Accumulation and Leaching Risk of Soil Phosphorus in Lei Bamboo Stands in the Upper Reaches of Taihu Lake

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Abstract: Phosphorus accumulation and losses were measured in the soils in Lei bamboo (Phyllostachys praecox) stands located in the upper reaches of Taihu Lake to determine evolution trend of soil P and its leaching risk. The contents of total P (TP) and available P (AP) in the soils increased with time or cultivation ages and decline with soil depth. Average annual rate of P accretion in 0-25 cm plow layer during 1999-2010 were 102 kg ha⁻¹ yr⁻¹. Rates of P accretion in 0-20, 20-40, 40-60 and 60-80 cm soil depth with 15 year-cultivation history were 135, 65, 40 and 20 kg ha⁻¹ yr⁻¹, respectively. The average contents of AP in the soils decreased in the order: Lei bamboo stand (652 mg kg⁻¹) > vegetable land (386 mg kg⁻¹) > Lei bamboo stand and Masson pine stands (6.1-6.6 mg kg⁻¹). Total P leaching loads via infiltration and runoff water in the treatments applied ranged from 4.32 to 7.77 kg ha⁻¹, which accounted for 5.3 to 7.5% of total P rates applied. Application of median P + pig manure, median P and phosphate rock decreased TP leaching loads by 15.4, 36.2 and 44.4%, respectively, as compared to the high P treatment. It is concluded that Lei bamboo stands have become important agricultural nonpoint source pollution in the upper reaches of Taihu Lake.

Key words: Environmental risks · Lei bamboo (Phyllostachys praecox) · Phosphorus accumulation · P leaching load and upper reaches of Taihu Lake

INTRODUCTION

Phosphorus not only is an essential nutrient for all plants, but also has the potential to induce eutrophication in the aquatic ecosystems. Although both P and N contribute to eutrophication, P ultimately controls eutrophication [1]. Effective eutrophication control can be achieved in both freshwater and coastal ecosystems by controlling P only.

Phosphorus fertilization is a vital component of modern agriculture. All modern food production and consumption systems are dependent on continual inputs of P fertilizers derived from phosphate rock yet phosphate rock is a non-renewable resource and we have approximately 50-100 years left of current known reserves [2, 3]. Effective, coordinated and sustainable management of the P resources is thus very important for both food production and protecting environment.

In vegetable and Lai bamboo production, the amount of fertilizer applied often exceeds the uptake by the plants and thus result in a build-up of P in the soil. Most of the excess P may become susceptible to transport via surface runoff and subsurface leaching. Phosphorus fertilization continues to be controversial and a topic of agronomic and environmental importance in these production systems.

Taihu Lake is the third greatest freshwater lakes in China with a water area of 2338 km². Eutrophication is the major environmental issues of the Taihu Lake watershed. Agriculture has been considered as an important nonpoint P source in Taihu Lake region [4, 5]. Phosphorus losses from mulberry gardens and vegetable land have been a major focus of research during the past decade, but limited studies were conducted to determine phosphorus loss of the soils under Lei bamboo stands.

Lei bamboo is an excellent variety for producing bamboo shoots and is widely distributed in vast regions of Yangtze River southward where Zhejiang province had the largest planting area with 6.0×10⁴ ha. Since 1980s, intensive management has widely applied to Lei bamboo production. Winter mulching and heavy-application of fertilizers are its key techniques. Usually, the rates of chemical fertilizers and organic fertilizers achieve 3.0 and 100 t ha⁻¹, respectively. In order to increase soil
temperatures and keep soil water in winter season, 5-10 cm of rice straw is covered on the soil surface under the bamboo stands and then 10-15 cm of rice hulls is covered on the rice straw. The rates of rice straw and rice hulls are 40 t·hm⁻² and 55 t·hm⁻², respectively [6].

In most cases, accumulation and loss in the soils has accelerated by increased inputs of P due to intensification of Lei bamboo production systems since the early 1980s. At present, the tendency of excessive fertilizer application of P fertilizers is still expanding. Excessive P fertilizer application resulted in ecological risks like P accumulation in the soils [6] and leaching of P into water bodies around Lei bamboo stands [7].

