EC AGRICULTURE
Research Article

Nitrogen and Phosphorus Losses Driven via Surface Runoff from Rice fields in Eastern China

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Received: November 30, 2018; **Published:** December 29, 2018

Abstract

Rice is one of the main food crops in China. However, the high fertilization and low utilization in main rice producing areas cause high nitrogen and phosphorus surface runoff inputs into water bodies, with concomitant impacts on water quality. Four representative paddy rice fields in Anhui province, China, were selected from 2008 to 2012 for quantitative monitoring and calculation of runoff loss of nitrogen and phosphorus under fertilized conditions using the runoff pool method. The results show that the annual mean surface runoff in the rice fields is 2189 m^3/ha. In fertilized applications, the annual mean runoff losses of total nitrogen and total phosphorus in the rice fields are 6.0 kg/ha and 0.8 kg/ha, respectively. The mean runoff loss rate of nitrogen and phosphorus fertilizer is 1.4% and 0.7% respectively.72.9% of the nitrogen lost through the runoff is in the forms of nitrate nitrogen and ammonium nitrogen, and 56.8% of the phosphorus is lost in the form of soluble phosphorus. We conclude with some strategies on how to reduce runoff loss of nitrogen and phosphorus in rice fields.

Keywords: *Rice Rotation; Nitrogen Loss; Phosphorus Loss; Runoff; Fertilization*

Introduction

Rice is one of the three major food crops in China, with 30 million hectares in China, accounting for 19% of global rice hectares. Anhui province is located in the southeast of China between latitude 29°41′ - 34°38′, across the three water systems of the Huai River, Yangtze River and Xin'an River, with a warm temperate zone and subtropical zone transition climate, which is favorable for rice production. As one of the key rice planting provinces in China, Anhui's rice area has the characteristics of both southern rice area and northern rice area, with numerous varieties including early, middle, late, non-glutinous, rough non-glutinous, glutinous [1]. The rice sowing area in Anhui accounts for 33.8% of provincial grain sowing area, and the rice yield accounts for 45.8% of total food yield in the whole province [2]. Rice is the staple food for 70% of Anhui's population, and rice production holds a crucial position in agricultural production in Anhui and China [3]. Non-glutinous rice is the most widely type in Anhui, with low production costs and high profit margins, and Anhui is an important commercial rice area in China [1].

However, the main way of fertilization is farmer's conventional fertilization in the province, the amount of fertilizer application in the main producing areas is high. The mean utilization rate of agricultural fertilization is only 30% - 35% [4,5]. This leads to substantial loss of nitrogen and phosphorus via surface runoff from rice fields resulting in low fertilizer utilization. And the loss of nitrogen and phosphorus in the field is one of the important causes of water eutrophication [6,7]. Therefore, the research on the mechanisms for runoff loss of nitrogen and phosphorus in rice fields of Anhui has important the oretical meaning and practical value to improving fertilizer utilization rate, reducing agricultural non-point source pollution and controlling water eutrophication from the source [8-10].

Materials and Methods

Overview on the monitoring sites

Four monitoring sites (four experiment fields) are set respectively in Langya District of Chuzhou (118°18′38″E, 32°21′53″N), Chaohu in Hefei (117°37′42″E, 31°40′11″N), Tongcheng in Anqing (117°2′48″E, 30°55′29″N) and Susong County (116°7′36″E, 30°8′46″N). The location in Google Maps is shown in figure 1 (Please indicate the sampling points in a map (Adapted from google earth). The four sites were selected, not only because they represent the different cropping systems and major crops in the southern, central and northern parts of the Anhui province, but also to cover different levels of precipitation. The soil types at the four monitoring sites are Typic Endoaquepts. Annual precipitation and major soil characteristics of the cultivated layer (0 - 20 cm) at the monitoring sites are given in table 1. Organic matter content was determined by The Kjeldahl method. Nitrate nitrogen was determined by ultraviolet spectrophotometry, ammonium nitrogen by Indigo phenol blue colorimetric method. Total phosphorus using antimony tartrate ($KSBOC.C_4H_4O_6$) in molybdenum blue ascorbic acid (Mo blue) method (Bray and Kurtz). Available phosphorus by sodium bicarbonate extraction-molybdenum antimony colorimetric method. Available potassium was determined by ammonium acetate extraction-flame photometer, and pH was determined by potentiometry. The specific determination methods are explicitly explained in Soil and agricultural chemistry analysis [11]. The annual rainfall information comes from local meteorological station.

