NITROGEN AND PHOSPHORUS LOSS CHARACTERISTICS UNDER AN IMPROVED SUBSURFACE DRAINAGE

YuanTao¹, ShaoliWang¹, XiaoyanGuan¹, Di Xu¹ and Haorui Chen¹

ABSTRACT

In this paper, nitrogen and phosphorus loss under improved subsurface drainage with different filter materials (gravel, layered sand-gravel, mixed sand-gravel, straw) were compared with the conventional subsurface drainage. The pH values, total nitrogen, ammonia nitrogen, and total phosphorus were studied. The results showed that the nitrogen and phosphorus concentrations of drain outflow under improved subsurface drainage with gravel filter were larger than that with layered sand-gravel filter and mixed sand-gravel filter. The improved subsurface drainage with layered sand-gravel filter and mixed sand-gravel filter had an effect on reducing the ammonia nitrogen and total phosphorus concentrations of the outflow. While the characteristics of nitrogen and phosphorus loss under the improved subsurface drainage with straw filter were different from layered sand-gravel filter and mixed sand-gravel filter. For the improved subsurface drainage with layered sand-gravel filter outflow, the ammonia nitrogen, total phosphorus concentrations were about 13%~78%, 38%~63% less and total nitrogen concentrations were 24%~80% more than that under conventional subsurface drainage. The improved subsurface drainage with straw filter outflow, compared with conventional subsurface drainage outflow, the percentage changes of the total nitrogen, ammonia nitrogen and total phosphorus concentrations were about -76%~62%, -152%~-274% and -103%~-400% respectively. In the outflow in all types of drainage filters, high total nitrogen concentrations were observed which should be focused and appropriate agricultural water management should be adopted.

Keywords: Improved subsurface drainage; nitrogen and phosphorus loss; filter materials; field experiment.

1. INTRODUCTION

Agricultural drainage is a main transport pathway for agricultural nutrient pollutants into rivers and lakes (Skaggs et al., 1994). Agricultural drainage management should be focused considering the comprehensive conditions of agriculture food production promotion, environmental impact and water resources comprehensive utilization (Ritzema, 2006). The improved subsurface drainage is a more efficient drainage system by laying high permeability materials as filter above the drains based on conventional subsurface drainage whose function is limited by soil hydraulic conductivity. The advantage in removing excess water from land surface and soil which is better for agricultural production promotion has been proved by laboratory experiment, field test and numerical simulation (Tao et al., 2016; Tao et al., 2017). However, the characteristics of nitrogen and phosphorus loss under the improved subsurface drainage had not been studied. Totally speaking, the filter materials of the improved subsurface drainage may be the sand and gravel, zeolite, straw or woodchip. These materials may influence the processes of nitrogen and phosphorus transfer in the soil and have different effects on reducing the nitrogen and phosphorus contents in the drain outflow (Ibrahim et al., 2015; Murnane et al., 2016; Wang et al., 2014).

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The subsurface drainage has been identified as a potentially significant source of nitrogen (Williams et al., 2015) and phosphorus (King et al., 2014). Compared with surface drainage or non-drained plots, many researchers have previously reported that the conventional subsurface drainage can reduce the content of phosphorus effectively. Grazhdani et al. (1996) assessed the effect of the subsurface drainage on reducing nutrient losses by experiments conducted from 1992 to 1995 in the Korca region, south-eastern Albania. The results showed that the average annual phosphorus losses under subsurface drainage could be reduced about 30% than the non-drained plots. Tan and Zhang (2011) showed that the dissolved reactive P, dissolved un-reactive P, particulate P and the total P concentrations in the subsurface drainage flow were 40%, 7%, 37% and 35% lower than that in surface runoff, respectively. Eastman et al. (2010) presented that the subsurface drainage in sandy loam soils had a significant beneficial effect in minimizing surface runoff and total phosphorus losses from the field.