Bamboo has been concerned as the best forest species for soil and water conservation and reducing nutrient losses [8] and thus there is a need to accurately identify change trend and loss risk of soil P in Lei bamboo stands following intensive management. Despite substantial measurements using both laboratory and field techniques, little is known about the spatial and temporal variability and loss risk across in soil P in Lei bamboo stands. Further research effort on optimizing P management to improve Lei bamboo sustainability and protect water quality is therefore warranted. The objective of this study were to (1) investigate temporal and spatial changes of P in the soils in Lai bamboo stands and its evolution trend, (2) to evaluate P lose via runoff and infiltration water from the soils in Lei bamboo stands and (3) to compare P loss from the soils with different utilization patterns.

MATERIALS AND METHODS

Both survey area and experimental site were located in Lin’an county (118° 51'-119° 52'E and 29° 56'-30° 23'N), Zhejiang Province, China. This area belongs to typically central-subtropical climate with an average annual temperature of 16.4 °C and an average annual rainfall of 1629 mm. The average annual sunshine hours and days free of frost in the region were 1847 h and 235 days, respectively.

Lei bamboo is widespread in plains, hills and low mountains in this county. It is mainly planted in red soils and paddy soils derived from different parent materials. The soil physical and chemical properties of the soils in the survey area were as follows: soil texture from light loam to light clay, pH in soil extraction (soil: H₂O = 1:5) 4.0-6.5; organic matter 12.5-102 g kg⁻¹; total N 2.22 g kg⁻¹, total P 0.153 g kg⁻¹; hydrolyzed N 228 mg kg⁻¹, available P (AP) 262 mg kg⁻¹; hydrolyzed N 41-257 mg kg⁻¹, available P (AP) 17-753 mg kg⁻¹ and available K 23-926 mg kg⁻¹.

Survey Study: For survey 1, hundred thirteen soil samples (0-25 cm depth) were sampled from Lai bamboo gardens with different management levels to provide ranges in TP an AP in early June, 2010. For survey 2, twenty soil samples were collected from Lai bamboo gardens with different cultivation years at 0-25 cm depth in early March of 2010. For survey 3, soil samples were collected at 0-20; 20-40 and 40-60 cm soil depth from Lai bamboo stands with 0, 1, 5, 10 and 15 cultivation years on March 7, 2010. For survey 4, seven soil samples were collected from the soils at 0-30 cm depth for each land utilization way (vegetable land, Moso bamboo, Masson pine and Lai bamboo) in early March of 2010.

Soil Sampling: Twenty cores (4 cm diameter) per sample were randomly taken and mixed together. Each soil sample was air-dried at room temperature and crushed to pass a 2-mm sieve and mixed thoroughly for analysis.

Rates of TP accretion in a soil depth (kg ha⁻¹ yr⁻¹)=(10000 m³×soil depth (m)×bulk density(kg m⁻³)×TP accretion (kg P t⁻¹ soil ) ] / interval years.

Field Infiltration and Runoff Experiments: Infiltration and runoff experiments began in early 2010 and conducted on a 15-year- Lei bamboo garden with slope gradients of 12.5%. The winter mulching was applied for 6 years on Lai bamboo garden studied and large amounts of mulching and littering materials had not been removed on the soil surface before the experiment. The soil used in the experiment was a red soil derived from sandstone that it is classified as Ferrisols in the U.S taxonomic classification system. The selected soil physical and chemical properties prior to the experiment were sand loam, pH (soil: H₂O = 1:5) 3.88; organic matter 43.9 g kg⁻¹; total N 228 mg kg⁻¹, total P 228 mg kg⁻¹; hydrolyzed N 228 mg kg⁻¹, available P 262 mg kg⁻¹ and available K 176 mg kg⁻¹.

Two experiments were established on a same bamboo garden. Fertilization experiment consisting five treatments (Table 1) was arranged in a randomized complete-block design with three replications. Experimental plot size was 12 m by 6.0 m. Fertilizer rate of figh P treatment in this experiment was similar to those applied by the farmers. With 40, 30 and 30% of chemical fertilizers were applied on May 28, September 2 and December 10, 2010, respectively. Pig manure is applied in May 28 and December 10, respectively. The bamboo garden was watered before the first fertilization and then was applied fertilizers to the soil with the light plow of 5cm. Winter mulching with 15 cm of rice straw and 20 cm of rice grain hulls was carried out in
Table 1: Fertilizer rates in the different treatments used in the experiment