Figure 1: *Map indicated sampling points specific location.*

Monitoring sites	Annual rainfall/ mm	Land form	Soil texture	Organic matter g/kg	Total nitrogen g/kg	Nitrate nitrogen mg/kg	Ammonium nitrogen mg/kg	Total phosphorus g/kg	Available phosphorus mg/ kg	Available potassium mg/kg	pH
Chuzhou	930	Plain	Loam	12.6	0.4	7.0	0.6	0.1	8.0	62.1	6.5
Chaohu	1074	Plain	Clay	34.4	1.3	0.0	14.7	0.3	5.6	179.8	6.2
Tongcheng	1172	Hilly	Clay	19.9	0.9	9.0	4.8	0.4	7.0	89.6	6.0
Susong,	1455	Hilly	Loam	31.8	0.5	1.6	7.1	0.5	7.8	120.9	6.0

Table 1: *Annual precipitation and major baseline soil (0-20 cm) characteristics of the monitoring sites.*

Treatments

The two treatments were: (1) control with no fertilizer application for a full year; (2) fertilized conventional fertilization with method, amount and timing of fertilizer application according to the typical production methods of local farmers. Nitrogen was applied twice at basal fertilizer and tillering fertilizer time in forms of urea, phosphate in forms of P_2O_5 and potash in forms of K_2O was applied once at basal-time. Method of application broadcast is sow. Except for different fertilization, other field management measures in the two treatments are completely same. Table 2 shows annual mean fertilization. The surface runoff test period is five years, from 2008 to 2012.

Each treatment was replicated three times, and the six runoff areas are distributed side by side on both sides of the runoff pool (Figure 2). The single cropped rice in Chuzhou, Tongcheng and Susong is sown in mid-May, transplanted in mid-June, and harvested in late September and early October. The double cropped rice in Chaohu is sown in early April, transplanted in early May, and harvested at the end of July in the first season, sown at the end of June, transplanted at the end of July and early August (after the harvest of the first crop) and harvested at the end of November.

Monitoring sites	N/(kg/ha)	P_2O_5/(kg/ha)	K_2O/(kg/ha)
Chuzhou	155	34	34
Chaohu	190	33	33
Tongcheng	225	68	82
Susong	159	62	62

Table 2: *The amount of mean applied fertilizer from 2008-2012 at the monitoring sites.*

