The Effect of Farmland Management on Soil Phosphorus Runoff in Taihu Basin*

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Abstract:

Phosphorus fertilizer levels related to the soil phosphorus loss directly. The studies assessed the effects of different phosphorus (P) fertilizer levels (0, 30, 75 and 150 kg/hm2) on characteristics and forms of soil P loss in runoff by artificial rainfall simulations. N, P and K fertilizers were used as basal fertilizers by surface broadcast. Each treatment had three replicates of rectangular 1 × 2 m with a random block design. Slope gradient was 7% and vegetable coverage density was uniform. Two day after fertilizer application to plots, rainfall was applied using the rainfall simulator at 1.67 mm/min (100 mm/h). It lasted for 30 min after effective runoff generation. Each sample was collected on a 5 min interval for the full 30 min of the runoff event. The results indicated that P concentrations of different forms in runoff were high at the early stage, then gradually decreased with time and finally reached a comparative steady stage after about 20 min of runoff generation. At the entire rainfall-runoff process, Particulate phosphorus (PP) occupied 72%~87% of total phosphorus (TP). This showed PP was main loss form of soil P. Flow-weighted mean concentrations of soil P loss at different P fertilizer levels followed the order from large to small: 150 kg/hm2 >75 kg/hm2 >30 kg/hm2 > treatment (0 kg/hm2). It was found that the runoff losses of dissolved phosphorus(DP), dissolved inorganic phosphorus(DIP), PP and TP in runoff significantly increased in linear function with P fertilizer increase at different P fertilizer levels (r2=0.99, 0.98, 0.89 and 0.93).

Key Words: Fertilizer, Rainfall simulation, Soil phosphorus loss, Surface runoff

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I. INTRODUCTION

Phosphorus (P) in surface runoff from agricultural lands is non-point sources of pollution and can accelerate eutrophication of surface waters (Daniel *et al.*, 1994, 1998; Foy and Withers, 1995). Long-term applications of P in chemical fertilizers have resulted in elevated levels of soil P in many locations in the United States. Soils high in P have aggravated water pollution problems in many areas (Lovejoy *et al.*, 1997).

A strong relationship exists between the rates of P fertilizer application (PFA) and the concentration of TP, dissolved reactive phosphorus (DRP), and PP in runoff (Sharpley *et al.*, 1993; Pote *et al.*, 1999; Cox and Hendricks, 2000).

There is an increasing amount of research on direct fertilizer effects on P runoff from agricultural systems that were mainly pastoral (Nash and Halliwell, 1999; Hart *et al.*, 2004). Fertilizer addition led to a significant increase in DIP and PP concentration in surface runoff in the first week following fertilizer application (Sharpley and Syers，1976，1979a，1979b，1983；Gillingham *et al.*，1997；Olness *et al.*, 1980). However, some studies on runoff from cultivated land indicate that most P losses are associated with the PP fraction (Zhang *et al.*，2003).

At present, most published work deals with P runoff loss from pastures, paddy field and grassland, rather than from cultivated land (especially from vegetable fields). Therefore, the potential influence of vegetable fields with high-rich P from P fertilizer on P runoff loss has received relatively little study. But it is of practical meaning to investigate characteristics of soil P loss at different PFA rates, which is important for discussing the mechanism of soil high-rich P discharging into water body and providing corresponding control measures. The objectives of this study were to (1) discuss the temporal trends of DP, DIP, PP and TP concentrations with rainfall time during the rainfall-runoff event; (2) evaluate the effects of PFA rates on DP, DIP, PP and TP concentrations during rainfall simulations in vegetable plots; (3) determine the relationships between DP, DIP, PP and TP losses and Soil Olsen-P.