<table>
<thead>
<tr>
<th>Treatment#</th>
<th>Kind† and annual rate of fertilizers (kg ha⁻¹ yr⁻¹)</th>
<th>Nutrient input (kg ha⁻¹ yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>No fertilizer</td>
<td>N</td>
</tr>
<tr>
<td>High P</td>
<td>Compound fertilizer 2250, urea 1125</td>
<td>855</td>
</tr>
<tr>
<td>Median P</td>
<td>Compound fertilizer 1125, urea 563</td>
<td>428</td>
</tr>
<tr>
<td>Median P+</td>
<td>Compound fertilizer 1125, urea 563, pig</td>
<td>444</td>
</tr>
<tr>
<td>Pig manure</td>
<td>Manure 10000</td>
<td></td>
</tr>
<tr>
<td>Phosphate rock</td>
<td>Urea 563, phosphate rock 673, KCl 280</td>
<td>428</td>
</tr>
</tbody>
</table>

† Compound fertilizer (NₕPO₅KₕO = 15:5:5); urea (N=46%); phosphate rock (110 g P kg⁻¹); KCl (550 g P kg⁻¹). Nutrient and water contents of pig manure: water 735 g kg⁻¹, C 142 g kg⁻¹, N 6.0 g kg⁻¹, P 9.1 g kg⁻¹, and K 52 g kg⁻¹.

Fig. 1: Monthly average precipitation in 2010

December 5, 2009. Fifteen cm of rice straw (40 t ha⁻¹) was covered on the soil surface and then 20 cm of rice hulls (55 t ha⁻¹) was covered on the rice straw.

Establishment of Runoff Plots and Installation of Infiltration Collection Devices: Each runoff plot with 12-m-long and 6-m-wide was isolated on the upper three sides by cement frames driven 5 cm into the soil surface. On downhill side of a plot, a gully of 20 cm depth, 30 cm top width and 20 cm bottom width was established and connected a runoff basin with length, width and height of 100 × 100 × 100 cm for collecting runoff water. At the same time, a rain gauge was installed to measure rainfall near the experiment site. Monthly average precipitation of 2010 is shown in Figure 1.

An infiltration collection device (lysimeter) was also buried at the depth of 30 cm from the soil surface in the center of each plot before the experiment (Oct. 8, 2009).

Collection and Analysis of Infiltration and Runoff Water: Collection of infiltration and runoff water was conducted following every a larger rainfall. Seventeen samples for each infiltration and runoff water were collected in a year, respectively. Each water sample was divided into two parts: half one was filtered with a 0.45μm filtration membrane for determination of dissolved phosphorus (DP); another half one was not filtered for the determination of total phosphorus (TP).

Analysis of Runoff and Infiltration Water and Soils: All analytical methods of runoff and infiltration water and soils used in the studies are cross-referenced to the literature [9]. Soil pH was determined by electrode method at a 1:5 soil to water ratio. Organic matter was determined by the K₂Cr₂O₇ digestion method. Soil texture was determined by the pipette method. Soil TP was determined by digestion –Mo-Sb dnti spectrophotometric method. Available N, P and K of the soil were determined by the diffusion absorption method, Bray-1 method and the NH₄OAc extract-flame photometric method, respectively.

Total P and dissolved phosphorus (DP) were determined by the colorimetric method. Particulate P is obtained from calculating the difference between TP and DP.

Statistical Analyses: The differences in among the treatments were analyzed statistically by a one-way ANOVA followed by the Duncan’s Multiple Range Test using software named Data Processing System developed by Tang and Feng [10].

RESULTS

Temporal Changes of TP and AP in the Soils: As P fertilizer rates increased year by year, contents of TP and AP in the soils in Lei bamboo stands increased with time (Figure 2). Contents of TP and AP in the soils (0-25 cm) in 1999, 2002, 2007 and 2010 were 0.81, 0.91, 1.08, 1.17 g kg⁻¹ and 15, 54, 126, 158 mg kg⁻¹, respectively. Compared with 1999, contents of TP and AP in the soils in 2002, 2007 and 2010 were increased by 12.3, 33.3, 44.4% and 2.6, 7.4, 9.5 times, respectively. According to calculation, average annual rate of P accretion in 0-25 cm plow layer during 1999-2010 were 102 kg ha⁻¹ yr⁻¹ (Figure 2).
Contents of TP and AP in the soils also increased with increasing cultivation ages (Figure 3). The TP in the soils were highly correlated to cultivation ages. However, correlation coefficient between the soil AP and cultivation ages \( r^2 = 0.649, P < 0.001 \) was greater than between soil TP and cultivation ages \( r^2 = 0.478, P < 0.05 \). Long-term P input can result in P accumulation in the top soil in Lai bamboo sands.

