Full Length Research Paper

Surface runoff and phosphorus (P) loss from bamboo (*Phyllostachys pubescens*) forest ecosystem in southeast China

Qi-Chun Zhang[1]*, Ying-ying Liang[1], Imran Haider Shamsi[2], Guang-huo Wang[1], Li-ping Lou[2] and Nazim Hussain[3]

[1]Key Laboratory of Polluted Environment Remediation and Ecological Health, Department of Natural Resources, Zhejiang University, Hangzhou 310029, People's Republic of China.
[2]College of Environmental and Resource Sciences, Zhejiang University, Hangzhou 310029, People's Republic of China.
[3]Institute of Crop Science, College of Agriculture and Biotechnology, Zhejiang University, Hangzhou 310029, People's Republic of China.

The effect of different fertilization treatments on runoff and nutrient losses under field conditions was investigated through setting runoff plots in bamboo (*Phyllostachys pubescens*) forests in a catchment of Taihu Lake. The results showed that, the runoff loss reached 356, 361 and 342 m^3 /hm^2, while the soil particle loss reached 393, 392 and 442 kg/hm^2, respectively, in the period from June 2009 to May 2010, under the treatments of control (CK), site-specific nutrient management (SSNM) and farmers' fertilizer practice (FFP). The runoff and soil particle losses were highly correlated with the precipitation during the period. The largest phosphorus losses happened in August, when it had the largest rainfall of that year. The total phosphorus (TP) concentration of the 95% of the observed runoff samples exceeded 0.10 mg/l. The average bioavailable phosphorus (BAP) concentration of the runoff was 0.23 mg/l and the various phosphorus forms lost was strongly inter-correlated. Compared with FFP, the SSNM treatment reduced total P (TP) by 5%, total dissolved phosphorus (DP) loss by 15% and total bioavailable phosphorus (BAP) loss by 8%.

Key words: *Phyllostachys pubescens,* ecosystem, surface runoff, phosphorus (P) loss.

INTRODUCTION

Taihu Lake of Southeast China has witnessed both the rapid economic bloom of its neighboring areas and a dramatic algal bloom of its water body in the past two decades. Water quality deterioration of the lake has become a national concern since the early 1980s. The Chinese government has shown its resolution to combat pollution of the lake by closing a large number of heavy polluting enterprises around the lake and by banning the selling and use of P-bearing detergents in its catchment. However, it seems the causes and effects of eutrophication of the lake are rather complex. Despite all the efforts dedicated to reduce urban and industrial emissions, water quality of the lake has not shown significant improvement in recent years (Chen, 2001; Zhang et al., 2001). Accelerated entrophication, the biological enrichment of surface waters stemming from anthropogenic inputs of nutrients, is the most common surface water impairment in the lakes of China (Zhu, 1995; Zhang et al., 2007). As P is generally considered to be the key element that controls or limits productivity of fresh water, the decrease of P loss in runoff has become a major target to minimize surface water degradation (Charpenter et al., 1998; Boesch et al., 2001; Wang et al., 2001).

The major P transport pathway for most agricultural soils is surface runoff (Han et al., 2010). The transport of P can be separated into particulate and dissolved phosphorus forms which are pp and DP. DP is the most immediately available for algal uptake (bio-available) (Peters, 1981; Hatch et al., 1999). In contrast, PP associated with sediment and organic material in runoff,

---
*Corresponding author. E-mail: qczhang@zju.edu.cn Tel: 86-0571-86971957.

may constitute a variable but long term source of potentially bio-available P in lakes (Sharpley et al., 1992). It is recognized by many scientists that a large portion of P enters water in particulate associated form (Yli-Halla et al., 1995; Uusitalo et al., 2001; Ellison and Brett 2006). Consequently, measurement of bio-available P is essential to more accurately estimate the impact of agricultural management practices on the biological productivity of surface waters. The soil management system has a strong influence on the concentrations of runoff (Bertol et al., 2007). The timing of fertilizer application in relation to rainfall events, as well as the form of placement of fertilizer in soil affects nutrient losses by runoff (Yang et al., 2009). However, the information on nutrient losses from forest soils is very limited. The processes of soil P losses, especially the dynamic characteristics of P loss by runoff and suspended materials under natural rainfall condition in forest catchments have not been well studied.

Bamboo (*Phyllostachys pubescens*) forests are widely distributed in its catchments of Taihu Lake which covers about 30% of the total hilly and mountainous area of the watershed, especially in Zhejiang province. In Zhejiang, the bamboo industry generates several billion Yuan per year and it ranks among the most important businesses (Zhang et al., 2001). With the rapid increase of the number of bamboo plantations under intensive management during recent years, serious problems such as the degradation of the bamboo forests, a decline in soil quality and water pollution caused by unfavorable cultivation practice, for example, over-fertilization and fertilizer broadcasting have begun to occur (Shen et al., 2000). It is therefore, very important to study nutrient transport processes of bamboo forests under intensive management to provide guidance to bamboo-planting farmers. The objectives of this work were to evaluate the P loss processes by runoff from bamboo (*P. pubescens*) forest in a year period and the possible factors effecting the nutrient P losses.