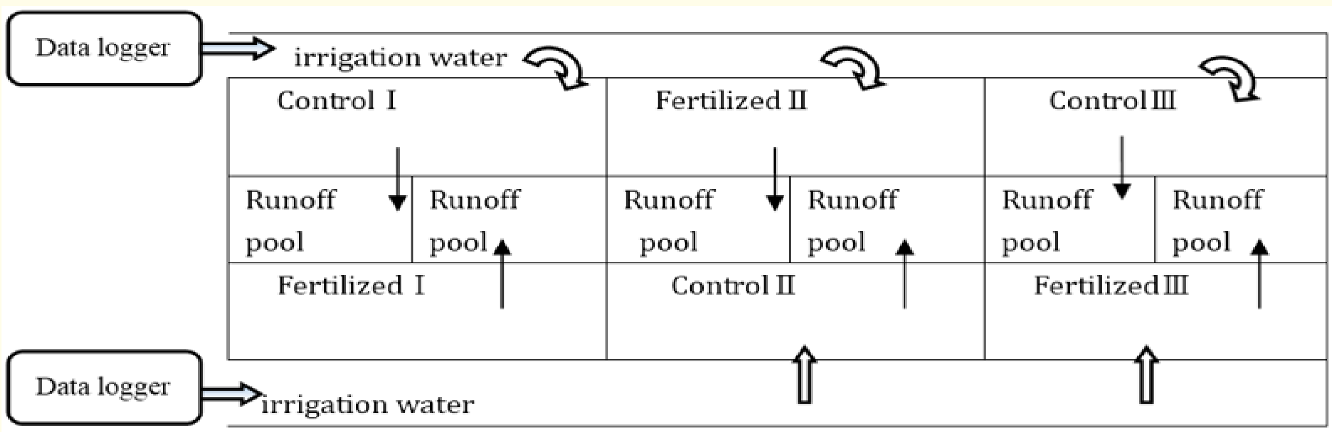

Figure 2: *Distribution of test area and runoff pools.*

Methods and sampling

The runoff pool method was applied for estimating the quantity of surface runoff and sampling runoff after rainfall. The dimensions of the pool consist of a length of 2m, a width of 1m and depth of 1.2m. The test area is 30 m^2, with the length of 4m, width of 7.5m. The volume of runoff was measured and the runoff samples were taken after each rainfall. During continuous rain days the runoff volume was measured, and the runoff samples were taken within 7 days when the water quantity in the runoff pool reached 80%. The magnitude of surface runoff is shown in table 3. Two 500 mL waters samples were collected from each pool. The water samples were refrigerated after being collected. A water meter with automatic data log was used to estimate the amount of applied irrigation water. The magnitude of irrigation is shown in table 4. With rainfall collector to collect rainfall samples, the magnitude of rainfall is shown in table 5.

Sample test

Runoff water samples were used to test total nitrogen, nitrate nitrogen, ammonium nitrogen, total phosphorus and soluble phosphorus. The test method used followed national standard analysis methods (Refer to table 6).

Monitoring sites	Treatment	Magnitude of surface runoff (m^3/ha)					
		2008	2009	2010	2011	2012	Average
Chuzhou	Control	2580	2167	2213	2804	/	2441
	Fertilized	2573	2196	2238	2831	/	2460
Chaohu	Control	3203	3220	2916	2607	/	2987
	Fertilized	3177	3205	2907	2609	/	2975
Tongcheng	Control	3384	1638	2239	209	1360	1766
	Fertilized	3380	1646	2220	214	1367	1765
Susong	Control	377	2335	2631	1265	1136	1549
	Fertilized	382	2387	2683	1243	1146	1568

Table 3: *The magnitude of surface runoff at monitoring sites.*

Monitoring sites	Magnitude of irrigation (m^3/ha)					
	2008	2009	2010	2011	2012	Average
Chuzhou	1548	1683	1789	1896	/	1729
Chaohu	4083	3980	3109	2089	/	3315
Tongcheng	3896	2012	4364	2949	8246	4293
Susong	876	2038	1000	899	1899	1342

Table 4: *The magnitude of irrigation at different monitoring sites.*

Monitoring sites	Magnitude of rainfall (mm)				
	2008	2009	2010	2011	2012
Chuzhou	548	529	530	553	/
Chaohu	467	372	757	622	/
Tongcheng	712	353	211	413	644
Susong	208	629	724	832	513

Table 5: *Rainfall from 2008-2012 of four monitoring sites in the rice season.*

Test index	Test method	Standard
Total nitrogen	Alkaline potassium persulfate digestion ----ultraviolet spectroscopy	GB11894-89
Nitrate nitrogen	Ultraviolet spectroscopy	HJ/T346-2007
Ammonium-- nitrogen	Indophenol blue colorimetric method	GB/T 8538-1995
Total phosphorus	Ammonium molybdate spectroscopy	GB 11893-89
Soluble-- phosphorus	Potassium per sulfate oxidation-molybdenum blue colorimetric method	GB 11893-89

Table 6: *Methods applied for analyzing the runoff water samples (nitrogen, phosphorus).*

Results

Runoff loss characteristics of nitrogen in rice field

Runoff loss of total nitrogen from rice fields

The loss of total nitrogen via rice field runoff at 4 monitoring sites from 2008 to 2012 is shown in table 7.

It can be seen from the table 7, in chuzhou, Control and Fertilized treatment of total nitrogen loss reached the 1% level of significant differences except the year 2009; Chaohu lake region is reached the 5% level of significant differences, of which 2009 reached the 1% level of significant differences; Tongcheng area have reached the 5% level of significant differences except 2009, besides, 2008 of 1% level significant differences; SuSong region are at 5% level of significant difference, even reached the extremely significant difference of 1%, except in 2010. Overall, Fertilized treatment of total nitrogen runoff reached significant difference compared with Control. Fertilized treatment has a certain influence on the loss of total nitrogen.