**Changes of TP and AP in the Soil Profiles with Increasing Cultivation Ages:** The changes trend of TP contents in the soil profiles (0-80cm) with increasing cultivation ages is shown in Figure 4. The contents of TP in the soils with different cultivation ages of Lei bamboo stand decreased with soil depth.

In the early period of planting Lei bamboo (1-5 years), P fertilization increased the contents of TP in the 0 to 20cm plow layer, but it did not increased or slight increased the contents of TP in the 20 to 80cm subsoil. However, continued long-term phosphorus fertilization could greatly increased the contents of TP in both surface soil and the subsoil layer in the later period (10-15 years).
Increased concentrations of AP were found down to the 20 to 80 cm soil layers, indicating a strong downward movement of this P form.

Total accumulation rates of TP in the 0-80 cm soil layer following planting Lai bamboo for 5, 10 and 15 year increased 825, 1675 and 2975 kg ha$^{-1}$. Rates of P accretion in the different soil depth increased with cultivation history. For example, rates of P accretion in the 0 to 20cm plow layer in the planted interval years of 0-5, 5-10 and 10-15 years were 88, 95 and 135 kg ha$^{-1}$yr$^{-1}$, respectively. Rates of P accretion in the soil profile reduced with soil depth, which is implying that long-term P fertilization could cause P accumulation down to 80 cm depth in the soil profiles.

The change trend of AP in the soils with soil depth was similar to that of TP (Figure 5). The contents of AP in the soils with different cultivation ages increased with soil depth up to 60cm subsoil. There were no differences of AP contents in 60-80 cm subsoil among different cultivation ages. The contents of AP in the different soil layers (0-20, 20-40 and, 40-60cm) increased as cultivation ages increased. Statistically significant differences were found for AP contents in subsoil among the soils with different texture.

Comparison of Soil Available P Contents in Different Land Utilization Ways: Comparison of the soils in Lei bamboo stands vs the other soils used for growing Masson pine, Moso bamboo (Phyllostachys pubescens) and vegetable revealed that average over the soil samples, the highest P contents (652 mg kg$^{-1}$) was found in plow layers (0-20cm) in Lei bamboo stand with intensive management, receiving high rates of P fertilizers (150-180kg P ha$^{-1}$ yr$^{-1}$). The next highest content (386 mg kg$^{-1}$) was observed in vegetable land, receiving medium rates of P fertilizers (75-100 kg P ha$^{-1}$ yr$^{-1}$). The lowest P contents (6.1-6.6 mg kg$^{-1}$) were observed in the soils in Moso bamboo and Masson pine stands with extensive management, which had never received any forms of P fertilizers (Figure 6). Phosphorus content in subsoil layer (20-40cm) in Lei bamboo stand was as high as 73.2 mg kg$^{-1}$, which suggesting the markedly migration of P from surface soil to subsoil. However, despite the plow layer in Moso bamboo stand had high P content, the markedly migration of P was not observed because its P content was very low (8.4 mg kg$^{-1}$). Phosphorus contents in 20-40cm soil layers in Moso bamboo and Masson pine stands were also very low (4.9-5.3 mg kg$^{-1}$).

Leaching Risks of P via the Infiltration and Runoff Water: Minimum, maximum and mean values of TP and DP concentrations in the infiltration and runoff water in the soils in Lei bamboo stand are given in Table 2. For the same treatments, TP and DP concentrations in the runoff water were close to those in the infiltration water. Mean values of TP in the infiltration and runoff water ranged from 1.3 to 3.3 mg kg$^{-1}$, with the lowest value (1.3 mg kg$^{-1}$) in the control treatment and the highest value (3.3 mg kg$^{-1}$) in the high P treatment.

Dissolved P (DP) in the infiltration and runoff water accounted for 60-62% and 50-71% of TP, respectively, whereas particulate P accounted for 38-40% and 39-50% of TP, respectively.