MATERIALS AND METHODS

Study area

The study was carried out from 2009 to 2010 in the Siling watershed, Yuhang County, Zhejiang Province, People's Republic of China. The Siling watershed drains into a tributary of Tiaoxi River and ultimately, into Taihu Lake. Bamboo forest covers about 70% of the total hilly and mountainous area of the watershed. It belongs to a typical sub-tropical monsoon climate, with mean temperature of 15.3 to 16.2°C. Average rainfall was 1550 mm; about 70% was concentrated in the period of March to August. The soil is mainly red soil series (Ultsol) according to the soil classification system of China. The experimental plots were established on slightly sloping bamboo land in the watershed.

Field experiment design

In May 2009, three typical bamboo growing areas in the watershed

were chosen for the experiment. Three runoff plots with different fertilizer treatments in each experimental area were established. The plot size (20 m x 15 m) was 300 m^2 with cemented walls surrounding it. The 6 cm thick cemented wall was 50 cm wide with 30 cm inserted into the soil surface layer and 20 cm above the soil surface to isolate it from adjacent plots. At the lower end of the plot, facilities for runoff collection were installed. WatchDog Weather Stations (WatchDog 2700) were also installed near the experimental area to collect meteorological data.

The fertilizer treatments included; no fertilizer application (CK), farmers' fertilizer practice (FFP) and site specific nutrient management (SSNM). The fertilizer NPK used was urea, superphosphate and potassium chloride, respectively. For FFP, according to the local farmers' practice, the fertilizer rate was 465 kg/hm^2 N, 112 kg/hm^2 P_2O_5 and 112 kg/hm^2 K_2O applied by broadcasting three times in February, May and September. Taking into account the indigenous nutrient supply of the soil, reasonable bamboo yield targets and corresponding nutrient demand, nutrient balance and nutrient use efficiency, as well as socio-economic factors, the fertilizer requirement was worked out for SSNM treatment according to the principle of site–specific nutrient management (Wang et al., 2003). The fertilizer rate for SSNM was 207 kg/hm^2 N, 105 kg/hm^2 P_2O_5 and 95 kg/hm^2 K_2O applied two times in February and September. The fertilizers were applied in 20 cm wide and 30 cm depth trenches that were horizontally parallel to each other with 2.5 m interval. The basic soil properties and bamboo growth status in the three experiments area are shown in Table 1.

Water sampling and chemical analysis

At the end of each rain runoff event, the total volume of runoff from each plot was measured and sampled immediately. The samples were stored at 4°C until analysis. Aliquots of runoff samples were filtered (0.45 μm) for dissolved P (DP) determination. The unfiltered runoff samples were used for total P (TP) determination following perchloric acid digestion (Olsen and Sommers, 1982). Particulate P (PP) was calculated as the difference between TP and DP. Bio-available P (BAP) concentration was determined by extraction of 20 ml of unfiltered sample with 180 ml of 0.1 M NaOH for 17 h on an end-over-end shaker (Sharpley et al., 1991). The bio-available particulate P (BPP) was calculated by subtraction of DP from BAP. Suspended sediments of runoff were determined as the difference in weight of 250 ml aliquots of unfiltered and filtered (0.45 μm) runoff samples after evaporating (105°C) to dryness. All the solution P was determined by the colorimetric method of Murphy and Riley (1962). Each measurement was conducted in duplicate.

Statistical analysis

Statistical analyses were performed using the Spss11.0. Comparisons of means were performed using Duncan's student range test at $p < 0.05$.

RESULTS AND DISCUSSION

Phosphorous concentrations and amounts of runoff

In the period from June 2009 to May 2010, 39 runoff events occurred after natural rainfall. Under the treatments of control (CK), site-specific nutrient management (SSNM) and farmers' fertilizer practice (FFP), the runoff loss reached 356, 361 and 342 m^3 /hm^2 and the soil particle loss reached 393, 392 and 442 kg/hm^2,

Table 1. Basic soil characteristics and bamboo growth at Siling watershed experiments in Yuhang, Zhejiang province.

Site	Slope	Aspect	DBH*	Stand density	pH	Organic C	Total N	Olsen-P	Available K
			cm	Bamboo/ha		g/kg	g/kg	mg/kg	mg/kg
P1	31°	22° E by S	9.9	3435	4.9	42.5	1.76	2.5	50.6
P2	31°	13°N by E	10.0	3301	4.9	55.5	3.29	2.7	51.6
P3	31°	13° N by W	10.1	3268	5.0	38.9	2.90	2.5	38.4