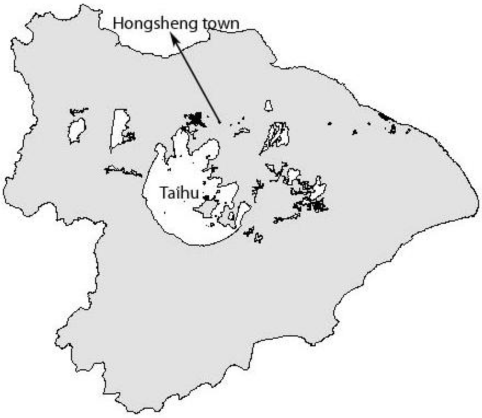


Figure I. The location of experiment site in Taihu Basin

II. MATERIALS AND METHODS

2.1 Field experiment site

Experiments of field runoff plots on 1 by 2 m were conducted in vegetable fields of Hongsheng town near Wuxi city, which was in the typical region of Taihu watershed from March to May, 2006. Experiment site is located near the Taihu, lying between 31°31′N and 120°30′E (Fig.1). The average annual rainfall is from 1200 mm. Mean annual air temperature is 15.5 ℃. Owing to preponderant geography location, lots of vegetable and covered vegetable plots have been planted in the town to supply vegetable for Wuxi city. Vegetable plots are high-rich P soils because lot fertilizers are amended into the soil with longer plantation time. It had more than 10 years for vegetable plantation. Basic physical and chemical properties of experiment soils were showed in Table I.

Table I Basic physical and chemical properties of the experiment site

Soil texture	**Bulk gravity (g/cm3)**	**pH**	**Organic matter (g/kg)**	**Total P (g/kg)**	**Olsen-P (mg/kg)**
Silt loam	1.23	5.85	29.75	1.23	174.47

2.2 Experiment design

Four PFA rates (treatments) 0(P0), 30 (P30), 75 (P75) and 150 (P150) kg/hm^2 were adapted. Rates of inorganic N fertilizer (Carbamide) and K fertilizer (Potassium Chloride) were 200 kg/hm^2 and 100 kg/hm^2,respectively. N, P and K fertilizers were used as basal fertilizers by surface broadcast. Each treatment had three replicates of rectangular 1 × 2 m^2 with a random block design. Slope gradient was 7% and vegetable coverage density was uniform. Plots were isolated on the upper three sides by PVC boards driven 15 cm into the soil and extending 10 cm above the soil. At the lower end of each plot, a gutter was inserted 5 cm into the soil with the upper edge level with the soil surface. The gutter was equipped with a canopy to exclude direct input of rainfall.

The portable artificial rainfall simulator of BX-1 type was produced by Institute of Soil and Water Conservation, Chinese Academy of Science (Chen et al.,2000). The instrument was composed of nozzle, driver, dynamical and providing-water systems. This rainfall simulator can be set to any preselected rainfall intensity, ranging from 10 to 332 mm/h, by programming the aperture of the nozzles. It had a height of 6 m above the soil surface and a coefficient of uniformity of > 80% within the 3 × 5 m^2 area. Two day after fertilizer application to plots, rainfall was applied using the rainfall simulator at 1.67 mm/min (100 mm/h). It lasted for 30 min after effective runoff generation.

2.2.1 Sampling and laboratory analysis

Each sample was collected on a 5 min interval for the full 30 min of the runoff event. Runoff volumes were measured and then samples were stirred uniformity. 500 ml of each sample was taken to measure concentration of different P forms. Runoff water samples were stored at 4 ℃ until analyzed. During the simulated rainfall, rainwater was collected as blank contrast.

Measured items included TP, DP and DIP. TP was determined by ammonium persulfate and sulfuric acid digestion on aliquots of unfiltered runoff water. DP was filtered through a 0.45 μm Millipore and determined with ascorbic acid method. DIP was determined by molybdenum blue colorimetry. PP was calculated by subtraction between TP and DP.

Soil samples included following items: pH (1:1 meter); Total phosphorus ($HClO_4$-H_2SO_4 digestion, molybdenum blue colorimetry); Olsen-P ($NaHCO_3$, molybdenum blue colorimetry); Organic matter (K_2CrO_7-H_2SO_4, oxidation); Bulk specific gravity (loop reamer); Soil containing water content (drying method). Detailed methods were described in “Analytical handbook of soil agricultural chemistry”(Lao, 1988).

2.2.2 P flow-weighted mean concentrations of different forms

$$\overline{C} = \left(\sum_{i=1}^{n-1} \frac{Q_i C_i + Q_{i+1} C_{i+1}}{2} \times \Delta t \right) / \left(\sum_{i=1}^{n-1} \frac{Q_i + Q_{i+1}}{2} \times \Delta t \right) \qquad (1)$$

In formula (1), $\overline{C}$ is P flow-weighted mean concentrations of different forms in runoff water, mg/L ; Q_i , Q_{i+1} represents runoff volume at i and $i+1$ time, ml/min; C_i , C_{i+1} represents P form concentration at i and $i+1$ time, mg/L; Δt represents time interval, min; n represents the amount of samples.

