Ecological Engineering 123 (2018) 193–201

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Plant uptake in subsurface wastewater infiltration systems plays an important role in removing nitrogen from sewage

Ying Ma[a], Jianyu Cui[a], Peng Zheng[c], Kaili Yuan[a], Songwei Chu[a], Kangguo Mu[a], Lin Hu[a,b,*]

[a] Beijing Key Laboratory of Farmland Pollution Prevention-control and Remediation, College of Resources and Environmental Sciences, China Agricultural University, Beijing 100193, PR China
[b] National Energy R&D Center for Non-Food Biomass of China, China Agricultural University, Beijing 100193, PR China
[c] Science and Technology Department, South China Agricultural University, Guangzhou, Guangdong 510642, PR China

ARTICLE INFO

Keywords:
Subsurface wastewater infiltration systems (SWIS)
Sewage treatment
Pollution load
Nitrate concentration
Total nitrogen removal
Turfgrass uptake

ABSTRACT

On the premise of maximizing nitrogen elimination in wastewater and recharging the effluent directly to groundwater, two groups of subsurface wastewater infiltration systems (SWIS), a turfgrass-covered system (S-G) and a bare soil system (S-B), were examined under a pollution load of 600 kg N ha^{-1} yr^{-1} to investigate the contribution of turfgrass in removing sewage nitrogen. The results showed that compared with S-B, the concentrations of total nitrogen (TN) and nitrate nitrogen (NO_3^--N) in S-G effluent were significantly lower. In 2014 and 2015, the average concentrations of NO_3^--N in S-B effluent were 38.9 and 36.8 mg L^{-1}. None of the NO_3^--N concentrations in S-B effluent satisfied the international standard for drinking water (10 mg L^{-1} NO_3^--N). While the average concentrations of NO_3^--N in S-G effluent in 2014 and 2015 were 2.96 and 0.80 mg L^{-1}, the proportions of NO_3^--N concentrations in S-G effluent, which were below 10 mg L^{-1} NO_3^--N, were 87.7% and 97.9%, respectively. The TN removal efficiency and removal quantity of the S-G were significantly higher than those of the S-B. In 2014 and 2015, the TN removal quantities of S-G were 646 and 647 kg ha^{-1} yr^{-1}, respectively, and the TN removal efficiencies reached 98.1% and 99.1%, for which the contribution efficiencies of turfgrass on nitrogen removal were 52.5% and 61.0%, respectively. Meanwhile, the TN removal quantities of S-B were 269 and 204 kg ha^{-1} yr^{-1}, and the TN removal efficiencies were 40.7% and 31.3% in 2014 and 2015, respectively. These obtained results indicated that plants play an important role in SWIS under these conditions.

1. Introduction

In recent years, centralized urban sewage treatment in China has made rapid progress, whereas the status of decentralized wastewater in rural areas remains concerning (MEPPRC, 2015). In 2014, less than 10% of rural sewage was treated (MEPPRC, 2015); meaning a large amount of rural sewage was directly discharged without treatment, which has caused serious environmental pollution. Therefore, it is particularly necessary to choose an onsite treatment technology and engineering applications suitable for decentralized domestic wastewater in China.

Onsite wastewater land treatment systems are important technologies for decentralized domestic wastewater treatment, including overland flow systems (Seguí et al., 2017), slow rate systems (Paranychianakis et al., 2006), rapid rate systems (Kadam et al., 2009), constructed wetland systems (Vymazal, 2011), and subsurface wastewater infiltration systems (SWIS) (Zheng et al., 2016), among which SWIS are the most commonly used (USEPA, 2002)). SWIS are suitable for decentralized sewage treatment with their advantages of easy construction, high practicality and low cost (Duan and Fedler, 2010; Duan et al., 2015). SWIS are often constructed on green land. They purify wastewater, provide vegetation with water and nutrients, and avoid the usage of extra land (Gao and Li, 1991; Yang et al., 1999).

SWIS have usually been effective in the removal of chemical oxygen demand, biochemical oxygen demand, suspended solids and phosphorus, but their performance in nitrogen removal is not satisfactory (Zhang et al., 2002; Zhang et al., 2005; Llorens et al., 2011; Qin et al., 2014). To enhance nitrogen removal performance, it is necessary to understand the importance of each mechanism for nitrogen removal in the SWIS (Pan et al., 2016).