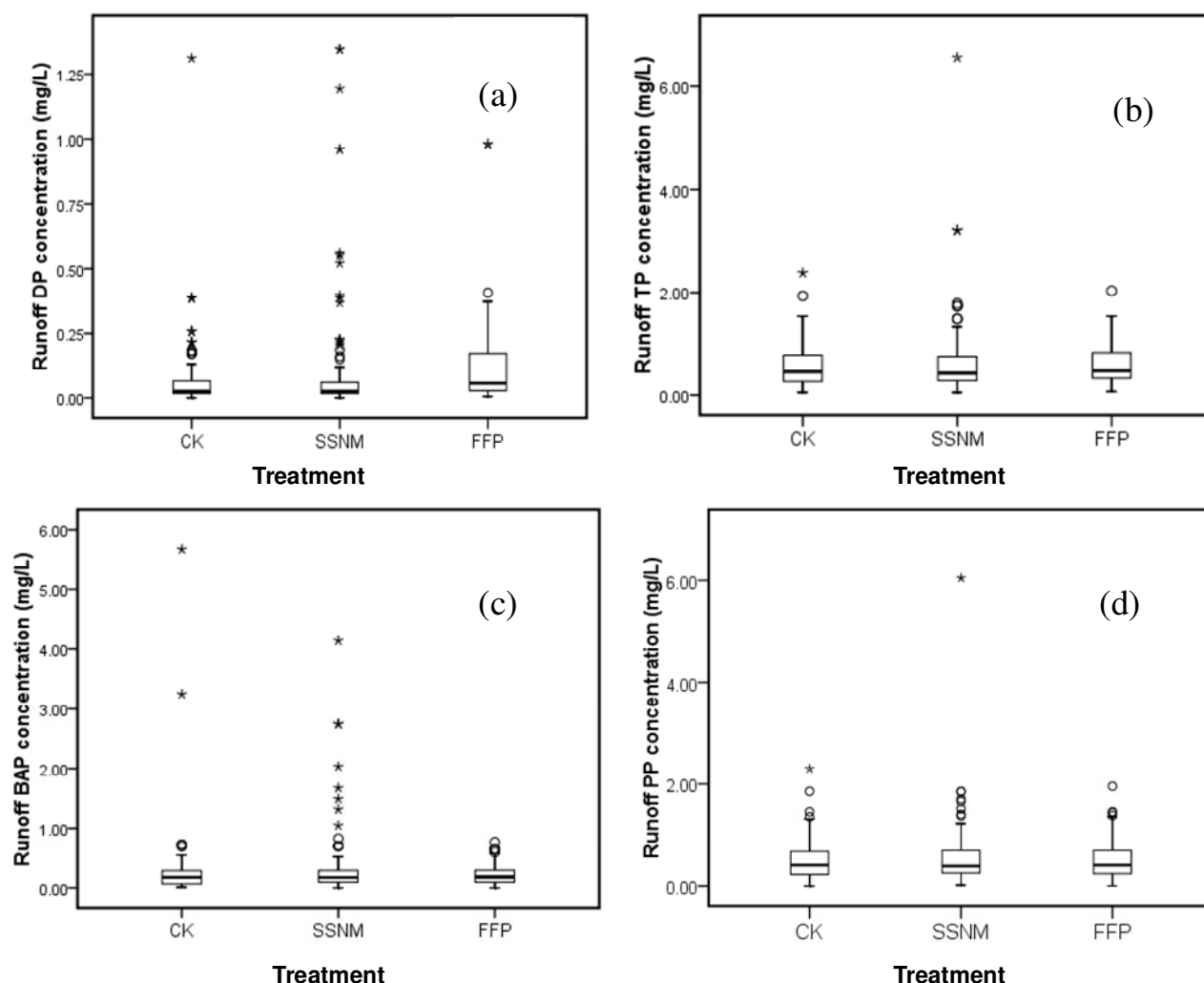*Average diameter at breast height of the bamboo stems.

Figure 1. The concentration of runoff DP (a), TP (b), PP (c) and BAP (d) in different fertilizer treatment under bamboo forest.

respectively. The runoff and soil particle losses were highly correlated with the precipitation during the period (R^2=0.86-0.92). The mean P concentrations of runoff were affected little by management practice in one year (Figure 1). The total P (TP) concentration of runoff ranged from 0.02 to 6.80 mg/l with the average value as 0.60 mg/l, while the particulate P (PP) concentration of runoff ranged from 0.06 to 1.4 mg/l with the average value as 0.44 mg/l. As we know, certain components of PP are readily usable by organisms, while others are more or less completely unavailable. Phosphorus that can be utilized by plants and bacteria is called bio-available phosphorus (BAP). BAP includes nearly all DP and the fraction of PP that is readily usable. The use of TP to estimate eutrophication risk is problematic for management purpose as it overestimates the amount of P that is biologically available to phytoplankton and bacteria. Previous studies have shown that BAP rather

Table 2. Soil loss, runoff volume, and amounts of soluble P (DP), bio-available particulate P(BPP), bio-available P (BAP), particulate P (PP), and total P (TP) from June 2009 to May 2010.