Monitoring sites	Treatment	Total nitrogen loss (kg/ha)				
		2008	2009	2010	2011	2012
Chuzhou	Control	8.6bB	8.4aA	3.0bB	4.3bB	/
	Fertilized	11.9aA	10.0aA	3.8aA	7.0aA	/
Chaohu	Control	2.4bA	3.3bB	1.5bA	1.7bA	/
	Fertilized	3.0aA	4.1aA	2.1aA	2.0aA	/
Tongcheng	Control	5.2bB	3.7aA	3.6bA	0.6bA	0.8bA
	Fertilized	8.3aA	4.4aA	4.5aA	1.1aA	1.3aA
Susong	Control	1.0bB	4.8bB	4.4bA	2.9bB	1.9bB
	Fertilized	2.8aA	8.2aA	6.2aA	16.9aA	10.4aA

Table 7: *Loss of total nitrogen caused by runoff at monitoring sites.*

a, b in the table indicate 5% significant difference ($p < 0.05$); A, B indicate 1% highly significant difference ($p < 0.01$).

Control treatment has certain nitrogen loss because the soil contains a certain amount of nitrogen in table 1. From the results of five years, the nitrogen loss declining, this is due to the soil nutrient depletion caused by years of no fertilizer.

Runoff loss of nitrogen forms in rice field

The runoff loss of nitrogen forms at 4 monitoring sites from 2008 to 2012 is shown in figure 3 and table 8. Figure 3 and table 8 shows the loss of nitrogen forms, which is basically consistent throughout the 4 sites. The proportional difference of nitrate nitrogen and ammonium nitrogen in total nitrogen loss is not very large; the mean proportion of nitrate nitrogen/total nitrogen is 38.9%, with the range of 5.9% - 78.3%; the mean proportion of ammonium nitrogen/total nitrogen is 33.8%, with the range of 4.0% - 67.4%. The ratio of nitrate nitrogen and ammonium nitrogen to total nitrogen is 72.9%.