Nitrogen removal mechanisms include ammonia volatilization, soil adsorption, plant uptake and nitrification-denitrification by

* Corresponding author at: Beijing Key Laboratory of Farmland Pollution Prevention-control and Remediation, College of Resources and Environmental Sciences, China Agricultural University, Beijing 100193, PR China.
E-mail address: hulin@cau.edu.cn (L. Hu).

https://doi.org/10.1016/j.ecoleng.2018.09.010
Received 9 December 2017; Received in revised form 9 August 2018; Accepted 9 September 2018
Available online 18 September 2018
0925-8574/

microorganisms (Degen et al., 1991; Beal et al., 2005; Vymazal, 2007). Among these, nitrification and denitrification are usually considered the main mechanisms responsible for eliminating nitrogen from sewage water (Zhang et al., 2002; Li et al., 2011; Pan et al., 2016). With regards to plant functions, few studies on the nitrogen removal contribution of plant uptake in SWIS have been recorded so far. Zhang et al. (2005) found that grass uptake accounts for 14.4–21.0% of the total nitrogen applied in SWIS, thus they argued that there was limited potential to enhance the nitrogen removal by promoting grass uptake and that improving the nitrification-denitrification processes was the key. Li et al. (2011) also indicated that nitrification-denitrification was the most significant mechanism for nitrogen removal in the SWIS, and other mechanisms such as grass uptake were generally less important, although they didn't provide any data support. However, in constructed wetlands and slow rate systems, which have similar removal processes to SWIS, numerous studies showed a different perspective on plant functions (Vymazal, 2007; Vymazal, 2011; Luo et al., 2018; Woodard et al., 2002; Adeli et al., 2003). The treatment performance of planted constructed wetlands was superior to that of unplanted soil filters (Vymazal, 2011; Vymazal, 2013; Yang et al., 2007). Luo et al. (2018) reported that the contribution of plant harvest uptake accounted for 13.0–55.0% of applied nitrogen, depending on the different inlet loading rates. Vymazal (2007) concluded that plant uptake was a major removal mechanism in constructed wetlands with free-floating macrophytes, while the removal of nitrogen via harvesting of aboveground biomass of emergent vegetation was low but could be substantial for lightly-loaded systems. In addition, in the slow rate system, previous studies reported that vegetation uptake was an important pathway for nitrogen removal in periodic harvesting and the removal of biomass (Tzanakakis et al., 2009; Woodard et al., 2002; Adeli et al., 2003; Valencia-Gica et al., 2012). Since SWIS have the similar nitrogen removal process to constructed wetlands and slow rate systems, plant cover may also influence the nitrogen removal performance of SWIS, but the contribution of plant uptake in SWIS is still uncertain, and more studies are necessary.

The growth and functions of plants can be impacted by pollutant loads (Luo et al., 2018; Saeed and Sun, 2012; Paranychianakis et al., 2006). The SWIS in the present study was intended to recharge the effluent directly to groundwater, which was considered the most suitable method for engineering applications (USEPA, 2002)). To protect groundwater from pollution, the nitrogen pollution load of SWIS should be controlled. Previous studies proved that under a nitrogen pollution load of 600 kg N ha^{-1} yr^{-1}, the nitrate concentration in effluents of SWIS was in the range of 1.67–9.65 mg L^{-1}, which was below the international maximum contaminant level (MCL) for drinking water (less than 10 mg L^{-1}) (Chen et al., 2014). Consequently, a nitrogen pollution load of 600 kg N ha^{-1} yr^{-1} was chosen in the following experimental investigation (Chen et al., 2014; Zheng et al., 2016). To the best of our knowledge, there is no report on the issue of the nitrogen removal contribution of plant uptake in SWIS under this condition.

The purpose of this study is to investigate the treatment effect of SWIS and the nitrogen removal contribution of plant uptake in SWIS under a pollution load of 600 kg N ha^{-1} yr^{-1}. This long-term investigation will provide a basis for better performance of the engineering application of SWIS.