Analysis of correlation showed that there were significant positive correlation between total P (TP) concentrations in the infiltration ($r^2=0.88$, $P<0.01$) or between runoff water ($r^2=0.72$, $P<0.05$) and Bray 1-P contents in the 0-20cm plow layers (Figure 7).
Table 2: Effect of different fertilization on the P concentrations in the infiltration water from Lei bamboo stand

<table>
<thead>
<tr>
<th>Treatment#</th>
<th>Infiltration water</th>
<th>Runoff water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>Control</td>
<td>0.5</td>
<td>4.1</td>
</tr>
<tr>
<td>High P</td>
<td>0.9</td>
<td>7.2</td>
</tr>
<tr>
<td>Median P</td>
<td>0.6</td>
<td>6.0</td>
</tr>
<tr>
<td>Median P+ PM</td>
<td>0.7</td>
<td>6.7</td>
</tr>
<tr>
<td>Phosphate rock</td>
<td>0.5</td>
<td>5.3</td>
</tr>
</tbody>
</table>

PM, pig manure
† Means followed by a different letter within columns are significantly different according to Duncan’s new multiple range test, P < 0.05.

Table 3: Effects of different fertilization on leaching loads of total P (TP) and dissolved P (DP) via infiltration and runoff water from the Lei bamboo stands

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Infiltration</th>
<th>Runoff</th>
<th>Total</th>
<th>Infiltration</th>
<th>Runoff</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>3.48 c†</td>
<td>0.77c</td>
<td>4.25d</td>
<td>2.37c</td>
<td>0.52c</td>
<td>2.89c</td>
</tr>
<tr>
<td>High P</td>
<td>6.16a</td>
<td>1.61a</td>
<td>7.77a</td>
<td>3.77a</td>
<td>0.95a</td>
<td>4.72a</td>
</tr>
<tr>
<td>Median P</td>
<td>3.74c</td>
<td>1.22b</td>
<td>4.96c</td>
<td>2.53c</td>
<td>0.73b</td>
<td>3.26c</td>
</tr>
<tr>
<td>Median P+ PM</td>
<td>5.36b</td>
<td>1.21b</td>
<td>6.57b</td>
<td>3.19b</td>
<td>0.85a</td>
<td>4.04b</td>
</tr>
<tr>
<td>Phosphate rock</td>
<td>3.52c</td>
<td>0.80c</td>
<td>4.32d</td>
<td>2.41c</td>
<td>0.55c</td>
<td>2.96c</td>
</tr>
</tbody>
</table>

PM, pig manure
† Means followed by a different letter within columns are significantly different according to Duncan’s new multiple range test, P < 0.05.
Phosphorus Leaching Loads via Infiltration and Runoff Water Decreased in the Order: high P > median P+ PM > median P > phosphate rock > control (Table 3). Application of median P+ PM, median P and phosphate rock reduced TP leaching loads by 15.4, 36.2, 44.4%, respectively, as compared to the high P treatment. Phosphorus leaching loads via infiltration water were greater than via runoff water because large amounts of mulching materials were covered on the soil surface, which was favorable to the increase in soil infiltration water and the decrease in soil runoff water. Total P leaching loads via infiltration and runoff water in the plots of high P rate, median P, median P+ PM, and phosphate rock accounted for 5.3, 6.7, 7.5 and 5.8% of total P rates applied, respectively.

DISCUSSION

Phosphorus Accumulation in the Soils: Phosphorus accumulation in the soils is closely linked to levels and kinds of P fertilizers applied. Long–term P fertilizer applications to a soil have caused P accumulate in the soils in Lai bamboo stands. Before the mid-1970s, extensive management with small amount of organic manure and no tillage was extensively used [11]. At that time, average contents of TP and AP in the 0-20 soil depth were 0.21 g kg\(^{-1}\) and 5 mg kg\(^{-1}\), respectively, which is below critical index [6]. In the mid-1970s to the mid-1980s, rates of chemical fertilizer increased year by year, which resulted in increase in TP and AP in the soils, in which TP and AP in the 0-25 cm soil depth was increased to 0.24 g kg\(^{-1}\) and 11 mg kg\(^{-1}\) in 1980, respectively [6]. Since 1980s, a intensive management modal has been extensively applied in Zhejiang, Jiangsu, Anhui, Jiangxi and Fujian provinces. The modal includes heavy chemical and organic fertilizer, cut down shrubs and weeds, as well as deep plough of surface layer and winter-mulching. The results of the present study showed that average annual rate of P accretion in 0-25 cm plow layer during 1999-2010 were 102 kg ha\(^{-1}\) yr\(^{-1}\) (Figure 1).