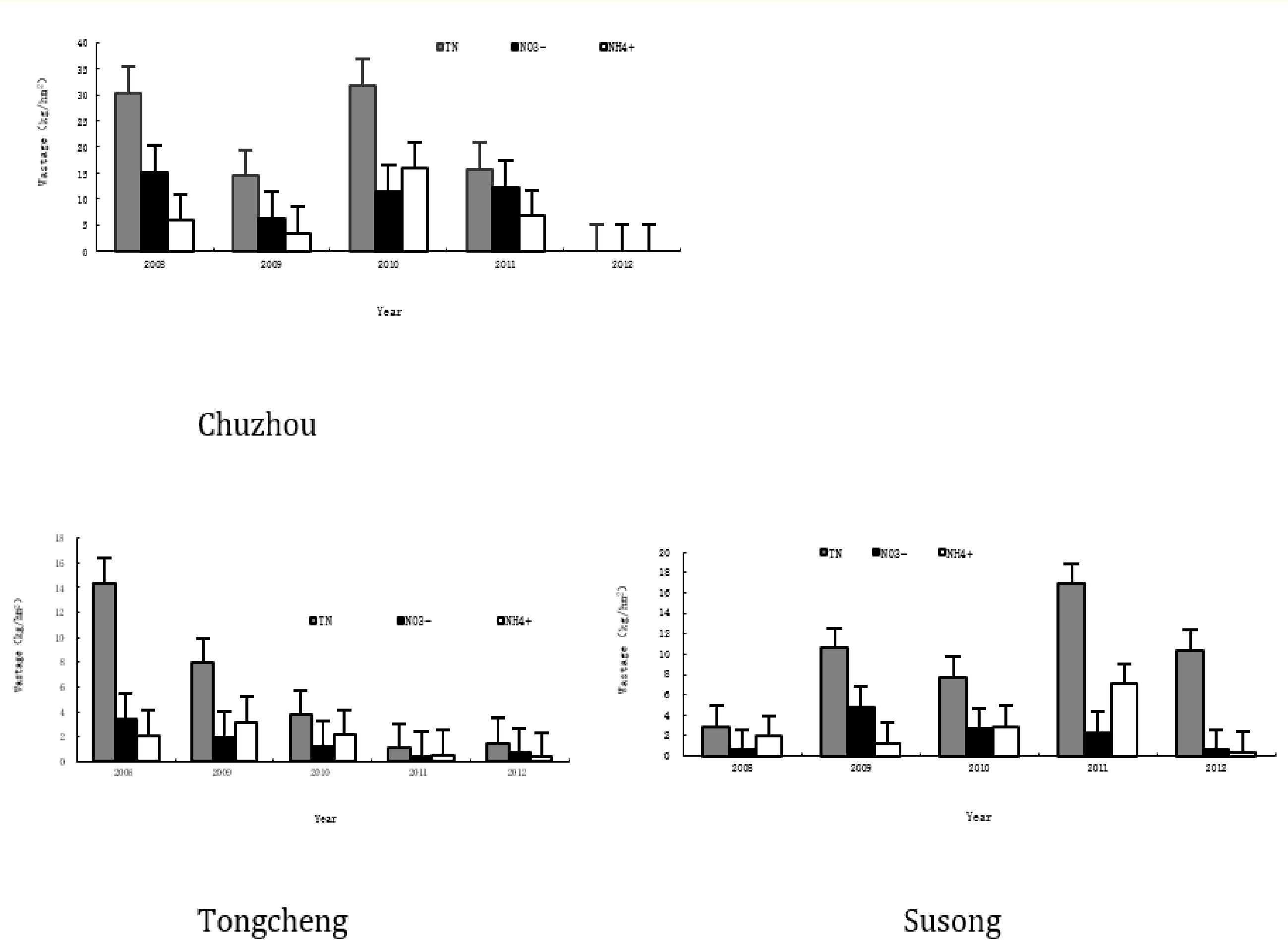

Figure 3: *Runoff loss form of nitrogen.*

Monitoring sites	TN	NO_3^-	NH_4^+
Chuzhou	8.123 ± 3.102	2.858 ± 0.940	2.663 ± 0.886
Chaohu	23.092 ± 8.113	11.326 ± 3.751	7.981 ± 3.567
Tongcheng	5.718 ± 2.476	1.545 ± 0.539	1.663 ± 0.535
Susong	9.702 ± 2.279	2.210 ± 0.775	2.723 ± 1.159

Table 8: *Standard error for TN, NO_3-N,NH_4^+-N from study sites.*

Runoff loss rate of fertilizer nitrogen in rice field

The calculated runoff rate of nitrogen at 4 monitoring sites from 2008 to 2012 is shown in table 9.

Nitrogen fertilizer loss rate (%) = (nitrogen loss under fertilized treatment-nitrogen loss under control treatment)/fertilizer nitrogen application×100%.

Monitoring-sites	Runoff loss rate of total nitrogen (%)					
	2008	2009	2010	2011	2012	Average
Chuzhou	1.5	1.2	0.4	1.0	/	1.0
Chaohu	2.5	0.8	2.6	1.5	/	1.8
Tongcheng	1.8	1.7	0.4	0.2	0.9	1.0
Susong	1.0	3.6	1.9	0.9	1.2	1.7

Table 9: *Runoffloss rate of nitrogen.*

The table 9 shows that the runoff loss rate of total nitrogen under fertilized application from 2008 to 2012 is 0.2% - 3.6%. The nitrogen loss coefficient is generally higher than phosphorus loss coefficient range from 0.0% to 0.8% (Table 10). The mean runoff loss rate of nitrogen fertilizer in rice field under fertilized is 1.4%.

Runoff loss characteristics of phosphorus in rice field

Runoff loss of total phosphorus in rice field

The runoff loss of total phosphorus under Fertilized and Control at 4 monitoring sites from 2008 to 2012 is shown in table 10.