2.2.3 Statistical analysis

Duncan’s New Multiple Range Test (DMRT) was employed to assess differences between the treatment means. The effects of PFA rates on P concentration were declared as significant at 0.05 and 0.01 probability levels. The capital and small letters indicate significant at 0.01 and 0.05 probability levels, respectively. All statistical analyses were performed with SAS software (SAS Institute, 1995).

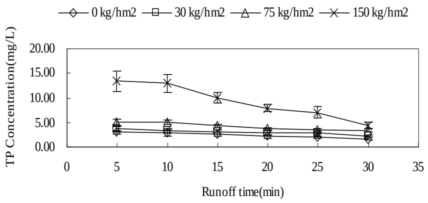
III. RESULTS AND DISCUSSIONS

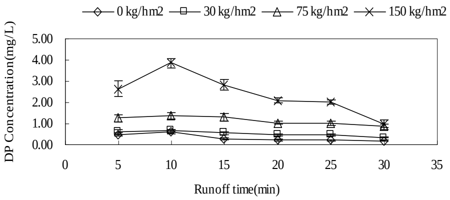
3.1. Properties of different P forms in runoff at different PFA levels

During the 30 min effective rainfall-runoff event, although dynamic changes of different P forms in runoff at different PFA levels showed some differences, general changes followed the consistent trends. TP concentrations versus runoff time at different PFA levels followed the order: 150 kg/hm^2 >75 kg/hm^2 >30 kg/hm^2 > 0 (unfertilized). This showed that the amount of fertilizer application had an obvious effect on TP concentration in runoff. When the amount of PFA increased from 75 to 150 kg/hm^2, the concentration of TP increased by 2.06 times. Therefore, TP concentration multiplied by increase of phosphorus fertilizer. The result was consistent with other research findings that there was a linear relationship between TP concentrations in runoff and PFA levels. In experiment plots, when PFA were at unfertilized and 30 kg/hm^2 levels, TP concentration in 30 min runoff decreased respectively from 2.97, 3.56 to 1.59, 2.17mg/L. The least TP concentration exceeded greatly the limit of surface water eutrophication(0.02 mg/L). Thus soil P loss in runoff in vegetable plots must be paid enough attention.

PP concentrations versus runoff time at different PFA levels followed the order: 150 kg/hm^2 >75 kg/hm^2 >30 kg/hm^2 > 0 (unfertilized), which was the same result of TP concentration in runoff. This was because PP concentration was main loss form and accounted for 70%~90% of TP. PP concentration respectively increased by 1.21 times from 30 to 75 kg/hm^2, and 2.09 times from 75 to 150 kg/hm^2, which showed PP concentration evidently increased with PFA. When PP was released into surface water, it would become potential inner pollution source of water eutrophication.

At different PFA levels, the trend of DP concentration was the same as the trend of TP and PP concentration. When PFA levels were respectively 150 and 75 kg/hm^2, DP concentration were correspondingly 0.97~3.83 mg/L and 0.83~1.35 mg/L, which greatly exceeded unfertilized treatment between 0.17~0.47 mg/L. Therefore, PFA could greatly accelerate DP loss with runoff. The change trend of DIP concentration with runoff-time was consistent with DP concentration at different PFA levels. During the 30 min effective rainfall-runoff event, DIP concentration at 150 kg/hm^2 was between 0.76 and 2.02 mg/L which showed greater decline than other treatments. DIP concentration at 150 kg/hm^2 was higher than other treatments. DIP concentration was main loss form of DP (58%~77% of DP) and an inorganic phosphate which could be directly used by biology. During whole the rainfall, least concentration of DIP was 0.11 mg/L, which was observably beyond watchful concentration for eutrophication (0.02 mg/L).The result showed the potential effect of DIP on surface water pollution was paid enough attention.





