Effect of organic fertilizers on nitrogen and phosphorus runoff in purple soil farmland

Hongxia Xia¹,a, Qihong Zhu²,a*, Shumin Wang³,a, Yucheng Chen⁴,b

¹Chongqing Key Laboratory of Environmental Materials & Remediation Technologies, Chongqing University of Arts and Sciences, Yongchuan, Chongqing 402160, China
²Key Laboratory of Eco-environments in the Three Gorges Reservoir Area (Ministry of Education), College of Resources and Environment, Southwest University, Chongqing 400716, P. R. China
³e-mail: 287670325@qq.com, ⁴e-mail: 412409763@qq.com
The corresponding author e-mail: 20050004@cqwu.edu.cn

Abstract: Fertilizer nutrient loss by surface water contribute to eutrophication becoming one of the international problems. In order to study the effect of application of organic fertilizer on N/P loss in purple soil, an indoor simulating artificial rainfall experiment and in-situ natural rainfall experiment experiment was conducted in Chongqing, southwestern China. The result shows that TN(total nitrogen) loss in the simulation rainfall experiment was in the order of cow dung>compound fertilizer>chemical fertilizer>biogas slurry>oil cake>blank, whereas, TP(total phosphorus) loss was in the order of cow dung>chemical fertilizer>compound fertilizer>oil cake>biogas slurry>blank. TN content form organic fertilizer treated soil in the in-situ runoff test were lower than in chemical fertilizer treated soil at first, whereas the proportion of TN content form organic manure was increase and even higher than that form chemical fertilizer overtime. Grain nitrogen was the dominant nitric species in runoff under 15°, whereas Ammonium nitrogen was the dominant nitric species in runoff under 5°. The slope significant affect grain nitrogen content in runoff, while it has little effect on soluble nitrogen. Soluble phosphorus content in chemical fertilizer treatment was higher than that in organic fertilizers treatments, while particulate phosphorus concentration in chemical fertilizer treatment was lower than that in organic fertilizers treatments. Particulate phosphorus is the main form in runoff simulation, accounting for 50%~90% of total phosphorus; while soluble phosphorus was the dominant phosphoric species with the slope, rainfall intensity and fertilizer dosage reduced. Rainfall intensity could increase P concentration in runoff. There was a significant positive correlation between the TN and TP concentration in runoff and rain intensity, fertilizer addition level, slope.

1. Introduction
Improper use of fertilizer increases excessive nitrogen and phosphorus to farmland ecosystem, resulting in a relative lower fertilizer utilization rate and a higher risk of nutrient loss [1,2]. Usually, N fertilizer efficiency generally ranges from 25% to 35% in Taihu Lake region [1]. The excessive N fertilizer application can cause a large amount of N losses and result in nonpoint-source pollution through surface runoff, drip washing and emission of NH₃ and N₂O eventually limiting the use of...
surface water [1,3].

Studies have shown that not all the phosphorus fertilizer applied could be absorbed by crops, the remaining phosphorus in soil have a great possibility to be diverted into surface water through runoff [4]. In addition, the N/P loss accelerates a lower utilization rate of fertilizer, which in turn may increase more fertilizer input. The high content of nitrogen and phosphorus benefit to the aquatic plants grow, resulting in eutrophication. Then, the numerous aquatic plants break the balance of ecosystem by the degeneration of the properties [5,6]. The reason why algas grow excessively is that phosphorus and nitrogen concentrations in surface water are increasing gradually and agricultural source of P considered as a main contributor [5,7,8].

Previous study reported that the decrease of fertilization by 20% could decrease TN loss by 8.2%~15.2% in Lalin River basin [9]. The P in recent application becomes mobile after reciprocity with rainfall, resulting in a short-term P loss. However, the remaining P that exceeds crop needs is absorbed by soil aggregate and cations but it constitutes a long-term loss of P [8]. P loss occurs only when high P concentration is combined with large runoff amount [8,10]. Researches have shown that compared with chemical fertilizer application, the application with the mixed which contain of chemical and manure fertilizer could reduce the total N loss through runoff by 53% [11]. Additionally, soluble P concentrations in runoff in the first storm after fertilizer addition was higher than that from unfertilized cropland. In most cases, soluble P loss in the first rainfall is highest [3].