Site	Treatment	soil loss	Runoff	DP	BPP	BAP	PP	TP
		kg ha^{-1}	m^3/ha			g/ha		
P1	CK	396	325	8	49	57	112	120
P2	CK	396	388	11	38	49	141	152
P3	CK	386	353	10	34	44	120	130
P1	SSNM	463	*389*	13	57	70	136	149
P2	SSNM	440	342	10	46	56	122	132
P3	SSNM	289	369	10	41	51	135	145
P1	FFP	429	344	17	44	61	124	141
P2	FFP	438	*346*	11	46	57	134	145
P3	FFP	443	342	11	62	73	146	157
Mean	**CK**	**393 b**	**355 a**	**10 b**	**40 c**	**50 c**	**124 b**	**134 b**
Mean	**SSNM**	**397 b**	**367 a**	**11 b**	**48 b**	**59 b**	**131 a**	**142 a**
Mean	**FFP**	**437 a**	**344 a**	**13 a**	**51 a**	**64 a**	**135 a**	**148 a**

In a column, means followed by the same letters are not significantly different by DMRT at 5% level.
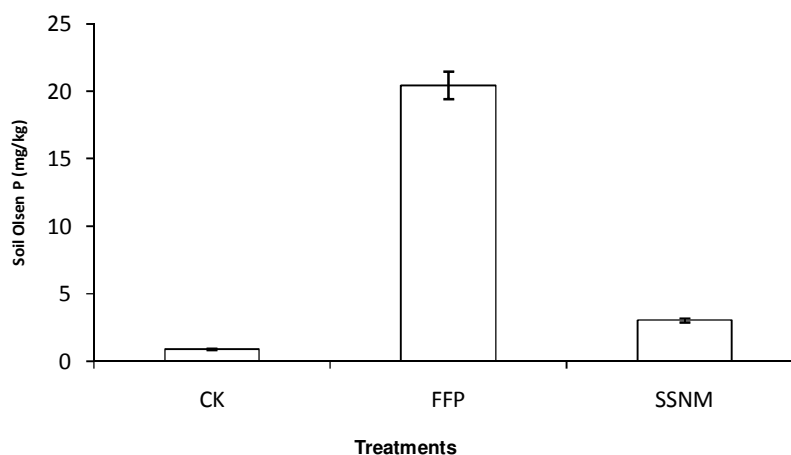
Figure 2. The concentration of Olsen-P in different fertilizer treatment under bamboo forest.

than TP provides the most accurate assessment of water quality conditions in lakes and streams (Butkus et al., 1988; Gerdes and Kunst, 1998). Figure 1 shows the BAP concentration of runoff ranged from 0.05 to 0.5 mg/l with the average value was 0.24 mg/l. Also, all forms of P concentration in runoff from the study varied considerably from rain event to event in one year period. Sharpley (1996) reported that runoff water was considered as degraded if total P exceeds a guideline concentration of 0.10 mg P L^{-1}. According to the Everglaes Forever Act in Florida (EFAF, 1994), concentrations of total P in surface runoff that discharges into the Everglades are mandated to be reduced to a threshold level of 0.05 mg P L^{-1}. Mean concentration of total P in the surface runoff from the bamboo forest we monitored in a year period was 12 times greater than the EFAF threshold and 6 times greater than the Sharpley's guideline level. Of particular importance is the fact that, among the samples, 95% of TP, 90% of BAP and 84% of PP concentrations were more than 0.10 mg/l. The higher DP concentration in FFP treatment (Figure 1) might have resulted in part from broadcast application of fertilizer P. This DP increase emphasizes the need for judicious fertilizer P management of conservation tillage in bamboo forest, which should include subsurface application.

The phosphorus loads by runoff from 39 individual runoff events for all plots were calculated by multiplying P concentration in runoff sample and runoff volume (Table 2). In contrast to DP and BAP, PP and TP for SSNM and FFP were not significantly different. Compared with FFP, the SSNM treatment reduced dissolved phosphorus (DP) loss by 15% and reduced total bioavailable phosphorus (BAP) loss by 8% (Table 2). We also analyzed the soil Olsen P after one year experiment (Figure 2). The higher
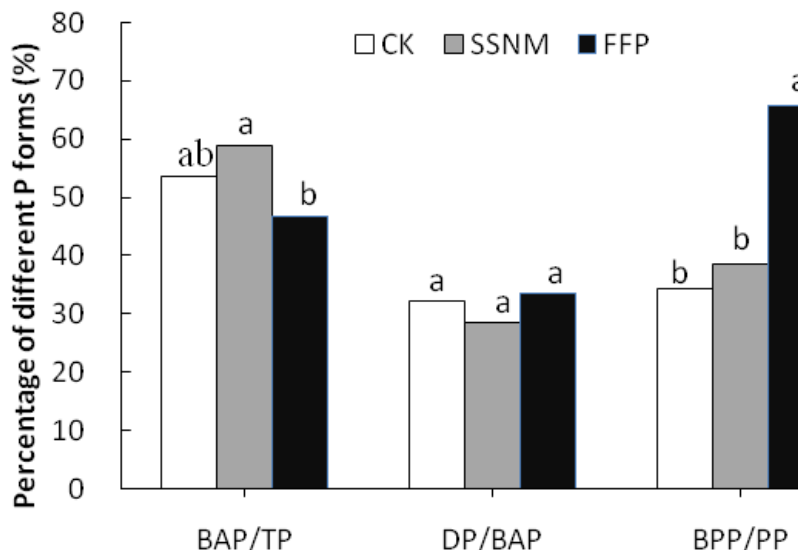
Figure 3. Ratio of BAP to TP, DP to BAP and BPP to PP in different fertilizer treatment under bamboo forest.

soil Olsen-P in FFP than in SSNM was observed. It is worth to note that, positive relationships were observed between the soil Olsen-P and BAP runoff (R^2=0.57*). Also, large part of the particulate P lost in runoff was bio-available P (Figure 3) and fertilizer P application significantly increased the bio-available P loss of bamboo land (Table 2).