Unlike the characteristic of phosphorus loss, there are no unanimous conclusions on the characteristic of nitrogen loss under subsurface drainage compared with surface drainage. The nitrogen adsorption by soils, nitrogen transfer in the soil and nitrogen leaching will reflect the subsurface drainage quality comprehensively. Bengtson (1995) showed that subsurface drainage was more effective in reducing the nitrogen loss by 17% than surface drainage during the growing season in the Lower Mississippi Valley. Grazhdani et al. (1996) reported that the subsurface drainage contained significantly lower nitrate nitrogen and ammonium nitrogen concentrations with about 30% and 25% reduction respectively. However, Baker et al. (2004) drew the conclusions that the ammonium nitrogen loss was decreased and the nitrate nitrogen loss was increased under subsurface drainage compared with surface drainage. Besides, Baker pointed out that soils, weather, and management (cropping, tillage, chemical application practices, and drainage parameters) influenced the nitrate nitrogen leaching. Wang (2008) carried out a three-year field experiment in Ontario, Canada from which we could find that the nitrate-nitrogen concentration in subsurface drainage was larger than that in surface run off.

Additionally, different materials also have varied effect on the nitrogen and phosphorus transfer. Turtola and Paajanen (1995) analyzed the influences of the subsurface drainage with topsoil or woodchips used as backfill in the drain trenches on phosphorus and nitrogen losses in a heavy clay soil and drew conclusions that the subsurface drainage with topsoil or wood chips could increase the discharge obviously, the subsurface drainage with topsoil could reduce particulate P and dissolved orthophosphate P losses, and the subsurface drainage with wood chips would not reduce the particulate P. Wang et al. (2013) analyzed the effects of different envelop materials including wheat straw, sawdust, ceramic, zeolite and fiber ball on nitrogen removal. Results showed that the inorganic material had a better ability to remove ammonium nitrogen, while organic material had a good ability to remove nitrate nitrogen. Besides, Wang also revealed that there was a positive relationship between the nitrogen removal capacity and the thickness of the envelope material, when the thickness increased by 10 cm the nitrogen removal efficiency of wheat straw and sawdust, ceramic and zeolite, fiber ball increased by 6%~8%, 6%~28%, 10%~20% respectively. Nie et al. (2012) studied the long-term purification effect of rainwater runoff by different infiltration systems constructed with the natural soil, quartz sand, sawdust, coal ash residues respectively and found that the coal ash residues did best in removing ammonium nitrogen, the sawdust did best in reducing total nitrogen for its ability of providing carbon source to the microorganism and all materials did well in removing total phosphorus.

The main objective of this paper was to study the characteristics of nitrogen and phosphorus loss under the improved subsurface drainage with different filter materials
and conventional subsurface drainage based on three-year field experiments from 2016-2018. The concentrations of total nitrogen, ammonia nitrogen and total phosphorus in drain outflow were measured.

2. METHODS

2.1 Field Experiment Design

The field experiments were conducted from 2016 to 2018 at Xinmaqiao experiment station in Huaibei plain, China (117° 22′ E, 33° 09′ N). Five plots of conventional subsurface drainage, improved subsurface drainage with gravel filter, layered sand-gravel filter, mixed sand-gravel filter, and straw filter were installed. Each plot contained three 75 mm diameter pipe drains. Drains were installed at 0.7625 m depth and 6 m spacing. Filter width and height of the improved subsurface drainage were 0.4 m and 0.5 m, respectively. For the layered sand-gravel filter, the upper fine-particle layer was 0.2 m and the lower coarse-particle layer was 0.3 m. The drain outflows from each plot flowed directly into observation wells, shown in Figure 1. The diameters of the gravel varied from 1 cm to 5 cm and the length of the straw was about 5 cm. The layered and mixed sand-gravel filters were mixed artificially based on the criteria of Terzaghi.

![Figure 1. Layout of the field experiment](image)

2.2 The Initial Soil Nitrogen and Phosphorus Contents.

Before the drainage test in 2016, the soil nitrogen and phosphorus contents were measured at three depths (0-20 cm, 20-50 cm, 50-80 cm). Five soil sample points were chosen randomly in each plot and the samples at same depth were mixed into one sample to be tested. Besides, the agricultural practices such as crop and fertilization and tillage method were the same in the five plots.

From Figure 2, it could be seen that the soil total nitrogen (TN) contents in plots of improved subsurface drainage with gravel, straw, layered sand-gravel filter and the conventional subsurface drainage were roughly equal at same depth layer respectively, while the TN content at 0-20 cm depth in the mixed sand-gravel improved plot was smaller than that at the same layer in other plots and the TN content at 50-80 cm depth was almost same with the conventional ones.