Organic fertilizer such as manure, is a kind of low-cost material, which is utilized extensively for maintaining sustainability in agricultural soils and reducing the N/P loss. For example, poultry dung is used as N fertilizer to crop rather than as P fertilizer that P can be excessive to accelerate eutrophication but incorporation can reduce the loss of P and N compared with other dungs due to the higher ratio of P/N in poultry manure [6,12].

Additionally, organic fertilizer with rich nutrient can improve soil N, P and K content for crops growth [13]. Therefore, organic fertilizer addition is a pathway for the reeducation of chemical fertilizer application and eutrophication [12].

However, some studies have shown that long-term unreasonable application of organic fertilizer can increase N and P loss [14,15]. Therefore, detailed investigations are needed to determine whether organic fertilizer is a positive or negative operator for nutrient retention. Purple soil is a young aged soil, which has a relative low binding sites for N and P. In order to study the effect of application of organic fertilizer on N/P loss in purple soil, an indoor simulating artificial rainfall experiment was conducted in Chongqing, southwestern China.

2 Materials and methods

2.1 Materials Material collection and characterization

Purple soil was collected from Beibei District of Chongqing China. After removing plants and sundries, top layer (0-20 cm) was collected by multipoint method. In order to improve the representation of experiment, selected fertilizers are chemical fertilizer and organic fertilizer which were generally used in Beibei District. The Chemical fertilizer is (NH₄)₂HPO₄ and organic fertilizers including cow dung, oil cake, biogas slurry, organic-inorganic compound fertilizer. Chemical fertilizer, oil cake and compound fertilizer are bought from farmers market in Beibei District. Cow dung and biogas slurry are collected from dairy breeding base of Tianyou group crop in Beibei District. In addition, cow dung was air dried and crushed before to use. The basic physical and chemical properties of the soil and fertilizers are given in Table 1 and 2.

| pH  | Organic matter(g·kg⁻¹) | TN(g·kg⁻¹) | TP(g·kg⁻¹) | CEC(emol·kg⁻¹) |
|-----|------------------------|------------|------------|----------------|
| 7.58| 25.13                  | 0.91       | 1.83       | 21.57          |
Table 2 Nutrient contents of fertilizers in simulating experiment (g·kg⁻¹)

|        | Cow manure (A2) | Biogas slurry (A3) | Oil cake (A4) | Organic-inorganic compound fertilizer (A5) | Chemical fertilizer (A6) |
|--------|-----------------|--------------------|---------------|-------------------------------------------|--------------------------|
| TN     | 24.56           | 1.92               | 41.57         | 142.75                                    | 185.16                   |
| TP     | 13.23           | 1.37               | 11.67         | 39.74                                     | 450.42                   |

2.2 Artificial runoff test
Artificial runoff groove was a self-made mold with a length of 1 meter, width 0.6 meters, 0.5 meters high. This groove could adjust slope by regulating height and collect runoff sample with its sump tank and outlet pipe. The cultivated slope in the lower hilly area of the city is concentrated in 5~20 degrees, then, this test chooses 5 degrees and 15 degrees as slope design value. The artificial rainfall model used is Norton Veejet80100 which breaks the water into different sizes of raindrops could simulates natural rainfall well. According to the meteorological data of Chongqing, the average annual rainfall in Chongqing is about 1100 mm, the maximum rainfall in June and July, the minimum rainfall in January and February, the average monthly rainfall between 10 ~ 200 mm. Considering the characteristics of surface runoff, material carried by runoff and specifications of experimental equipment, experimental rainfall intensities are designed into 83 mm/h and 104 mm/h. As the artificial rainwater is tap water, the total nitrogen and total phosphorus contents in the water should be determined as background values before experiment. Experimental design of runoff simulation test is shown in table 3.