Monitoring sites	Treatment	Total phosphorus loss（kg/ha）				
		2008	2009	2010	2011	2012
Chuzhou	Control	0.10 bB	0.16aA	0.57bA	1.00bB	/
	Fertilized	0.20 aA	0.21aA	0.82aA	1.99aA	/
Chaohu	Control	0.22 bA	0.16bA	0.22aA	0.16aA	/
	Fertilized	0.35 aA	0.24aA	0.26aA	0.16aA	/
Tongcheng	Control	0.27 bA	0.10bA	1.04bA	0.11bA	0.52bA
	Fertilized	0.31 aA	0.22aA	1.25aA	0.19aA	0.76aA
Susong	Control	0.03 aA	0.26bB	1.21bB	0.19bA	1.67bB
	Fertilized	0.05 aA	0.35aA	1.39aA	0.32aA	5.76aA

Table 10: *Runoff loss of total phosphorus at monitoring sites.*

a, b in the table indicate 5% significant difference (p < 0.05); A,B indicate 1% highly significant difference (p < 0.01).

The table 10 shows that under the fertilized treatment, the loss of total phosphorus at four monitoring sites is more than the loss of total phosphorus in Control; the runoff loss of total phosphorus at the monitoring sites under fertilized treatment ranges from 0.05 to 5.76 kg/ha, and the runoff loss of total phosphorus under control treatment ranges from 0.03 to1.67 kg/ha. Fertilized and Control processing of phosphorus loss almost reached the 5% level of significant differences, some reach the 1% level of significant differences. Indicate that fertilized treatment has certain influence on phosphorus loss. Runoff loss form of phosphorus in rice field.

The runoff loss form of phosphorus in rice field at 4 monitoring sites from 2008 to 2012 is shown in figure 4.

Figure 4 and table 11 depicts that the losses of total phosphorus and soluble total phosphorus at four monitoring sites in the five years is basically consistent, and that consistency is more obvious in Chuzhou. Except for Tongcheng in 2012, Susong in 2008 and 2012,the proportion of soluble phosphorus in total phosphorus is large, and higher than 50% of the loss of total phosphorus, reaches 56.8% on average, which indicates that the runoff phosphorus in rice field is mainly lost in the soluble form.

Runoff loss rate of fertilizer phosphorus in rice field

The calculated runoff loss rate of fertilizer phosphorus in rice field under fertilized at 4 monitoring sites from 2008 to 2012 is shown in table 12.

The table 12 shows that the mean runoff loss rate of phosphorus fertilizer in rice field under fertilized fertilization from 2008 to 2012 is 0.3% and the maximum loss rate can reach 0.8%. The loss rate of phosphorus is much less than the loss rate of nitrogen (Table 9), for compared with nitrogen, phosphorus is fixed by soil more easily through adsorption, chemical precipitation and biological fixation.