2. Materials and methods

2.1. Device description

As shown in Fig. 1, the column simulation device for SWIS mainly includes four components: the soil column, the influent channel, the perforated water distribution pipe and the percolation trench. Each of the components is made of PVC materials. The inner diameter of the soil column is 30 cm, with a corresponding height of 100 cm. From the bottom up, the column is gradually filled with a 5-cm gravel layer, a 5-cm coarse sand layer (the ratio of particle size ranging from 0.5 to 2.0 mm is 93.7%) and 60 cm of loam sand. The percolation trench, an uncovered PVC box with a dimension of 25 cm × 15 cm × 15 cm, is installed at a depth of 30 cm from the upper surface of the soil column. In the percolation trench, a 5-cm gravel layer and a 5-cm coarse sand layer are placed in order. Sandy loam soil are used to fill the empty part of the trench and the column. A perforated water distribution pipe with a diameter of 1.5 cm is placed in the gravel layer of the percolation trench. There are small drip holes arranged in the form of a plum blossom on the pipe. Each hole is 0.2 cm in diameter. This pipe extends beyond the soil column and connects to the influent channel. The influent channel is a covered cylinder that is 35 cm tall and 10 cm in diameter. The sewage influent is poured into the influent channel, flows through the perforated water distribution pipe, and finally drips into the percolation trench. For testing purposes, there is a drain pipe on the bottom of the column. When it is connected to the hose, the effluent can be collected in a collecting bottle.

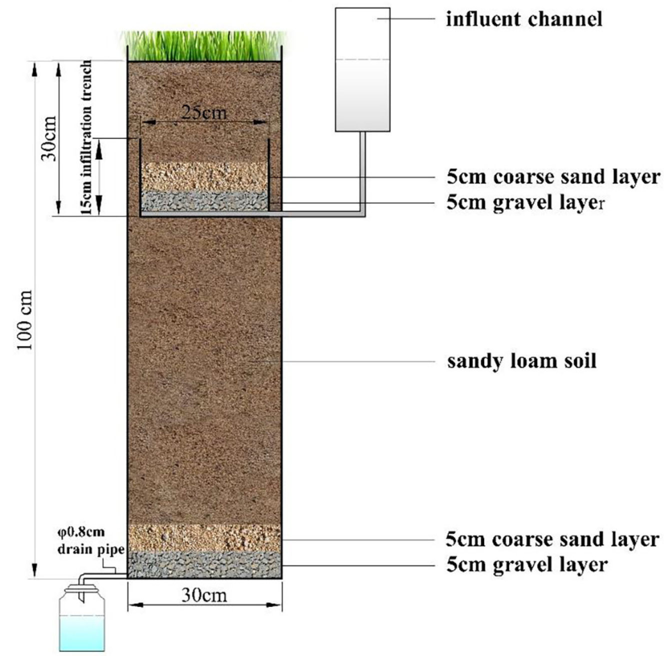

Fig. 1. Profile of experimental device.

2.2. Experimental scheme

The soil column experiments were carried out at China Agricultural University (40°01′31″N, 116°16′34″E), Beijing (Fig. 2). Two treatments with three replications were arranged, including the "turfgrass-covered SWIS" (S-G) and the "bare soil SWIS" (S-B).

Tall fescue (*Festuca arundinacea,* hereinafter referred to as turfgrass), one of the most widely-used cool-season turfgrasses in Beijing, was sown in the S-G treatment in late March 2014. When the sewage treatment experiment began, the S-G treatment had been generally covered by turfgrass. Subsurface wastewater infiltration systems were operated from April 18 to December 2 in 2014 and from March 22 to November 23 in 2015. Due to the low temperatures in winter, the sewage in the influent channel and the soil in the columns were easily frozen; thus, the SWIS could not operate from early December to late March of the following year. Rainfall and mean monthly temperature during the experiment are shown in Fig. 3.

This experiment was conducted outdoors and there was no rain-proof measure. Sewage influent and precipitation were the water source for turfgrass growth in SWIS. The study used total nitrogen (TN) as a control indicator for the input of pollutants, and the annual pollution

