that denitrification and plant uptake were responsible for nitrogen losses annually. Lin et al. (2016) observed that the retention rate of total nitrogen was increased as the width of buffer strips (1 m, 3 m, 4 m, and 6 m widths) increased and the highest rate was found in 6 m width (42.9%) throughout the rainfall erosion process. They concluded that this was because soil moisture increase in buffer strips during rainfall and so the water absorption ability of the soil gradually decreased; different equilibrium time for infiltration and saturation caused the differences in the removal rates of total nitrogen with different widths in the riparian buffers.

On the other hand, Pinnay & Decamps (1988) argued that higher plant uptake and denitrification led to notable nitrate reduction occurred in 50 m wide riparian zone. Aguiar et al. (2015) also reported that effective removals of nitrogen in woody buffer vegetation were 43% in 12 m, 93% in 36 m and 100% in 60 m respectively. Highest retention capacity of nitrogen was obtained in 60 m width (100%). Mayer et al. (2007) pointed out that wide buffers (>50 m) more constantly reduced remarkable parts of nitrogen entering a riparian zone than narrow buffers (0-25 m). Their meta-analysis suggested that although buffer width is an essential consideration, soil type, subsurface hydrology (e.g., soil saturation, groundwater flow paths), and subsurface biogeochemistry (organic carbon supply, nitrate inputs) are also dominant factors limiting nitrogen removal in riparian buffers.

Retention efficiency of ammonium nitrogen of buffer strip widths

There are relations between retention capacity of ammonium nitrogen and buffer strip widths. Maximum removal efficiency to mitigate ammonium nitrogen in runoff water was identified at the width of 30 m in the riparian buffer zone. If some ammonium nitrogen escapes through surface runoff from 30 m to 40 m width, removal efficiency and concentration of ammonium nitrogen might be easily flowing into the lake. In this study, removal rate of ammonium nitrogen in runoff water in runoff water increased as the width increased, reaching a maximum at a width of 30 m (84%). This finding is similar with

Vought et al. (1994) who found that riparian buffer zone with 10-20 m width was ample to remove most forms of N from surface runoff. Peterjohn & Correll (1984) noted that removal rate of ammonium nitrogen was 74% from corn land 50 m through mature riparian forest in Maryland. Likewise, Zhang et al. (2010) observed that nitrogen was reduced about 91 to 100% in 30 m buffer width under favorable slope conditions (≈ 10%). They also found that trees were more effectual in reducing more nitrogen than grasses because of their deeper rooting system. Thus, it can be concluded that the results support H_1.

H_2: High stand density reduces more nutrients (total dissolved phosphorus, total phosphorus, total nitrogen, ammonium nitrogen) than low stand density.

Retention efficiency of total dissolved phosphorus of stand density

There are no correlations between removal efficiency of total dissolved phosphorus and stand density of buffer strip. 400 stem per hectare of Poplar forest has highest content of total dissolved phosphorus. To date, there are only few researches on effects of different plant densities on phosphorus removal ability. This result is similar with results of Song (2012) who found that there was no significant relationship between the stand density of trees and nitrogen and phosphorus interception efficiency. Likewise, Mao (2018) observed that the removal rate of total dissolved phosphorus increased as the stand density increased, and the highest interception was noted in 1600 stem per hectare.

Retention efficiency of total phosphorus of stand density

There are no relationships between removal efficiency of total phosphorus and stand density of buffer strip. Most total phosphorus removal efficiency was found at 1000 stem per hectare of Ascendens forest in the buffer strip. This result support Song (2012) who established the plant density-water quality model of the riverbank buffer zone, and found that the optimal density of the stand for phosphorus retention capacity was 1074 stem per hectare in the riverside buffer zone. Similarly, Zhu et al. (2016) also noted that the maximum interception efficiency of total phosphorus was in *Ascendens mucronatum* forest. Mao (2018) said that with the increasing of tree density, the removal rate of total phosphorus increased, and maximum retention capacity was noticed in stand density of 1600 stem per hectare.

Retention efficiency of total nitrogen of stand density

There are no associations between removal efficiency of total nitrogen and stand density of buffer strip. The retention capacity of total nitrogen in forest buffer strip decreased with the increase of forest density. If we grow monoculture plantations of Poplar and Ascendens with spacing of 2m × 3m, total nitrogen is highly absorbed by Ascendens forest with low density of 400 stem per hectare (43%). Minimum total nitrogen removal rate is found in 1600 stem per hectare (high density) of Ascendens forest (37%) which is much less than removal rate of total nitrogen in CK site (38%). It may be noted that stand density of monoculture plantations is probably not be able to absorb total nitrogen. Presently, there is little research on the effects of different plant densities on the nitrogen reduction ability. This finding is in line with the result of Meng et al. (2016) who reported that there was no significant difference in nitrogen removal rates between three different plant compositions and plant densities of riparian buffer zone. The best total nitrogen removal rate was detected

Ascendens-poplar mixed forest with a plant density of 1600 stem per hectare. They presumed that this might be connected with the age of the buffer zone plants.

Retention efficiency of ammonium nitrogen of stand density

There existed no significant correlation between removal efficiency of ammonium nitrogen and stand density of buffer strip. Maximum retention efficiency of ammonium nitrogen was showed in Ascendens forest with low density (400 stem per hectare). In contrast, Meng et al. (2016) found that ammonium nitrogen was the best in medium forest density (1000 stem per hectare) of poplar forest. They concluded that it may be associated with the age of the buffer zone plants. Song (2016) also perceived that there was no significant correlation between the forest stand density and nitrogen interception capacity. And with suitable stand density, the retention efficiency of nutrients (nitrogen and phosphorus) in forest buffer zone could be enhanced. Overall, it is possible to conclude that the results do not completely support H_2.

7. Conclusion

Buffer width is an important factor in the removal of pollutants, especially N and P. In this study, the width of buffer strips significantly affected nitrogen and phosphorus removal rates. And with the increasing of riparian buffer strip widths, the removal rates of phosphorus increased first and then decreased. The buffer strip of 30 m width (86%) intercepts most of total dissolved phosphorus. Highest retention capacity of total phosphorus was found in 5 m width (81%). Maximum removal rates to alleviate total nitrogen were identified at the width of 15 m (59%). Highest interception efficacy of ammonium nitrogen was recognized at 30 m (85%) in runoff water in the riparian buffer zone.

There was no significant difference in terms of nitrogen and phosphorus removal rates between different plant densities of buffer strips. Poplar plantation of total dissolved phosphorus removal rate was higher in low stand density (400 stem per hectare) while total phosphorus reduction rate was higher in Ascendens plantation with medium stand density (1000 stem per hectare). Maximum retention efficiencies of total nitrogen and ammonium nitrogen were found in Ascendens plantation with low stand density (400 stem per hectare).

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