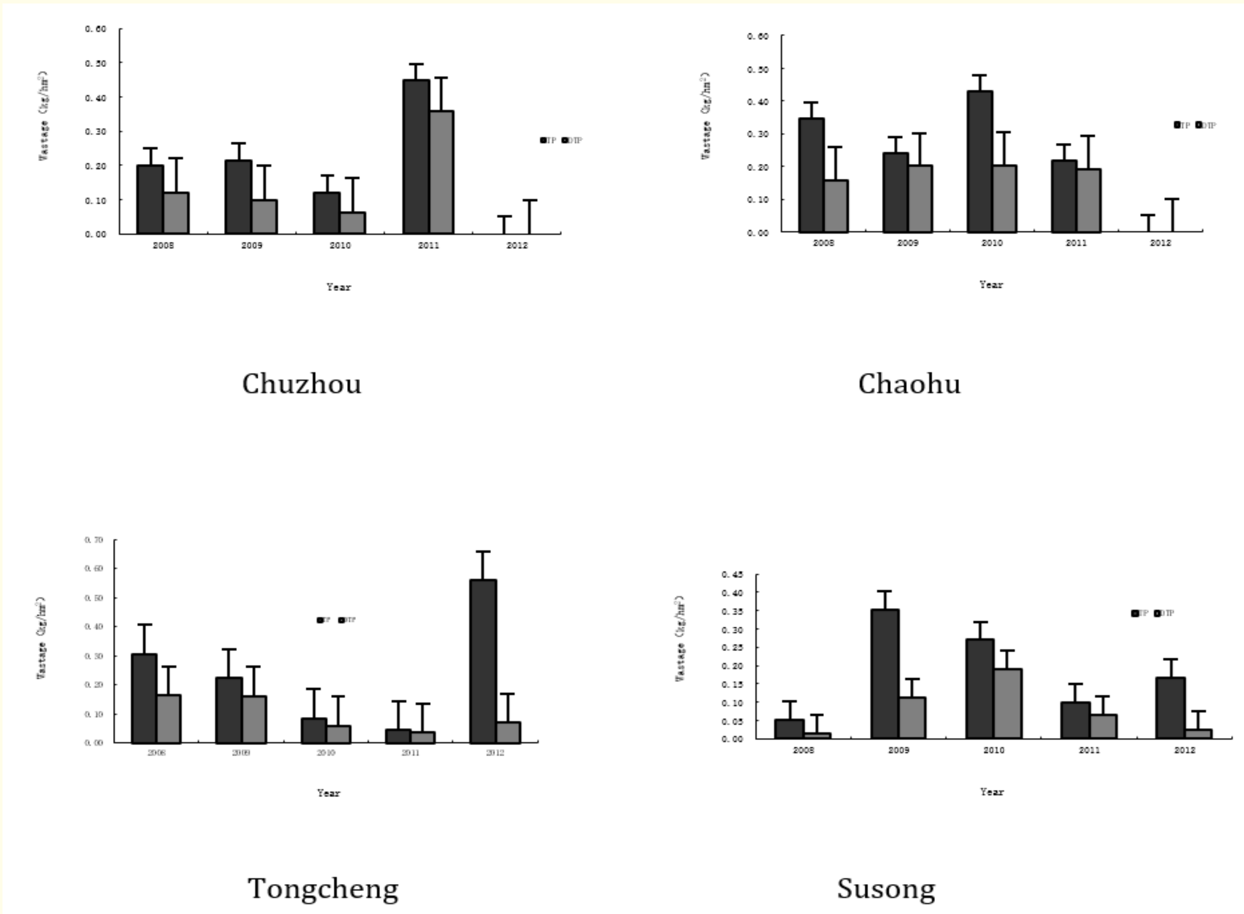

Figure 4: *Runoff loss form of phosphorus.*

Monitoring sites	TP	DNP
Chuzhou	0.245 ± 0.100	0.160 ± 0.081
Chaohu	0.308 ± 0.101	0.190 ± 0.056
Tongcheng	0.244 ± 0.092	0.099 ± 0.027
Susong	0.188 ± 0.055	0.082 ± 0.032

Table 11: *Show the standard error for study sites and TP, DTP.*

Monitoring sites	Runoff loss rate of total phosphorus (%)					
	2008	2009	2010	2011	2012	Average
Chuzhou	0.8	0.5	0.1	0.5	/	0.5
Chaohu	0.5	0.2	0.1	0.0	/	0.2
Tongcheng	0.2	0.6	0.0	0.0	0.4	0.2
Susong	0.1	0.4	0.1	0.1	0.1	0.1

Table 12: *Runoff Loss Rate of Total Phosphorus at monitoring sites from 2008 - 2012.*

Influence of rice field nitrogen and phosphorus loss on rice yield

The rice yield under Control treatment and Fertilized at 4 monitoring sites from 2008 to 2012 is shown in table 13.

As can be seen from table 13, under fertilized, the rice yield range is 5,500 - 11,800 kg/ha, and the yield range under control treatment is 3,367 - 5,850 kg/ha, the yield of fertilized treatment is much greater than control treatment, and reached 5% significant differences, quite a part even reached 1% level of significant differences. Fertilized treatment increase rice yield significantly.