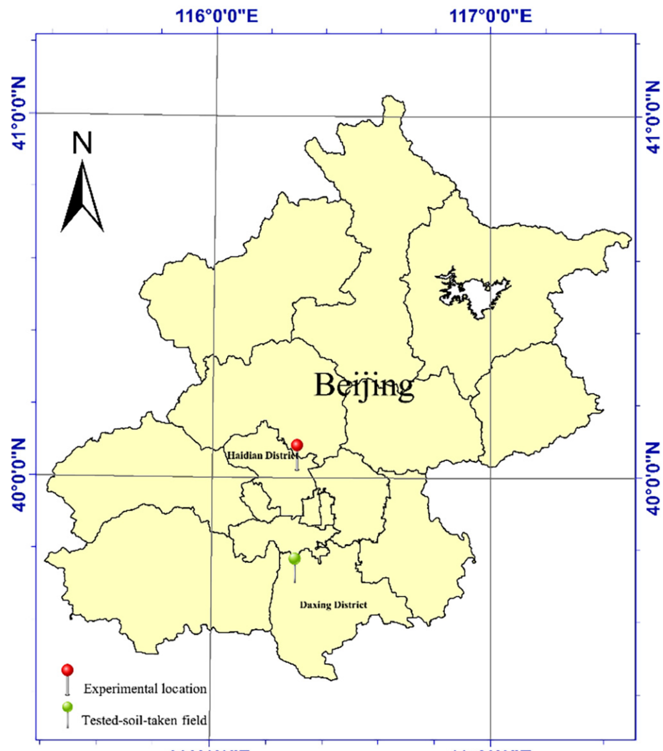

Fig. 2. Location of the studied SWIS in Beijing.

load was controlled at 600 kg N ha^{-1} yr^{-1}. Raw sewage was obtained from septic tank in the university, which needed to be preliminarily filtered to avoid clogging the system. Sewage influent of SWIS was the dilution of the raw sewage. The total nitrogen concentration of the sewage influent was manually diluted with tap water to approximately 40 mg L^{-1}, which may represent typical characteristics of nitrogen pollution in domestic sewage (Zheng et al., 2016). Therefore, the total nitrogen concentration of the raw sewage should be tested the day before each influent distribution, to calculate the raw sewage/tap water ratios for raw sewage dilution. The concentrations of other indices in sewage influent fluctuated with season. The hydraulic loading of SWIS was set as 5 mm d^{-1}, which may not only meet the control requirement for nitrogen pollutants but also satisfy the turfgrass water requirement. The sewage influent was distributed into the system with 15 mm every three days, at 8:00 a.m. during the two-year experimental period. Influent samples were taken after the raw sewage being mixed with tap water. Effluent water samples were taken from the collecting bottle every three days before each sewage influent distribution. Rainwater was collected after precipitation. The volume and quality of the influent, effluent and rainwater were tested afterwards.

To ensure a favorable landscape effect, the turfgrass was kept mowed to about a 5 cm height. According to the “one-third” mowing rule, mowing should be performed every 7–10 days, with no more than 1/3 of the blade cut at one time (Emmons, 2007). Turfgrass clippings were collected after mowing. The dry weight and total nitrogen concentration of the clippings were measured.

2.3. Characteristics of the tested materials

The tested soil was taken from Daxing District (39°44′55″N, 116°20′48″E) in Beijing, and its texture is sandy loam. The physical and chemical properties of the tested soil were a pH of 9.0, organic matter at 1.76 g kg^{-1}, total nitrogen at 0.044 g kg^{-1}, available phosphorus at 1.72 mg kg^{-1}, and potassium at 18.6 mg kg^{-1}. The main indices of water quality for sewage influent are shown in Table 1.

2.4. Testing and analysis method

The water samples were analyzed according to water and wastewater monitoring and analysis methods (APHA, 2012). The alkaline potassium persulfate digestion ultraviolet spectrophotometric method was used for the total nitrogen (TN) test, the ultraviolet spectrophotometric method was used for the nitrate nitrogen (NO_3^--N) test, Nessler’s reagent spectrophotometry was used for ammonia nitrogen (NH_4^+-N), total phosphorus (TP) was tested by total phosphorus ammonium molybdate spectrophotometric method, and chemical oxygen