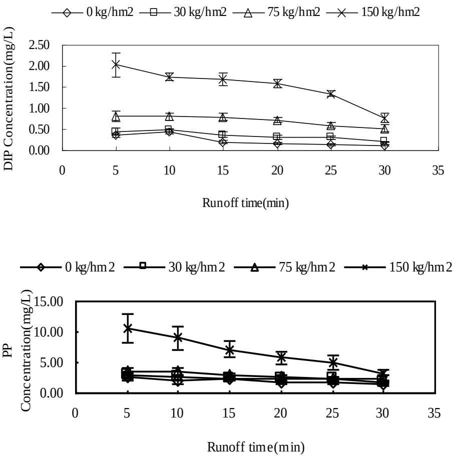


Fig.2 Characteristics of TP, DP, DIP and PP loss with runoff at different PFA levels

3.2. P flow-weighted mean concentrations at different PFA levels

According to the formula (1), P flow-weighted mean concentrations of different forms were calculated during 30 min effective rainfall-runoff (Fig. III).As illustrated in Fig.3, DP and PP concentration distinctly increased with PFA. At unfertilized level, flow-weighted mean concentration of DP and TP was respectively 0.28 and 2.23 mg/L, and PP accounted for 87% of TP. When PFA levels were 30, 75 and 150 kg/hm^2, flow-weighted mean concentration of DP was respectively 1.68, 3.87 and 7.65 times higher than unfertilized treatment, flow-weighted mean concentration of PP was respectively 1.19, 1.44 and 3.00 times higher than unfertilized treatment. Therefore, PFA levels could accelerate DP and PP loss in runoff, especially DP loss. The result accorded with other researchers (Zhang *et al.*, 2003; Sharpley *et al.*, 1993). However, conflicting information exists that there was no obvious relationships between fertilizer application and DP concentration (Yan *et al.*, 1999). This may be because mechanism of phosphorus cycle is different from mechanism of vegetable fields. The different results mean that further researches should be done.

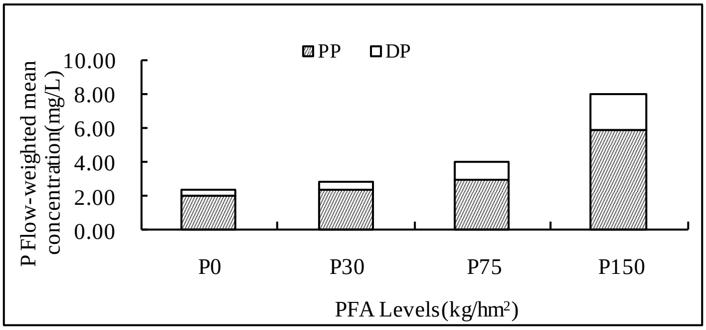


Figure 3. P Flow-weighted mean concentration of DP and PP at different PFA levels

3.3. P loss of different forms in runoff at different PFA levels

During 30 min effective rainfall-runoff event, different PFA rates had a significant effect on P loss of different forms. TP loss at different PFA rates followed the order: 150 kg/hm^2 >75 kg/hm^2 > 30 kg/hm^2 > unfertilized. Therefore, TP loss significantly increased with PFA rates. Because PP loss accounted for 72% to 87% of TP, its loss at different PFA rates was similar to trends of TP loss. Analysis of variance by Duncan's New Multiple Range Test (DMRT) showed that effects of different PFA rates on TP and PP loss were extreme significant (p < 0.01)(Table II).

Although the orders of DP and DIP loss at different PFA rates were same as those of TP and PP loss, but DP and DIP loss significantly increased with PFA rates than TP and PP loss. As illustrated in Table 2, DP and DIP losses of unfertilized treatment were respectively 11.15 g/hm^2 and 7.85 g/hm^2. Compared between different rates of 150, 75, 30 kg/hm^2 and unfertilized plots, DP losses were respectively 7.62 times, 3.68 times and 1.71 times. And DIP loss respectively 7.22 times, 3.26 times and 1.62 times. The majority of variations in DP loss were conducted by change of DIP loss because DIP accounted for 62% to 70% of DP. Analysis of variance showed that DP and DIP loss had extreme significant difference at rates of 0, 30, 75and 150 kg/hm^2.