Runoff phosphorus and rainfall

On an individual runoff event basis (Table 3), PP bioavailability (BPP) was not significantly (p > 0.05) related to the soil sediment concentration (data not presented), possibly due to the difference in P transport processes from event to event. The amount of PP loss was highly correlated with the soil loss in runoff indicating that the PP transported in the runoff increased with an increase in soil loss of runoff (Figure 4). The correlation coefficient between PP and soil loss in FFP and SSNM treatment was 0.88 and 0.78, respectively.

Single relationships were also used to describe the runoff on TP, BAP, PP and DP (Figure 5). At each rainfall event, there was a significant (p < 0.01) linear increase in runoff TP, BAP, PP and DP with runoff (R^2 ranged from 0.93 to 0.97) indicating that, P transported in runoff increased with surface runoff. We calculated the amounts of rainfall and rainfall intensive through weather stations during the period from June 2009 to May 2010 (Table 3).The largest rainfall happened in August, while the largest rainfall intensive happened in July. Although, there was significant correlation between phosphorous and rainfall, rainfall intensity as well as solar radiation and temperature were not consistently related with P

concentration in runoff (Table 4). In contrast to this study, the concentration of DP, PP and TP was significantly (P < 0.01) greater in runoff with a rainfall intensity of 75 than 50 mm h^{-1} for all the P sources in the Mahantango Creek, observed by Francirose et al. (2007). The relative differences with this study in relation between rainfall intensity and P loss in runoff might have resulted from the fact that, rainfall was applied designedly using a rainfall simulation after P source application by Francirose et al. (2007). A rainfall simulation study could be quite different from natural rainfall conditions, because temporal variations of rainfall intensity and duration, length of time between runoff events would occur during natural conditions. Clearly, there is a need for further information on the long-term effects of meteorological factors on the transport of bio-available P in both soluble and particulate forms in runoff under field conditions as natural rainfall. Similar relationships between runoff BAP loss and runoff TP loss was also observed (Figure 6). Positive relation-ships were observed between phosphorus fractions in surface runoff (Table 4).

Dynamic of runoff phosphorous

The dynamic changes of the DP, TP, BAP losses in one year period under the bamboo field are shown in Figure 7. In the period from June 2009 to May 2010, the largest P losses happened in August followed by July and June. Total P losses in August were about 51% of the total P loss during the period, while DP, BAP and PP losses in August were about 43, 62 and 51% of its total loss, respectively (Figure 7). In addition, the largest rainfall in August observed was 479.8 mm, and then in July and

Table 3. Rainfall characteristics.

| Rainfall event	Date	Rainfall (mm)	Rainfall intensive (mm h^{-1})	Rainfall event	Date	Rainfall (mm)	Rainfall intensive (mm h^{-1})	Rainfall event	Date	Rainfall (mm)	Rainfall intensive (mm h^{-1})
1	2009-06-03	14.5	1.8	14	2009-07-30	73.4	2.3	27	2009-11-21	10.8	0.7
2	2009-06-09	14.5	2.4	15	2009-07-31	21.0	4.2	28	2009-12-11	17.6	0.7
3	2009-06-20	31.2	5.2	16	2009-08-02	21.1	4.2	29	2009-12-16	42.8	1.4
4	2009-06-22	23.1	3.9	17	2009-08-06	73.3	12.2	30	2010-01-22	16.5	0.5
5	2009-06-23	31.0	8.9	18	2009-08-13	298.3	5.3	31	2010-02-08	72.5	0.8
6	2009-06-27	11.0	3.1	19	2009-08-15	19.6	2.3	32	2010-02-22	51.5	7.4
7	20090-6-28	4.0	4.0	20	2009-08-23	31.8	7.1	33	2010-02-28	14.9	1.2
8	2009-07-01	71.1	4.9	21	2009-08-28	19.5	5.6	34	2010-03-11	180.0	4.5
9	2009-07-03	23.8	23.8	22	2009-09-19	112.1	3.0	35	2010-03-18	10.5	1.3
10	2009-07-07	29.8	5.0	23	2009-09-23	14.7	0.9	36	2010-03-25	16.9	0.6
11	2009-07-12	1.1	0.6	24	2009-10-01	45.9	1.7	37	2010-04-16	27.2	0.5
12	2009-07-23	19.9	3.3	25	2009-11-13	129.7	2.6	38	2010-04-22	9.7	0.6
13	2009-07-25	75.6	5.2	26	2009-11-18	50.9	1.4	39	2010-05-23	20.6	0.3
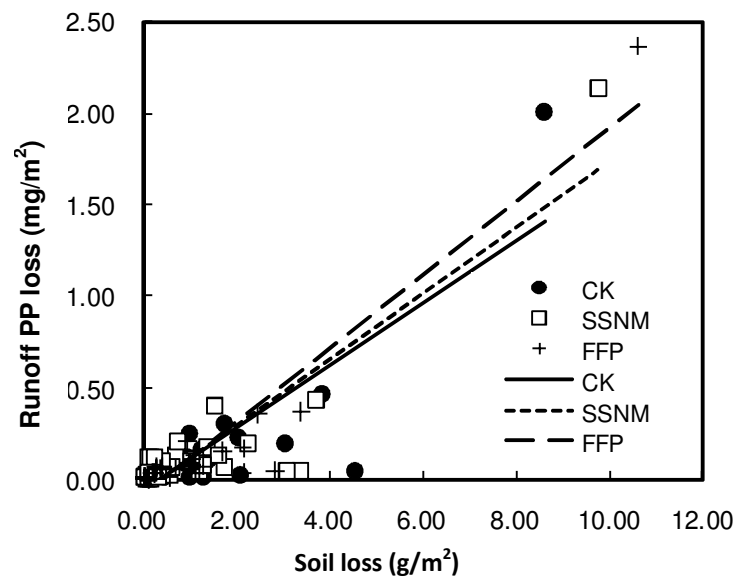
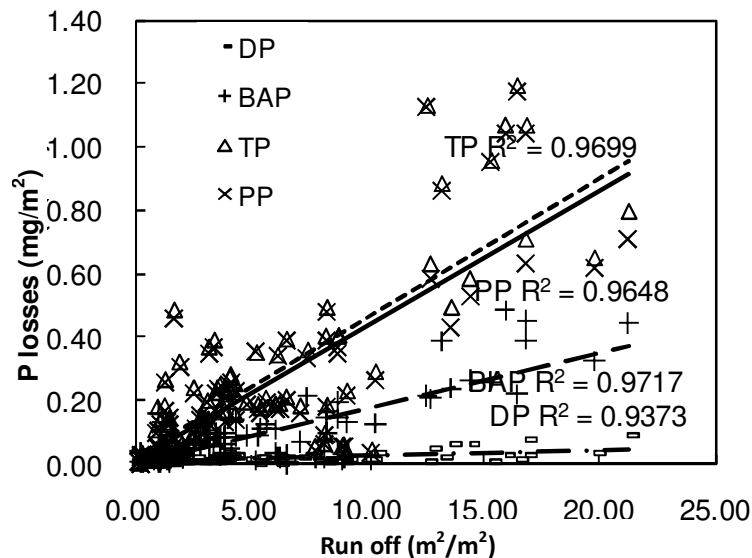**Figure 4.** The relationship between PP loss and soil loss in runoff.