Evolution trend of the soil P in Lei bamboo stands obtained from our survey study was supported by a study in situ conducted by Xu et al. [12] in Lei bamboo stand in Lin’an county of Zhejiang Province. They found that contents of TP and AP in the soils in 0-20cm plow layer increased from 0.94 g kg\(^{-1}\) and 17 mg kg\(^{-1}\) in 2002 to 1.44 g kg\(^{-1}\) and 305 mg\(\text{kg}^{-1}\) in 2009, respectively. The contents of TP and AP in the soils were increased by 53.2% and 16.9 times, respectively. Average annual rate of P accretion in 0-25cm plow layer during 2002-2009 were 179 kg ha\(^{-1}\) yr\(^{-1}\).

Characteristics of soil P accumulation in Lei bamboo stands were concluded as follows: (1) the results of the present study and other meng studies [6, 13, 14, 15] showed that the contents in TP (1.41-2.08 g kg\(^{-1}\)) and AP (156-627 mg kg\(^{-1}\)) in the top soil of 0-20cm were much higher than that of a change-point (60 mg kg\(^{-1}\)), (2) rate of P accretion in the soil profiles increased with time or cultivation years and the trend has continued [6, 13, 14, 15]; (3) long-term continuous P input from chemical fertilizers and manure has resulted in P translocation from surface soil to subsoil (20-80cm) [13].

The reasons for rapid-and over-accumulation of P in the soil may be: first, the rate of P fertilizers from chemical fertilizers and organic fertilizers was as high as 180-240 kg ha\(^{-1}\) yr\(^{-1}\), whereas P use efficiency was only 10-15% [16]; secondly, input amounts of P (165-210 kg ha\(^{-1}\)) was 10-15 times greater than output those in the Lei bamboo production [15]; and thirdly, the movement distance of P in the soils did not exceed 0.1-0.2mm due to very strong adsorption and fixation of P by soil [17], thereby P leaching from soil was not easy relative to N and K.

Phosphorus Loss Risks and its Evaluation: Soils with high concentrations of extractable P are considered to be a greater risk of causing nonpoint dissolved P losses. When accumulation amount of soil P exceed amounts of adsorption and fixation by soil, heavy rainfall results in P losses via desorption of soluble P forms to runoff and infiltration water. Several studies reported that the critical concentrations or the change point producing P losses were 60 mg Olsen-P \(\bullet\) kg\(^{-1}\) [17, 18], 60 mg Blay-1 P \(\bullet\) kg\(^{-1}\) [19]. Above this, there was a rapid increase in DP up to the maximum Olsen-P concentration [18]. The results of the present study showed that soil P concentrations in Lei bamboo stands were far greater than the critical concentrations or the change point. For instance, average content of Blay-1 P in the plow layers in Lin’an County was 158 mg kg\(^{-1}\) in 2010 with the highest concentration of 753 mg kg\(^{-1}\) (Figure 1).

The average concentrations of TP in the infiltration and runoff water as well as leaching loads of TP were related to concentrations of Blay-1 P in the plow layers (Figure 7). This finding was supported by the other researchers [18, 20] who reported that there was a positive relationship \((r=0.95)\) between dilute acid-fluoride-extractable P of the subsoil 60 cm and soluble inorganic P in drainage water. Heckrak et al. (1995) also suggested that above the change point, P losses in the drainage water were much more closely related to Olsen-P than commonly suggested [18].
The average concentrations and leaching loads of TP depended on rates and kinds of P fertilizers applied. The average concentrations and leaching loads of TP in the treatments with lower P rates were much lower than with high P rate (p<0.05) (Table 3). For the treatments of median P, the average concentration of TP in the plots applied compound fertilizer was much higher than that applied phosphate rock (p<0.05) (Table 3), which was contributed to very low availability of P in phosphate rock. Application of pig manure could significantly increased risk of P loss from the soils as compared to the soil receiving inorganic P (Table 3), which was contributed to mineralization of organic P in the upper layers of the manure-treated soils [21, 22].

The average concentrations of TP in the infiltration and runoff water were also related to rainfall amounts. The maximum concentrations of TP and DP in the infiltration and runoff water were observed on June 24 (date not showed) because there was a largest rainfall on that day (Figure 1).