TABLE II PHOSPHORUS RUNOFF LOSS OF DIFFERENT FORMS AT DIFFERENT P LEVELS

	Phosphorus runoff loss(g/hm2)				**Percent of TP(%)**		**Percent of DP(%)**
P fertilizer(kg/hm2)	***TP***	***DP***	***DIP***	***PP***	***DP***	***PP***	***DIP***
0	88.44Dd	11.15Cc	7.85Cc	77.30Dd	13	87	70
30	114.21Cc	19.05Bb	12.70Bb	95.15Cc	17	83	67
75	148.70Bb	41.04Aa	25.60Aa	107.65Bb	28	72	62
150	326.15Aa	84.95Aa	56.65Aa	241.15Aa	26	74	67

Note: The capital and small letters indicate significant at 0.01 and 0.05 probability levels, respectively

DP, DIP, PP and TP loss significantly increased with PFA increase at different PFA treatments(0, 30, 75 and 150 kg/hm^2). There was a significant linear relationship between TP and PP loss and PFA increase (r^2=0.93 and r^2=0.89), an extreme significant linear relationship between DP and DIP loss and PFA increase (r^2=0.99 and r^2=0.98). Our results were similar to other researches (Sharpley *et al.*, 1976; Olness *et al.*, 1980; Zhao *et al.*,2005). However Wang *et al.* (2004) compared TP and PP loss in wheat-paddy rotation following PFA at 0, 30, 70, 150 and 300 kg/hm^2 and found that TP and PP loss had no significant increase (except at 300 kg/hm^2). The reason may be that the mechanism of soil P loss from paddy fields was different from that from high-rich P vegetable fields.

3.4. Relationships between soil Olsen-P and P loss in surface runoff at different PFA levels

Soil Olsen-P content was up to 174.47 mg/kg in experiment site, which had exceeded the feasible level of plant growth (Olsen-P, Bray-P respective is 25 and 30 mg/kg). If more P fertilizer will be added in experiment site, it has no obvious increase production, but more P is accumulated into the soil. Immobility capacity for soil P is weakened along with high soil Olsen-P content, which showed dissociative PO_4^{3-} concentration gradually increased. The trend increased the risk of soil P transferring into surface water.

Soil physical and chemical properties produced a series of changes along with PFA increase. When PFA levels were 0 and 150 kg/hm^2, the content of soil organic matter and total phosphorus respectively increased from 29.75 to 33.75 g/kg, from 1.23 to 1.49 g/kg. Along with fertilizer increase, Olsen-P content had obvious change and increased from 174.47 to 240.68 mg/kg, which showed soil Olsen-P content significantly increased with fertilizer application.

By analyzing the relationships between soil surface Olsen-P content and TP, DP, PP in runoff (Table III), it was indicated that there was an extreme significant or significant linear relationship(r^2 =0.99, 0.85, 0.86 and 0.98). Therefore soil Olsen-P content could predict the potential effect of soil P loss on surface water quality in some extent.

TABLE III CORRELATION COEFFICIENTS BETWEEN OLSEN-P IN SOILS AND P IN SURFACE RUNOFF

Soil Olsen-P	**Phosphorus in surface runoff**			
	TP	***DP***	***DIP***	***PP***
Related coefficient	0.99***	0.85*	0.86*	0.98***

Note: *p < 0.05; **p < 0.01; ***p < 0.001.

IV. CONCLUSIONS

The results showed P fertilizer addition induced a significant increase in DP, PP and TP concentrations in surface runoff following fertilizer application. There was an extreme significant linear relationship between DP, DIP, PP, TP in runoff and fertilizer levels. During 30 min effective rainfall-runoff event, P loss of different forms mainly happened in the first week following fertilizer application. So farmers should avoid that fertilizer application and rainfall occur simultaneously. Additional research was conducted in vegetable fields to further assess the relationships between different P runoff loss and soil Olsen-P content. There were significant relationships between DP, DIP, PP, TP loss in runoff and soil Olsen-P content. Therefore, soil Olsen-P content could predict potential risk of P loss in runoff. Thus, vegetable fields in Taihu watershed are larger contributor of water phosphorous. Enough attention must be paid to more fertilizer amended into vegetable fields to pursuing vegetable production.

This study will provide useful reference to farm management and treatment of water environment in relevant regions. The research is beneficial to assess soil P loss from vegetable fields at a large scale. But in the experiment, DP and DIP concentrations from different plots were a little higher. This may be attributed to following reasons: 1) Soil Olsen-P was higher in vegetable fields of Taihu watershed; 2) Validity of soil P was higher because soil pH was 5.85,which was between 5.50 and 7.00; 3) The experiment conditions of presented results were that rainfall occurred only two day after fertilizer application to the plots, so DP was main P form in soil.

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