Figure 5. The relationship between P forms loss and runoff.

Table 4. The relationship between concentration of P form (mg/l) and meteorological factors.

Parameter	DP	BAP	TP	PP
DP	1			
BAP	0.99**	1		
TP	0.98**	1.00**	1	
PP	0.98**	1.00**	1.00**	1
Rainfall (mm)	0.95**	0.97**	0.97**	0.97**
Solar radiation (W/m^2)	-0.06	-0.1	-0.13	-0.13
Humid (%)	0.26	0.24	0.22	0.22
Air temperature (°C)	0.18	0.16	0.14	0.13
Rain intensive (mm/min)	0.01	0.04	0.06	0.06
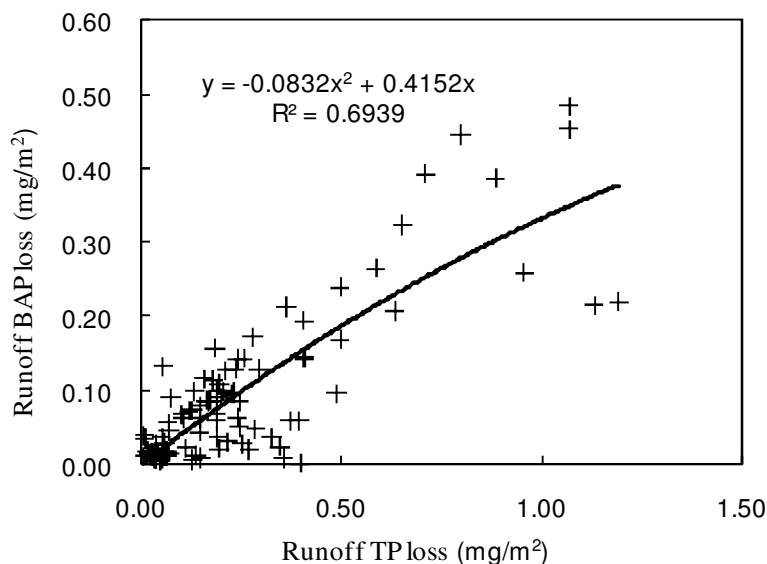
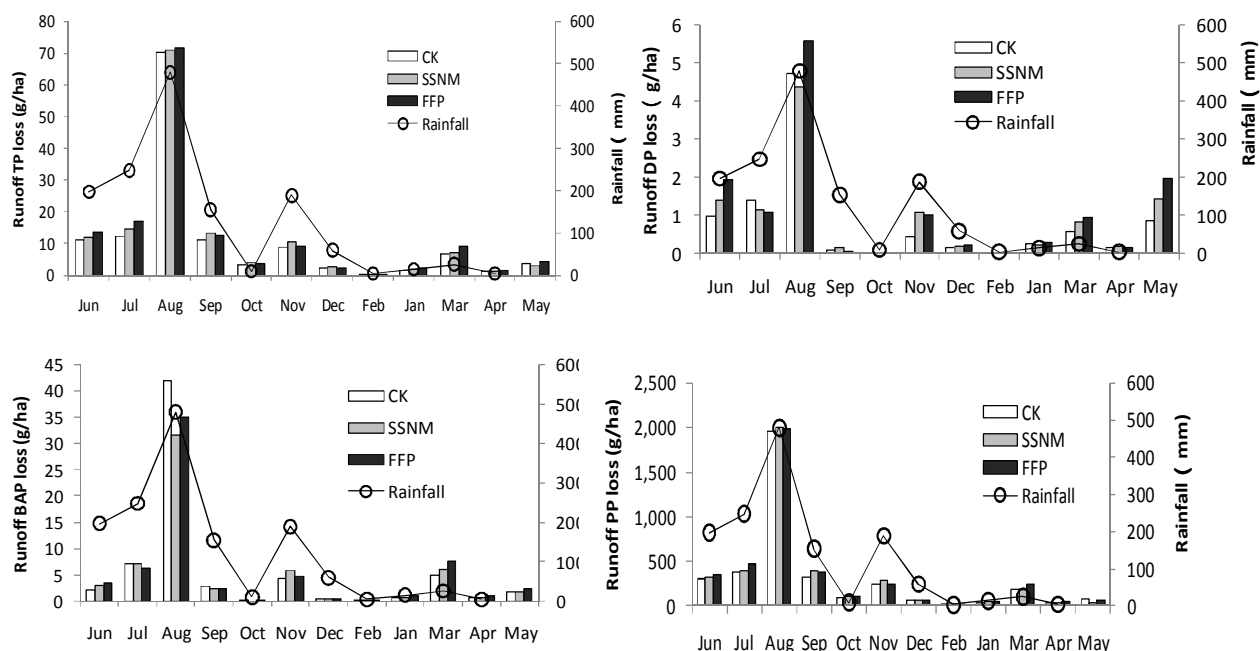**Figure 6.** The relationship between BAP loss and TP loss in runoff.