The results of the present study revealed that TP leaching loads via infiltration and runoff water in the treatments applied P ranged from 4.32 to 7.77 kg P ha⁻¹ yr⁻¹, which accounted for 5.3-7.5% of total P rates applied. Our results are much greater than normal P losses that below 1 kg total P ha⁻¹ yr⁻¹ or <1 to 2% of the P fertilizer input (Heckkrk et al., 1995), suggesting that total P leaching load from the soil under Lei bamboo stands is very serious. The high TP leaching load resulted in the pollution of water system around Lei bamboo stands [7]. The analytical results showed that the concentrations of TP in the drainage (0.25 mg P L⁻¹) and river water (0.1 mg P L⁻¹) around Lei bamboo stands with intensive management were 9.1 and 2.8 times greater than that around natural forests, respectively [7] and also were much greater than a critical P concentration (0.02 to 0.035 mg P L⁻¹) for triggering eutrophic effects in lakes [18].

Comparison of P Loss from the Soils with Different Utilization Patterns in Taihu Lake Regions: Phosphorus loss from the soils with different utilization patterns in Taihu Lake regions has been regarded by many researchers. Qian et al. [5] reported that the average concentrations of TP in the drainage water from the soils were decreased in the order: mulberry garden (0.86 mg L⁻¹) > vegetable land (0.86 mg L⁻¹) > rice field (0.32 mg L⁻¹) > wheat-rapeseed (0.32 mg L⁻¹) > fallow land (0.16 mg L⁻¹) [23], Cao et al. [24] reported that the P loss loads via the runoff were decreased in the order: mulberry garden (1.1 kg ha⁻¹ during 4 months) > vegetable land (0.6 kg ha⁻¹ during 5 months) > wheat-rapeseed (0.52 kg ha⁻¹) > rice (0.26 kg ha⁻¹). Some researcher also reported that the P loss loads from mulberry garden and vegetable land ranged from 5 to 10 kg P ha⁻¹ yr⁻¹ [25], thereby, the regions of planting mulberry garden and vegetable land have been recognized as the main control regions of agricultural non-point source pollution in Taihu Lake regions [26].

It can be seen very clearly from the following comparisons that Lei bamboo stands have become the largest source pollution source. First, the rates of P fertilizer were greater in Lei bamboo stands (150 to 200 kg P ha⁻¹ yr⁻¹) than in mulberry garden (90 to 150 kg P ha⁻¹ yr⁻¹) and vegetable land (80 to 120 kg P ha⁻¹ yr⁻¹) [25]. Average content of soil AP in Lei bamboo stands in Lin’an County was 158 mg kg⁻¹ in 2010, whereas the contents of AP in plow layers of mulberry gardens and vegetable land ranged 120-180 and 50-80 mg kg⁻¹ [25]; Second, average concentrations of TP in the drainage or runoff and infiltration water from the Lei bamboo stands (1.3-3.3 mg kg⁻¹) were greater than from mulberry gardens and vegetable land (<1.0 mg kg⁻¹); Third, TP loss loads via the runoff and infiltration water in Lai bamboo stands (7.8 kg P ha⁻¹ yr⁻¹) were much greater than in mulberry gardens and vegetable land (2.5 to 4.4 kg P ha⁻¹ yr⁻¹); fourth, planting area of Lai bamboo stands is much larger than that of mulberry gardens and vegetable land in Talhu Lake regions.

Phosphorus fertilizer management strategies for Lai bamboo production are aimed at balancing agronomic requirement of crops while reducing the risks of P accumulation and subsequent transport to the environment. Many studies have shown that that proper P fertilization management including reducing P fertilizer rates, applying controlled-release fertilizer, special compound fertilizer, phosphate rock and microbial fertilizer as well as establishing the buffer strips may mitigate P lose from the soils and maintain higher bamboo shoot yield and economic benefits [15, 27, 28].

In conclusion, long-term application of manures and fertilizers has resulted in an over-accumulation of soil P and an increased potential for excessive P losses via runoff and infiltration water to water bodies nearby Lei bamboo stands. Accretion rate in the soil P and loss risk of P has exceeded protected vegetable land in the same area. At present, the intensification of Lei bamboo production have been identified as the largest nonpoint source of P to water bodies in Taihu Lake regions followed by protected vegetable land.

Moso bamboos (Phyllostachys pubescens) are one of the most important forest plantations in South China with a panting area of 3.37×10⁶ ha [29]. Because it can produce
both bamboo woods and bamboo shoots, P fertilizer rates have been increased in the production year by year. Although rates of P accretion in the soils in Moso bamboo stands is not as great as Lei bamboo, further work is needed for a better understanding of buildup of P in the soil and risk of P loss.

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