For the soil total phosphorus (TP) content, it could be seen that the TP contents were different at 0-20 cm and 20-50 cm depth in the five plots, especially for 0-20 cm depth layer, while the TP contents at 50-80 cm depth layer in plots of the improved...
subsurface drainage with gravel and straw and layered sand-gravel were roughly equal. Additionally, the TP contents in the plot of improved subsurface drainage with mixed sand-gravel were approximately equal to that in the conventional subsurface drainage plot (Figure 4).

2.3 Measurement of the Nitrogen and Phosphorus in Outflow

During 2016-2018, six field experiments were carried out. The nitrogen and phosphorus concentration of the drain outflow were measured three times with about 2~4 hour interval, shown in table 1. The pondushydrogenii value (pH), TN, ammonium-nitrogen (NH$_4^+$-N) and TP had been considered.

<table>
<thead>
<tr>
<th>Table 1. The sampling time after drainage (unit/min)</th>
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<td>June 5, 2016</td>
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<td>Initial stage</td>
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<td>Middle stage</td>
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<td>End stage</td>
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3. RESULTS AND DISCUSSION

3.1 pH

The pH of agriculture drainage which will affect the phosphorus and nitrogen release of the deposit sediment (Fisher, 2004) and impact eutrophication in river and lake, is very important for the water environment (Kim et al., 2003). Besides it, pH of the outflow can indirectly reflect the pH of the soil which will influence the migration and transformation of the phosphorus and nitrogen in the soil (Xu-Qian et al., 2011). Figure 5 showed the pH values under different subsurface drainage patterns at the initial, middle and end stage of the test. G/S/L/M/N stood for improved subsurface drainage with gravel filter, straw filter, layered sand-gravel filter, mixed sand-gravel filter and no filter (conventional subsurface drainage). From Figure 4, we could see that the pH values varied from 6.5 to 7.4 which satisfied the requirement of Chinese National Environmental Standard for Surface Water Quality. Compared with conventional subsurface drainage, the pH values of the outflow under the improved subsurface drainage with gravel, layered sand-gravel, mixed sand-gravel filter were a little larger. While for the improved subsurface drainage with straw, the pH value of the outflow was obviously lower than the conventional ones which indicated that the straw filter could lower the pH of the soil. The straw was decomposed to generate the humic acid and organic acid in the soil (Cui et al., 2017).

![Figure 4. Observed pH of the subsurface drainage outflow](image)

3.2 Total Nitrogen

Total nitrogen concentrations of the outflow at initial, middle and end stage were the same for conventional subsurface drainage and improved subsurface drainage. From Figure 5, we also see that total nitrogen concentrations of the outflow under improved subsurface drainage with gravel filter, layered sand-gravel filter and mixed sand-gravel filter were larger than that under conventional subsurface drainage, respectively by about 39%~78%, 24%~49% and 14~34% more in 2016, 160%~163%, 68%~80%, 48%~58% more in 2017, and 20%, 32%, -7% more in 2018. However, compared with conventional subsurface drainage, the total nitrogen concentrations of improved subsurface drainage with straw filter outflow were 62%, 23%, 15% less on June 5/ June 7/ June 24, 2016 and 76%, 54% more on September 6 / September 12, 2017 and 21% more on June 29, 2018.
3.3 Ammonia Nitrogen

For conventional subsurface drainage, the ammonia nitrogen concentrations of the outflow at initial, middle and end stage were respectively 1.57 mg/L, 1.38 mg/L and 1.10 mg/L on June 5, 2016, 0.116 mg/L and 0.084 mg/L on September 6, 2017, 0.184 mg/L, 0.054 mg/L and 0.031 mg/L on June 29, 2018. The ammonia nitrogen concentrations of the outflow at initial, middle and end stage of the test presented a decrease tendency (Figure 7). The reasons might be that the previous soil ammonium nitrogen accumulation around the pipe made the ammonia nitrogen concentration of the outflow large at initial stage and the ammonium nitrogen obtained by nitrogen mineralization was not enough to replace the loss of ammonium nitrogen within a short time. The ammonia nitrogen concentrations on June 5 and June 7, 2016 presented a decreasing tendency with average concentrations of 1.35 mg/L and 0.42 mg/L. Then with the temperature rising, the increasing nitrogen mineralization would produce more ammonia nitrogen (Lin et al., 2016) and might cause the phenomenon that ammonia nitrogen concentration on June 24, 2016 to be larger than that in June 7, 2016. Additionally, the ammonia nitrogen concentrations of the outflow in 2016, 2017 and 2018 reduced successively with about 1.35 mg/L, 0.091 mg/L and 0.09 mg/L in average respectively under conventional subsurface drainage (Figure 6). We could draw a conclusion that the ammonia nitrogen concentrations of the soil presented a decreasing tendency based on the background of same agricultural practice such as crop and fertilization and tillage method in these three years.