Table 3 Experimental design of runoff simulation

| Items                  | Treatments |
|------------------------|------------|
|                        | 1 2 3 4 5 6 7 8 |
| Fertilizer dosages (kg N/hm²) | 450 300 450 300 450 300 450 300 |
| Slope (°)              | 15 15 15 15 5 5 5 5 |
| Rainfall (mm/h)        | 104 104 83 83 104 104 83 83 |

2.3 Analysis
The runoff collected. The samples were filtered through 0.45 μm cellulose acetate membrane before analysis. The phosphorus was determined by the molybdenum blue colourimetric method. The nitrogen was determined by the colourimetric method [16].

2.4 Statistics
Statistical analysis was performed using SPSS and the results were visualized in excel. Duncan Multiple comparison were used to determine the differences among treatments.

The relative loss rate of TN and TP is calculated as Eq. (1).

\[
\text{TN/TP loss rate (\%)} = \frac{C_1 - C_2}{C_3 - C_2} \times 100
\]  

Where, \(C_1\) is the TN(P) content in organic fertilizer treatment; \(C_2\) is TN(P) content in CK; \(C_3\) is TN(P) content in the fertilizer treatment.

3 Results and discussion
3.1 Nitrogen loss in runoff
Fig.1 shows the relative runoff TN loss rate in different fertilizer treatments. It shows that the
concentrations of TN loss in organic fertilizer treatments were 75.62%−137.29% of chemical fertilizer treatment. In the 8-runoff test, the concentration of TN loss in cow manure treated soil was higher. The N loss concentration in the 2-6 simulated runoff tests were higher than chemical fertilizer treated soil by 4%−37.29%, and in the remaining three fields were lower than chemical fertilizer treated soil by 2.38%−9.85%. The results showed that there was no significant difference between organic fertilizer treatments and chemical fertilizer treatment (p>0.05), but it was significantly higher than control (p<0.05). The nitrogen loss in different tests was in the order of cow dung >compound fertilizer> chemical fertilizer> biogas slurry>oil cake> CK. The higher N content in loss in cow dung treatment may be induced by the greater soluble nitrogen in cow dung. The N content in organic fertilizer treated soils may higher than that in chemical fertilizer treated soil. Organic fertilizer addition accelerates the N translation due to the high N content and microbial activity, which provide more soluble N [17]. Accordingly, the application of organic fertilizer can increase the N loss.

Fig 1 Relative runoff TN loss rates of organic fertilizer treatments in simulating rainfall experiment

3.2 Phosphorus loss in runoff

Fig.2 has shown the TP concentration of the simulated runoffs. The results showed that there was no significant difference between organic fertilizer treatments and chemical fertilizer treatment (p>0.05), but it was significantly higher than that of control (p<0.05). The phosphorus loss in different tests was in the order of in the tests was cow dung >chemical fertilizer >compound fertilizer > oil dry> biogas slurry> CK. The application of organic fertilizer increase P loss presumably caused by the higher P content, and the competitive adsorption by ions form the decompose of organic matter. The chemical fertilizer also can increase the P loss due to the high P content after chemical fertilizer intervention. The effect of P loss in organic fertilizer treatment lower than chemical fertilizer treatment [18]. P would undergo a series of chemical, physical and biochemical reaction in soil after fertilizer application, which would be binding by soil mineral, resulting in a low bio-availability. Organic phosphorus has higher mobility than other phosphoric species, which could be fixed harder. The organic phosphorus content in chemical fertilizer can be release in rainfall, and therefore, the migration of P is higher [19]. TP loss concentration of cow dung was higher than chemical fertilizer treated soil by 8.06%−33.33% in four simulated runoff experiments and lower than chemical fertilizer treated soil by 0.56%−9.38% in the other four tests. The TP loss concentration of in organic fertilizer treatments is higher than chemical fertilizer treatment by 73.44% ~133.33%. The TP concentration in runoff in cow dung treated soil was relatively higher than others organic fertilizers treatments due to the higher P content in cow dung, and the TP content in runoff in the organic fertilizers treatments, i.e. biogas slurry, oil cake and organic-inorganic compound fertilizer is lower than that of chemical fertilizer treatments. The TP contents in runoff in biogas slurry, oil cake and organic-inorganic compound fertilizer treatments were lower than chemical fertilizer treatments by 1.75%~26.56%, -21.88%~15.79%, -16.48%~12.33%, respectively. The TP loss in runoff from organic fertilizer was no different from chemical fertilizer applied soil. Then, both organic and chemical fertilizer addition can
increase P loss. Fertilizers application can increase P loss due to the improvement of P content in soil. However, organic fertilizers might increase P content in soil by increasing P absorption capacities and the reduction of P release. Besides, the degradation of organic matter increases organic acid content, which benefit to bacteria growth, resulting in P dissolution [20].