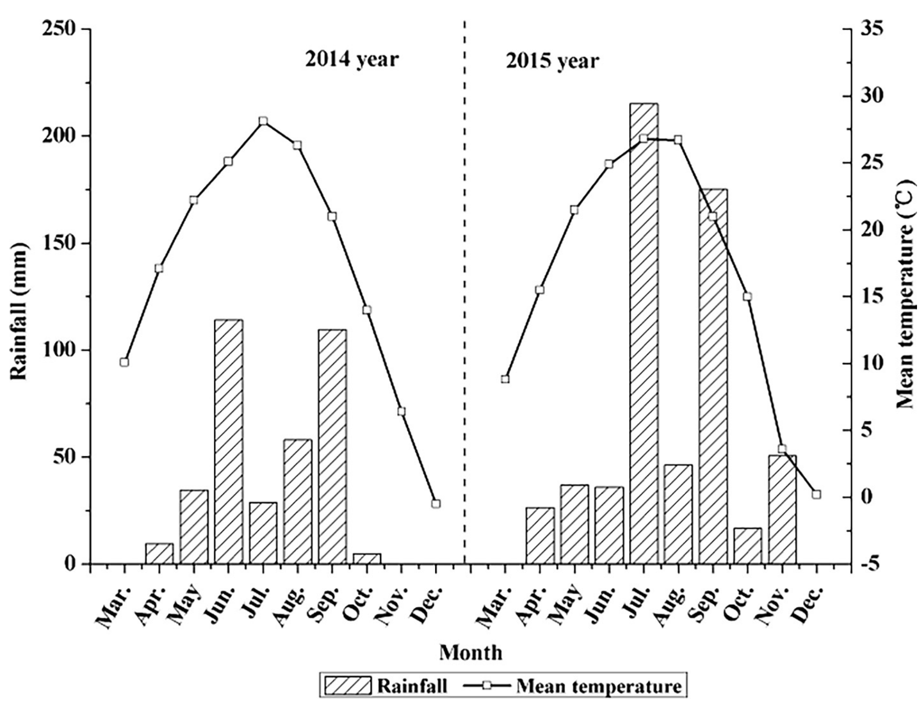

Fig. 3. Rainfall and mean monthly temperature during the experiment.

Table 1
Main indices of water quality for sewage influent.

Water quality indices	Range ($mg\,L^{-1}$)	Average value ($mg\,L^{-1}$)
TN	37.3–48.0	41.5
NO_3^--N	2.01–4.92	3.38
NH_4^+-N	26.4–43.8	34.1
TP	1.45–9.23	2.94
COD_{Mn}	17.7–78.4	34.0

demand (COD_{Mn}) was determined by the water bath potassium permanganate titration method. The biomass of turfgrass clippings was weighed after being dried for 48 h at 75 °C. The total nitrogen concentration of turfgrass clippings was tested using the H_2SO_4-H_2O_2 digestion-distillation method.

Calculation formulas are shown as the following:

1) Total quantities of the influent pollutant and the effluent pollutant

$$Q_1 = \Sigma c_1 \times V_1 \quad (1)$$

$$Q_E = \Sigma c_E \times V_E \quad (2)$$

where Q_I and Q_E indicate the total quantities of influent pollutant and effluent pollutant respectively, mg; C_I refers to the influent pollutant concentration, including sewage and the rainwater, $mg\,L^{-1}$; C_E is the effluent pollutant concentration, $mg\,L^{-1}$; V_I is the influent volume, including sewage and the rainwater, L; V_E is the effluent volume, L.

2) Pollutant removal efficiency

$$\eta_1 = \frac{Q_1 - Q_E}{Q_1} \times 100\% \quad (3)$$

where η_1 refers to the pollutant removal efficiency, %.

3) Daily pollutant removal quantity and annual pollutant removal quantity

$$Q_{Day} = \frac{Q_I - Q_E}{S \times t} \quad (4)$$

$$Q_{Year} = Q_{Day} \times T \times 10 \quad (5)$$

where Q_{Day} refers to the daily pollutant removal quantity, $g\,m^{-2}\,d^{-1}$; S is the area of the soil column, m^2; t is the actual operation period of SWIS, d; Q_{Year} means the annual pollutant removal quantity, $kg\,ha^{-1}\,yr^{-1}$; T is the annual operation period in theory, 300 days, d.

It should be noted that SWIS cannot operate in winter due to the soil freezing conditions in Beijing. Therefore, the year-round operation in this study refers to the experimental length of approximately 300 days per year, in theory. 300 days are used as an estimate in calculating the annual removal quantity and the annual pollution load.