The improved subsurface drainage with different filter materials presented distinctive characteristics of ammonium nitrogen loss. Overall, the ammonium nitrogen concentrations of the outflow under the improved subsurface drainage with gravel filter, layered sand-gravel filter and mixed sand-gravel filter were smaller than that under conventional subsurface drainage, respectively about 60%, 78% and 76% less in 2016, 13%, 30% less in 2017, and 30%, 43%, 78% less in 2018. Two reasons might lead these cases. Firstly, the organic nitrogen contents in sand and gravel were much less than that in the soil (Wang et al., 2016). Hence, the ammonium nitrogen produced by nitrogen mineralization in sand and gravel were smaller than the soil which would make the ammonium nitrogen amount around the pipe less than the
conventional condition. Secondly, the gas permeability of soil under improved subsurface drainage was better than that under conventional subsurface drainage which could increase soil nitrification rate and then decrease the soil ammonium nitrogen content.

However, the improved subsurface drainage with straw filter presented an opposite conclusion that the ammonium nitrogen concentrations of the outflow were larger than the conventional subsurface drainage case. In 2016, the ammonium nitrogen concentrations with straw filter were in between about 207% larger than that under conventional subsurface drainage. Correspondingly, the increasing percentage in 2017 and 2018 were 274% and 152% respectively. Decomposition of the straw could promote microbial activity which would increase the soil ammonium nitrogen adsorption ability of the soil and make more ammonia nitrogen leach out. Furthermore, for the whole improved subsurface drainage patterns, the ammonia nitrogen concentrations of the outflow at initial, middle and end stage of the test also reduced in turn.

![Graph](image)

**Figure 6.** Observed ammonia nitrogen concentration of the subsurface drainage outflow

### 3.4 Total Phosphate

The total phosphate concentrations of the outflow at initial, middle and end stage decreased gradually, which was same as the trend observed in case of ammonia nitrogen for both conventional subsurface drainage and improved subsurface drainage (Figure. 7). The average total phosphate concentrations in the outflow under conventional subsurface drainage were 0.44 mg/L, 0.23 mg/L, 0.35 mg/L in 2016, 2017, 2018. The average total phosphate concentrations under the improved subsurface drainage with layered sand-gravel filter and mixed sand-gravel filter were about 40%~79% and 68~88% less than that under conventional subsurface drainage. While the average total phosphate concentrations under the improved subsurface
drainage with gravel filter and straw filter were about 0%~134% and 103%~400% more than that under conventional subsurface drainage.

**Figure 7.** Observed total phosphate concentration of the subsurface drainage outflow

### 4. CONCLUSIONS

This study showed the characteristics of nitrogen and phosphorus loss under the conventional subsurface drainage and improved subsurface drainage with different filter materials. Based on the experimental results, conclusions were drawn as follows. Firstly, the improved subsurface drainage with gravel filter, layered sand-gravel filter, mixed sand-gravel filter and straw filter showed different features on nitrogen and phosphorus loss. Secondly, compared with conventional subsurface drainage, the improved subsurface drainage with layered sand-gravel filter, mixed sand-gravel filter had better function on reducing the ammonia nitrogen and total phosphate concentrations of the outflow, but they increased the total nitrogen concentrations. The concentrations of nitrogen and phosphorus under the improved subsurface drainage with gravel filter are higher than that with layered sand-gravel filter and mixed sand-gravel filter. Thirdly, the concentrations of ammonia nitrogen and total phosphorus under the improved subsurface drainage with straw filter were higher than the conventional subsurface drainage. While the total nitrogen concentrations under improved subsurface drainage with straw filter might be influenced by the crop growing season.

With the customary fertilization method, nitrate nitrogen and total nitrogen concentrations in the outflow under all subsurface drainage pattern are much larger than the standard of water environmental quality in China. Agricultural water management such as fertilization management, controlled drainage, drainage water reuse should be adopted to reduce the nitrogen loss especially at the early stage of the drainage.
5. REFERENCES


Tao Y, Wang S, Xu D, Qu X. Experiment and analysis on flow rate of improved subsurface drainage with ponded water Agricultural Water Management 2016.