Fig.7. Dynamic of the DP, TP, BAP losses from June 2009 to May 2010 under the bamboo field.

June the rainfall were 248 and 196.8 mm, respectively. It suggested that, phosphorus losses were highly correlated with rainfall as Table 3 also indicated. Therefore, the main factor influencing soil P loss in the bamboo field was precipitation.

Particulate P (PP) is a long-term source of potentially bio-available P in lakes (Andrew et al., 1992). Various physical, chemical and biological processes influence the bioavailability of this P fraction. The losses of PP were about 92, 93 and 91% of the total P losses in the CK, SSNM and FFP treatment, respectively, indicating that particulate associated with P was the predominant form exported from bamboo forest. This result was consistent with many studies that indicated that PP was the predominant form exported from agricultural land (Sharply et al., 1994; Carpenter et al, 1998; Hart et al., 2004).

Conclusions

During the period of this study, the runoff loss reached 356, 361 and 342 m^3 /hm^2 and the soil particle loss reached 393, 392 and 442 kg/hm^2, respectively, under the treatments of control (CK), site-specific nutrient management (SSNM) and farmers' fertilizer practice (FFP). The total P loss in CK, SSNM and FFP reached 132, 141 and 148 g/ha, respectively, indicating that the application of P fertilizer to the plots of bamboo forest increased P loads in surface runoff. Compared with FFP, SSNM decreased TP loss by 5%, DP loss by 15% and

BAP loss by 8%.

The bioavailability of TP (20 to 85% as BAP) and PP (9 to 65% as BPP) varied appreciably with rain events. It will be necessary to determine the BAP transport in runoff, as both DP and BPP, to more reliably evaluate the biological response of a water body to forest surface runoff. The percentage of PP was about 90% of TP in samples from three treatments. Therefore, particulate P was the dominant form of the total P in the runoff from bamboo forest.

The average total phosphorus (TP) concentration of the runoff was 0.60 mg/l, while the average bio-available phosphorus (BAP) concentration was 0.24 mg/l. The results of this study provided evidence that P losses from bamboo forest would potentially contributes to water eutrophication of a receiving water body.

Significant correlations existed between phosphorus losses with both rainfall and runoff. The greatest potential risk of P loss by runoff might occur in August, and then in July and June because this period has the largest rainfall in a year. Since the main factor influencing soil P loss is precipitation, it will be necessary to control runoff P concentration to decrease P exported from bamboo forest by relevant measures, such as conservation tillage and deeper fertilizer P application.

ACKNOWLEDGEMENTS

REFERENCES

Andrew NS, Smith SJ, Jones OR, Berg WA, Coleman GA (1992). The transport of bioavailable phosphorus in agricultural runoff. J. Environ. Qual., 21: 30-35.

Bertol I, Engel FL, Mafra AL, Bertol OJ, Ritter SR (2007). Phosphorus, potassium and organic carbon concentrations in runoff water and sediments under different soil tillage systems during soybean growth. Soil Till. Res., 94: 142-150.

Boesch DF, Brinsfield RB, Magnien RE (2001). Chesapeake Bay eutrophication: scientific understanding, ecosystem restoration, and challenges for agriculture. J. Environ. Qual., 30: 303-320.