Fig. 2 Relative runoff TP loss rates of organic fertilizer treatments in simulating rainfall experiment

3.3 Comparison of nitrogen forms in runoff
In order to better understand the N loss, we investigate the nitrogen forms in the runoff, and the result has shown in Fig. 3. The result showed that there was no difference between organic fertilizers and chemical fertilizer treated soils in the concentration of various nitrogen forms. The soluble nitrogen and grain nitrogen content in the fertilizers treated soils were significantly higher than control (p<0.05), the grain nitrogen content was significant higher than control (p<0.01). The content of soluble nitrogen, ammonium nitrogen and nitrate nitrogen in runoff in chemical fertilizer treatment was higher slightly than that in organic fertilizer treatments, whereas grain nitrogen content in chemical fertilizer treatment was lower than organic fertilizer treatments. As was shown in Table 4, grain nitrogen is the main form of nitrogen loss in runoff under 15°. The concentration of grain nitrogen accounts for more than 70% of the total nitrogen concentration, especially in the first four rainfall experiments. The first four runoffs were under the gradient of 15 degrees, however, the other four is under the gradient of 5 degrees. Therefore, the effect of slope on the of soluble nitrogen loss in runoff is not significant, while it significant affect the grain nitrogen content in runoff. Under the same conditions, the concentration of grain nitrogen in runoff produced at 15 degrees was 2~3 times higher than under 5° condition. The concentration of ammonium nitrogen in runoff water samples is higher than nitrate nitrogen content, which accounts for 10%~15% of total nitrogen and 2%~15% of nitrate nitrogen. This indicates that ammonium nitrogen was the dominant nitric species in runoff under 5° in all treatments. This is due mainly to the ammonium nitrogen was the dominant nitric species in cropland, which is can be converted into nitrate nitrogen by microorganisms, and assimilate by soil biota [21]. Then, the nitrogen release in the form of ammonium nitrogen. In the first season runoff test soluble N was the dominant nitric species in runoff, whereas grain N was the dominant nitric species in runoff in second season runoff.
Fig. 3 Comparison of each N forms in test

3.4 Comparison of phosphorus forms in runoff
The concentration of soluble nitrogen in water sample was determined after filtration, and the concentration of phosphorus was obtained by using the molybdenum blue colourimetric method. The
results have shown in figure 4. There was no significant difference between the two forms of phosphorus in the runoffs in all treatments (P>0.05), and the concentration phosphorus in runoff in the fertilizers treatments was remarkably higher than that in control (p<0.01). This showed that both chemical fertilizer and organic fertilizers could significantly increase the phosphorus loss.