4) Turfgrass clipping contribution efficiency

Turfgrass clipping contribution efficiency in this study refers to the proportion of nitrogen nutrients absorbed by the turfgrass clippings to the pollutant removal quantity during the actual operation period. The calculation formula is shown as the following:

$$\eta_2 = \frac{\Sigma c_G \times M_G}{Q_I - Q_E} \times 100\% \quad (6)$$

where η_2 indicates the turfgrass clipping contribution efficiency, %; C_G is the nitrogen concentration in the turfgrass clippings, $mg\,g^{-1}$; and M_G represents the dry weight of turfgrass clippings, g.

SAS statistical software (SAS Institute, Cary, NC, USA) was used for analysis of variance, where $p < 0.05$ was considered statistically significant. The method of Least Significant Difference (LSD) was used for mean comparison.

3. Results

3.1. Effect of the SWIS on NH_4^+-N removal

The results for 2014 (Fig. 4, a) showed that the NH_4^+-N concentration in effluents was in the range of 0.08–1.76 $mg\,L^{-1}$ in the S-B

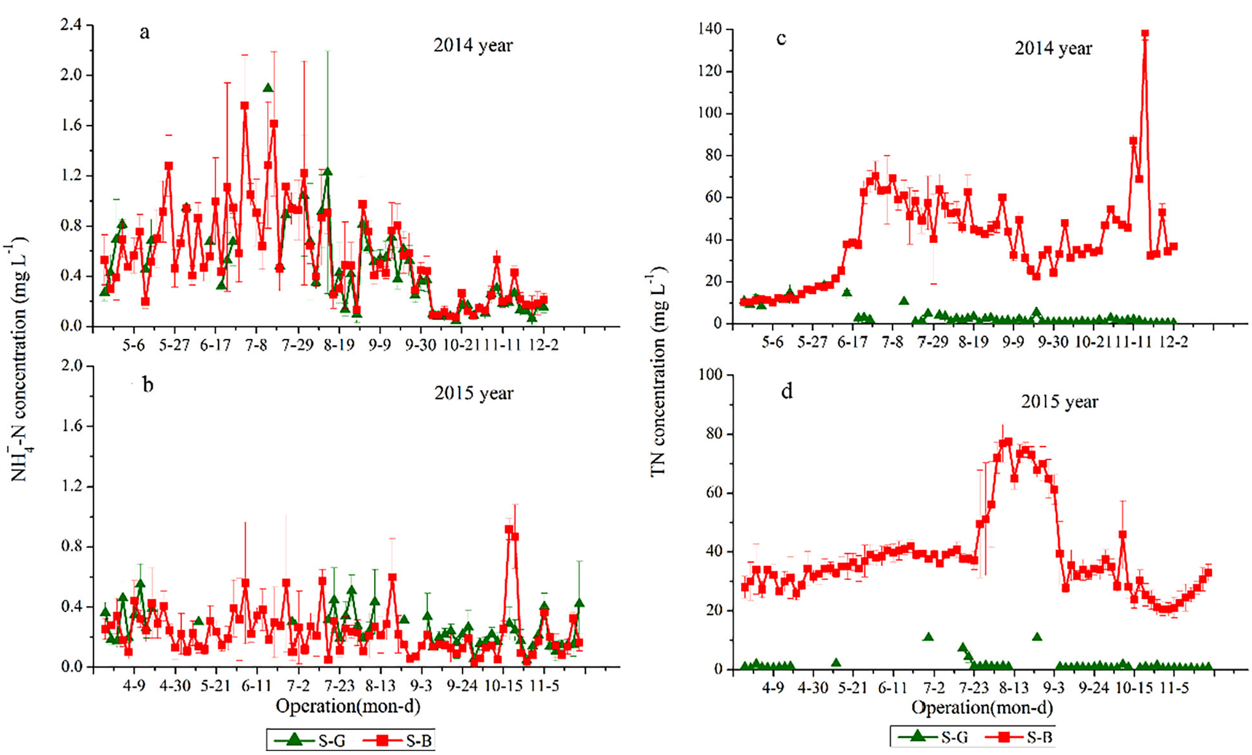

Fig. 4. Ammonia nitrogen and total nitrogen concentration changes of SWIS effluent.

system and in the range of 0.04–1.90 $mg\,L^{-1}$ in the S-G system. The average NH_4^+-N concentration of the S-B treatment in effluents (0.56 ± 0.37 $mg\,L^{-1}$) was significantly higher than that of the S-G treatment (0.45 ± 0.35 $mg\,L^{-1}$). The removal efficiencies of NH_4^+-N were very high in both the S-B and S-G treatments, at 99.2% and 99.7% respectively. The daily and annual removal quantities of NH_4^+-N were 0.191 $g\,m^{-2}\,d^{-1}$ and 572 $kg\,ha^{-1}\,yr^{-1}$, respectively, in the S-B system, while for the S-G system, the daily and annual removal quantities of NH_4^+-N were 0.192 $g\,m^{-2}\,d^{-1}$ and 575 $kg\,ha^{-1}\,yr^{-1}$, respectively.