Butkus SR, Welch EB, Horner RR, Spyridakis DE (1998). Lake response modeling using biologically available phosphorus. J. Water Pollut. Control Fed., 60: 1663-1669.

Carpenter SR, Caraco NF, Correll KL, Howarth RW, Sharplye AN, Smith VH (1998). Nonpoint pollution of floodwaters with phosphorus and nitrogen. Ecol. Appl., 8(3): 559-68.

Chen H (2001). Restoration project of the ecosystem in Tai Lake. Resour. Environ. Yangtze Basin, 10(2): 173-178 (in Chinese).

Ellison ME, Brett MT (2006). Particulate phosphorus bioavailability as a function of stream flow and land cover. Water Res., 40: 1258-1268.

Everglades Forever Act in Florida (EFAF) (1994). Anon. Florida Statutes, 20: 94-115

Francirose S, Sharpley A, Prochnow LI (2007). Rainfall intensity and phosphorus source effects on phosphorus transport in surface runoff from soil trays. Sci. Total Environ., 373: 334-343.

Gerdes P, Kunst S (1998). Bioavailability of phosphorus as a tool for efficient P reduction schemes. Water Sci. Technol., 37: 241-247.

Han JG, Li ZB, Li P, Tian JL (2010). Nitrogen and phosphorous concentrations in runoff from a purple soil in an agricultural watershed. Agri. Water Manage., 97: 757-762.

Hart RM, Quin BF, Long NM (2004). Phosphorus runoff from agricultural land and directr fertilizer effects: A review. J. Environ. Qual., 33: 1954-1972.

Hatch Lk, Reuter JE, Goldman GR (1999). Relative importance of stream-borne particulate and dissolved phosphorus fractions to Lake Tahoe phytoplankton. Can. J. Fish. Aquat. Sci., 56: 2331-2339.

Murphy J, Riley JP (1962). A modifield single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta, 27: 31-36.

Olsen SR, Sommers LE (1982). Phosphorus. In A L Page et al. (ed) Methods of soil analysis. Part. 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI, pp. 403-429.

Peters RH (1981). Phosphorus availability in lake Memphremagog and its tributaries. Limnol. Oceanogr., 26: 1150-1161.

Sharpley A, Daniel TC, Sims JT, Pote DH (1996). Determining environmentally sound soil phosphorus levels. J. Soil Water Conser., 51: 160-166.

Sharpley AN, Smith SJ, Jone OR, Berg WA, Coleman GA (1992). The transport of bioavailable phosphorus in agricultural runoff. J. Environ. Qual., 21: 30-35.

Sharpley AN, Troeger WW, Smith SJ (1991). The measurement of bioavailable phosphorus in agricultural runoff. J. Environ. Qual., 20: 235-238.

Sharpley N, Chapra SC, Wodepohl R, Sims JT, Daniel TC (1994). Managing agriculture phosphorus protection of floodwater: Issues and options. J. Environ. Qual., 23: 437-451.

Shen H, Cao ZH, Xu ZH (2000). Effects of fertilization on different carbon fractions and carbon management index in soils. Acta Pedol. Sin., 37: 166-173 (in Chinese).

Uusitalo R, Turtola E, KauppilaT, Lilja T (2001). Particulate phosphorus and sedimentin surface runoff and drain flow from clayey soils. J. Environ. Qual., 30: 589-595.

Wang GH, Zhang QC, Huang CY (2003). SSNM-A new approach to increasing fertilizer N use efficiency and reducing N loss from rice fields. J. Zhejiang Univ. (Agric. Life Sci.), 29(1): 67-70.

Wang K, Zhang Z, Zhu Y, Wang GH, Christie P (2001). Surface water phosphorus dynamics in rice fields receiving fertilizer and manure phosphorus. Chemosphere, 42: 209-214.

Yang JL, Zhang GL, Shi XZ, Wang HJ, Cao ZH (2009). Dynamic changes of nitrogen and phosphorus losses in ephemeral runoff processes by typical storm events in Sichun Basin, Southwest China. Soil Till. Res., 105: 292-299.

Yli-Halla M, Hartikainen H, Ekholm P, Turtola E, Puustinen M, Kallio K (1995). Assessment of soluble phosphorus load in surface runoff by soil analyses. Agric. Ecosyst. Environ., 56: 53-62.

Zhang W, Wang X, Jiang Y, Zhou X (2001). Effect of emission control on water quality of the Taihu Lake. Rural Eco-Environ., 17(1): 44-47 (in Chinese).

Zhang YX, Zhang ZQ, Zhang XJ, Liu QY, Jin J (2001). Population dynamics of phytophagous and predatory mites (Acari: Tetranychidae, Eriophyidae, Phytoseiidae) on bamboo plants in Fujian, China. Exp. Appl. Acarol., 25: 383-391.

Zhang Z, Zhang JY, He R, Wang ZD, Zhu YM (2007). Phosphorus interception in floodwater of paddy field during the rice growing season in TaiHu Lade Basin. Environ. Pollut., 145: 425-433.

Zhu YM (1995). Fertilizers and eutroophiation of rivers and lakes fertilizer application and environment. Chinese science and technology press. Beijing.