![Diagram showing phosphorus forms in different treatments](image)

Fig. 4 Comparison of each P forms in test

Soluble phosphorus content in chemical fertilizer treatment was higher than that in organic fertilizers treatments, while particulate phosphorus concentration in chemical fertilizer treatment was lower than that in organic fertilizers treatments. It can be observed that particulate phosphorus is the main form in runoff simulation, accounting for 50%~90% of total phosphorus, and the concentration of soluble phosphorus are higher than that of particulate phosphorus in the eighth runoff, where the
slope, rainfall and fertilization are the smallest. Particulate phosphorus was dominant in the top layer which was dominant destruction in soil by rainfall. In addition, the dispersion of soil become the main source of nutrient loss. The soil particulate release in rainfall, which carried particulate phosphorus. Therefore, the particulate phosphorus was the dominant phosphoric species in runoff [22], especially in the strong rainfall condition. It showed that in the in-situ experiment, concentrations of two forms P are both highest when rainfall maximum, indicating that rainfall intensity could increase P concentration in runoff obviously.

4 Conclusion
There was no significant difference in the nitrogen and phosphorus concentration in runoff in organic fertilizers and chemical fertilizer treatments in purple soil under the same condition. Compared with control, the application of organic fertilizer and chemical fertilizer can significantly increase the nitrogen and phosphorus concentration in the surface runoff. The result shows that TN loss in the simulation rainfall experiment was in the order of cow dung>compound fertilizer>chemical fertilizer>biogas slurry{oil cake>blank, whereas, TP loss was in the order of cow dung>chemical fertilizer>compound fertilizer{oil cake>biogas slurry>blank. Significant positive correlation exists between the TN and TP concentration in runoff and rain intensity, fertilizer addition level and slope.

In addition, soluble nitrogen, soluble phosphorus, ammonium nitrogen and nitrate nitrogen content in chemical fertilizer treatment were higher than that of organic fertilizers treatments, whereas but the concentrate of grain nitrogen and particulate phosphorus in chemical fertilizer treatment were lower than that of organic fertilizers treatments. Ammonium nitrogen was the dominant nitric species in runoff under 5°. The slope significant affect grain nitrogen content in runoff, while it has little effect on soluble nitrogen. During the first season runoff test soluble N was the dominant nitric species in runoff, whereas grain N was the dominant nitric species in runoff in second season runoff. Soluble phosphorus content in chemical fertilizer treatment was higher than that in organic fertilizers treatments, while particulate phosphorus concentration in chemical fertilizer treatment was lower than that in organic fertilizers treatments. Particulate phosphorus is the main form in runoff simulation, accounting for 50%~90% of total phosphorus; while soluble phosphorus was the dominant phosphoric species with the slope, rainfall intensity and fertilizer dosage reduced.

Acknowledgments
We would like to thank financial support from the Program of Natural Science Foundation of Chongqing (cstc2014jcyjA20013), Scientific and Technological Research Program of Chongqing Municipal Education Commission (KJ1601120, Natural Science Foundation of Yongchuan (Ycstc2015nc1002) and Natural Science Foundation of Arts and Sciences of Chongqing University (Y2015CH31).

References
[1] Shan L., He Y., Chen J., et al. (2015) Nitrogen surface runoff losses from a Chinese cabbage field under different nitrogen treatments in the Taihu Lake Basin, China. Agricultural Water Management, 159: 255-263.
[2] Smith D. R., Owens P. R., Leytem A. B., et al. (2007) Nutrient losses from manure and fertilizer applications as impacted by time to first runoff event. Environmental Pollution, 147(1):131-7.
[3] Vadas P. A., Owens L. B., Sharpley A. N. (2008) An empirical model for dissolved phosphorus in runoff from surface-applied fertilizers. Agriculture Ecosystems & Environment, 127(1):59-65.
[4] Rice P. J., Horgan B. P. (2017) Off-site transport of nitrogen fertilizer with runoff from golf course fairway turf: A comparison of creeping bentgrass with a fine fescue mixture. Science of the Total Environment, 580:533-539.
[5] Jr Lewis W. M., Wurtsbaugh W. A., Paerl H. W. (2011) Rationale for Control of Anthropogenic Nitrogen and Phosphorus to Reduce Eutrophication of Inland Waters. Environmental Science
& Technology, 45(24):10300-10305.