In 2015, the average NH_4^+-N concentration of the S-B and S-G treatments in effluents were 0.24 ± 0.16 $mg\,L^{-1}$ (ranging from 0.03 to 0.92 $mg\,L^{-1}$) and 0.25 ± 0.12 $mg\,L^{-1}$ (ranging from 0.05 to 0.55 $mg\,L^{-1}$), respectively, which showed no significant differences (Fig. 4, b). The removal efficiencies of NH_4^+-N achieved 99.5% and 99.7%, respectively, in the S-B and S-G treatments. The daily NH_4^+-N removal quantities were 0.166 $g\,m^{-2}\,d^{-1}$ in both the S-B and S-G treatments, which were equivalent to the annual NH_4^+-N removal quantities of 497 $kg\,ha^{-1}\,yr^{-1}$.

The two-year results indicated that the majority of NH_4^+-N in the influent was removed in the S-B and S-G treatments. The NH_4^+-N removal efficiencies and removal quantities of the two treatments were very high, which showed that both the S-B system and S-G system can have positive effects on NH_4^+-N removal.

3.2. Effect of the SWIS on TN removal

In 2014, the TN concentration of the S-B system in effluents ranged from 10.2 to 139 $mg\,L^{-1}$, with an average value of 40.5 ± 21.6 $mg\,L^{-1}$, while the TN concentration of the S-G system in effluents varied between 0.30 and 18.3 $mg\,L^{-1}$, with an average value of 3.31 ± 4.22 $mg\,L^{-1}$. In 2015, the TN concentration of the S-B system in effluents exhibited an average value of 38.7 ± 14.3 $mg\,L^{-1}$, varying between 20.5 and 77.5 $mg\,L^{-1}$, while in the S-G system, the average value of the TN concentration in effluents was 1.54 ± 2.29 $mg\,L^{-1}$, ranging from 0.30 to 10.86 $mg\,L^{-1}$. As indicated by the two-year results, the average TN concentration of the S-B system in effluents was significantly higher than that of the S-G system. As shown in Fig. 4c, at the beginning of the experiment in 2014, the TN concentration of the S-B system in effluents was much lower than the annual average concentration of 40.5 $mg\,L^{-1}$, and there was no significant difference with the S-G system. Approximately 90 days later, the TN concentration of the S-B system in effluents began to obviously rise and fluctuate constantly, whereas the TN concentration of the S-G system in effluents decreased and gradually trended towards stability. In 2015, the TN concentration of the S-B system in effluents stayed stable approximately 20–40 $mg\,L^{-1}$, except the peak in August and September, whereas the TN concentration of the S-G system in effluents remained at a lower value all year round (Fig. 4, d).

The SWIS sewage influent is from septic tank supernatant, and the main forms of nitrogen are ammonia-nitrogen and organic nitrogen. Nitrification and denitrification reactions occurred inside the system so that the existing forms of nitrogen in the collected effluents were transformed into NH_4^+-N, NO_3^--N, etc. As displayed in Table 2, the TN removal efficiency of S-G reached as high as 98.1% in 2014 and 99.1% in 2015, respectively, which was significantly higher than that of the S-B treatment (40.7% in 2014 and 31.3% in 2015). The daily and annual TN removal quantities of S-B in 2014 were 0.09 $g\,m^{-2}\,d^{-1}$ and 269 $kg\,ha^{-1}\,yr^{-1}$, respectively, which were significantly lower than those of the S-G treatment (0.22 $g\,m^{-2}\,d^{-1}$ and 646 $kg\,ha^{-1}\,yr^{-1}$ respectively). In 2015, the daily and annual TN removal quantities of S-G were more than three times higher than those of the S-B treatment. According to the results, the TN removal efficiency and quantity of S-G were more than double the values of those in S-B, and there were significant differences in the two treatments. This indicated that the nitrogen removal ability of S-G was much higher than that of S-B.