Monitoring sites	Treatment	2008	2009	2010	2011	2012
Chuzhou	Control	5200bB	4800bB	4976bB	4278aA	/
	Fertilized	9100aA	8500aA	8448aA	5500bA	/
Chaohu	Control	4150bA	3850bA	4068bA	3367aA	/
	Fertilized	5675aA	5800aA	6292aA	5967bA	/
Tongcheng	Control	5850bB	4200bB	4911bB	5378bB	4133bB
	Fertilized	11800aA	9000aA	9078aA	9356aA	7978aA
Susong	Control	4200bB	3900bB	4067aA	5733aA	4322aA
	Fertilized	8600aA	8300aA	6167bA	7733bA	6000bA

Table 13: *Rice Yield under Control and Fertilized from 2008 - 2012 at 4 monitoring sites (kg/ha).*

a, b in the table indicate 5% significant difference ($p < 0.05$); A,B indicate 1% highly significant difference ($p < 0.01$).

Blank production is higher because the nutrient supply of soil background, look from the result of five years, blank production trends to decrease year by year.

Discussion

The loss of nitrogen and phosphorus from paddy rice fields is not only an important factor on the utilization rates of nitrogen and phosphorus fertilizer, but also a major source of pollution caused by agriculture impacting the quality of nearby water bodies [12-16]. Our results show that under fertilized management, the runoff loss of nitrogen and phosphorus during the growth period of rice is 1.3 - 3.0 times and 1.3 - 2.3 times higher than that in control, respectively, reached the significant difference. With fertilized, the runoff loss of total nitrogen, total phosphorus in rice field is respectively 6.0 kg/ha and 0.8 kg/ha, equal to 6.1% and 1.6% of the total amount applied during the rice season. According to Erguven and Yildirim [17] some herbicides containing nitrogen was eliminated slower from the soil until the last week of March, however, as April came in, and as the ambient air and hence soil temperature rose and the precipitation increased, the elimination process was reversed.

Some research results of nitrogen and phosphorus loss of other authors are listed in the table 14 below in terms.

Author	Year	N loss (kg/ha)	P loss (kg/ha)	Place
Yan Weijin [15]	1999	11.2	0.69	Chaohu
Cho [18]	2003	110		Korea
Gao [19]	2004	10.5		Taihu
Zhao Jianning [20]	2005		1.3-5.1	Taihu
Kim [21]	2006	11.6	0.7	Korea
Yin Weiqin [22]	2007	0.97	0.24	Taihu
Tian Yu-Hua [23]	2007	1.0 - 17.9		Taihu
Jiao Shaojun [24]	2007	38.8	0.95	Yanghu
Shi Li Hong [25]	2010	3.71 - 7.29	0.20 - 0.32	Hunan
Duan Xiaoli [26]	2012	4.90 - 10.67	0.63 - 1.44	Hubei

Table 14: *Research results of nitrogen and phosphorus loss of other authors.*

Compared with the research above, the loss of nitrogen in our result is close to ShiLiHong in Hunan and Duan Xiaoli in Hubei, the phosphorus loss is close to Yan Weijin in Chaohu and Duan Xiaoli in Hubei. For these sites are close to our research sites, a similar climate and topography and cropping system make a similar loss of nitrogen and phosphorus [27-34].

Conclusions

The mean runoff quantity of Anhui rice field is 2,189 m3/ha per year, with the average runoff loss of total nitrogen, total phosphorus in rice field under fertilized condition from four sites is 6.0 kg/ha and 0.8 kg/ha, it's 1.3 - 3.0 times and 1.3 - 2.3 times higher than the runoff loss of nitrogen and phosphorus under control, respectively.

During the rice growth period in rice field, 36.7% of the nitrogen lost through runoff is in the form of nitrate nitrogen, about 36.2% is lost in the form of ammonium nitrogen; The higher portion of nitrate nitrogen loss indicates that the nitrate nitrogen in rice field is easier to lose. About 56.8% of the phosphorus lost through runoff is in the form of soluble phosphorus.

Under double cropping rice rotation system, the loss of total nitrogen is higher than the loss under rice-wheat, rice-cole (a kind of oil crops) and rice-vegetable rotation system. The rotation of double cropping rice could be modified into rice field-upland field rotation to reduce the runoff loss.

The shorter the time interval of fertilization and surface runoff, the greater the concentration of nitrogen and phosphorus in surface runoff. So we should pay attention to avoid fertilizing in the heavy rain, reducing the runoff loss of nitrogen and phosphorus.

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