[6] Mcmullen R. L., Brye K. R., Miller D. M., et al. (2014) Long-Term Runoff Water Quality as Affected by Broiler-Litter Application to a Udult in the Ozark Highlands. Soil Science Society of America Journal, 78(6):2017.

[7] Jr Lewis W. M., Wurtsbaugh W. A. (2008) Control of Lacustrine Phytoplankton by Nutrients: Erosion of the Phosphorus Paradigm. International Review of Hydrobiology, 93(4-5): 446-465.

[8] Hua L., Liu J., Zhai L., et al. (2017) Risks of phosphorus runoff losses from five Chinese paddy soils under conventional management practices. Agriculture Ecosystems & Environment, 245:112-123.

[9] Zhang S., Wang L., Ma F., Zhang X., Fu D. (2016) Reducing nitrogen runoff from paddy fields with arbuscular mycorrhizal fungi under different fertilizer regimes. Journal of Environmental Sciences, 46(8): 92-100.

[10] Liu J., Zuo Q., Zhai L. M., et al. (2016) Phosphorus losses via surface runoff in rice-wheat cropping systems as impacted by rainfall regimes and fertilizer applications. Journal of Integrative Agriculture, 15(3):667-677.

[11] Shi Y. P., Duan Z. Q. (2009) Integrated Management of Water and Fertilizer to Reduce Nitrogen, Phosphorus Loss from Chinese Chive Field in the North Bank of Dianchi Lake. Journal of Agro-Environment Science, 28(10):2138-2144.

[12] Sweeney D. W., Pierzynski G. M., Barnes P. L. (2012) Nutrient losses in field-scale surface runoff from claypan soil receiving turkey litter and fertilizer. Agriculture Ecosystems & Environment, 150(6):19-26.

[13] Pashaki K. M. G., Mohsenabadi G., Majidian M., Nosratabad A. R. F. (2017) Effect of Application of Nitrogen, Phosphorus and Organic Fertilizers on Yield and Yield Components of Bean (Phaseolus vulgaris L.) in Lahijan, Northern Iran. Journal of crop production and processing winter, 6(22): 47-60.

[14] Wang R. P., Liao X. R., Yu W. M., et al. (2013) Pollution risks of phosphorus in vegetable field soil by application of organic fertilizer. Ecology & Environmental Sciences, 22 (8): 1428-1431.

[15] Zhu X. H., Du X. Y., Zhang W. L. (2013) Effects of manure type on available-P accumulation in soil and its loss risk. Soil & Fertilizer Sciences in China, 5: 1-10.

[16] Bao S. D. (2000). Soil and agricultural chemistry analysis. China Agriculture Press. Bei Jing.

[17] Cosico V. B., Damo C. M., Puyot C. V. (2003) Utilization of N-enriched bio-organic fertilizer and microbial inoculant in cotton production. British Journal of Pharmacology, 114 (1): 166-170.

[18] Maguire R. O., Sims J. T. (2002) Soil testing to Predict Phosphorus leaching. Journal of Environmental Quality, 31: 1601~1609.

[19] Verloop J., Oenema J., Burgers S. L. G., Aarts H. F. M., van Keulen H. (2010) P-equilibrium fertilization in an intensive dairy farming system: effects on soil-P status, crop yield and P leaching. Nutrient Cycling in Agroecosystems, 87: 369-382.

[20] Lechtenfeld O. J., Kattner G., Flerus R., McCallister S. L., Schmitt-Kopplin P., Koch B. P. (2014) Molecular transformation and degradation of refractory dissolved organic matter in the Atlantic and Southern Ocean. Geochimica Et Cosmochimica Acta, 126(2): 321-337.

[21] Bergstrom L., Kirchmann H.(1999) leaching of total nitrogen from nitrogen-15-labeled poultry manure and inorganic nitrogen fertilizer. Journal of Environmental Quality, 28: 1283~1290.

[22] Gburek W. L., Sharpley A. N. (1998) Hydrologic controls on phosphorus loss from upland agricultural watersheds. Journal of Environmental Quality, 27: 267-277.