Table 2
Total nitrogen removal efficiency and removal quantity of SWIS in 2014–2015.

Year	Treatment	Removal efficiency (%)	Removal quantity per day ($g\,m^{-2}\,d^{-1}$)	Removal quantity per year ($kg\,ha^{-1}\,yr^{-1}$)
2014	S-B	40.7 ± 2.54b	0.09 ± 0.0053b	269 ± 15.9b
	S-G	98.1 ± 0.34a	0.22 ± 0.0008a	646 ± 2.27a
2015	S-B	31.3 ± 0.02b	0.07 ± 0.005b	204 ± 14.1b
	S-G	99.1 ± 0.0004a	0.22 ± 0.00009a	647 ± 0.27a

Note that different lowercase letters indicate significant differences between treatments.

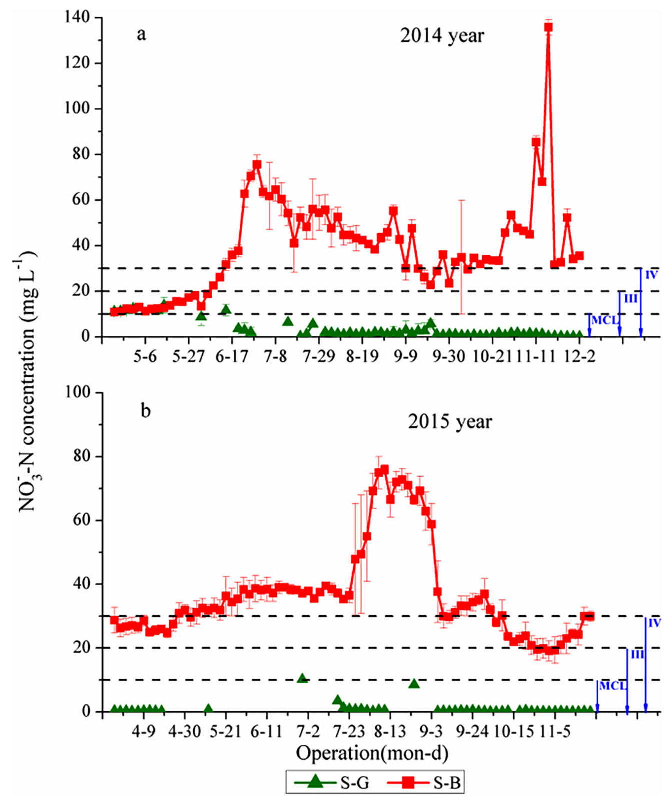

Fig. 5. Nitrate nitrogen concentration change of SWIS effluent.

3.3. Effect of the SWIS on NO_3^--N removal

Nitrate-nitrogen has an important impact on human health and is thus a critical indicator of pollution control. Nitrate-nitrogen was the major component of nitrogen in SWIS effluents, accounting for 70.6–95.9% of the total nitrogen. The changing trend of NO_3^--N concentration in effluents was consistent with the changing trend of TN concentration (Fig. 5). In 2014, the NO_3^--N concentration of the S-B system in effluents varied between 10.9 and 136 $mg\,L^{-1}$, with an average value of 38.9 ± 20.8 $mg\,L^{-1}$, while the NO_3^--N concentration of the S-G system in effluents ranged from 0.21 to 13.8 $mg\,L^{-1}$, averaging 2.96 ± 3.74 $mg\,L^{-1}$. In 2015, the average values of the NO_3^--N concentrations of the S-B and S-G systems in effluents were 36.8 ± 14.6 $mg\,L^{-1}$ and 0.80 ± 1.90 $mg\,L^{-1}$, respectively, and showed variations ranging between 19.1 and 75.9 $mg\,L^{-1}$ for the S-B system, and 0.11–10.2 $mg\,L^{-1}$ for the S-G system. The obtained results indicated that the average NO_3^--N concentration of the S-B system in effluents was significantly higher than that of the S-G system.

The environmental risk of nitrates in the SWIS effluents can be evaluated by two standards. One is the drinking water maximum contaminant level (MCL) of 10 $mg\,L^{-1}$ for NO_3^--N, which is set by the World Health Organization (WHO) (WHO, 2011). The other is China's

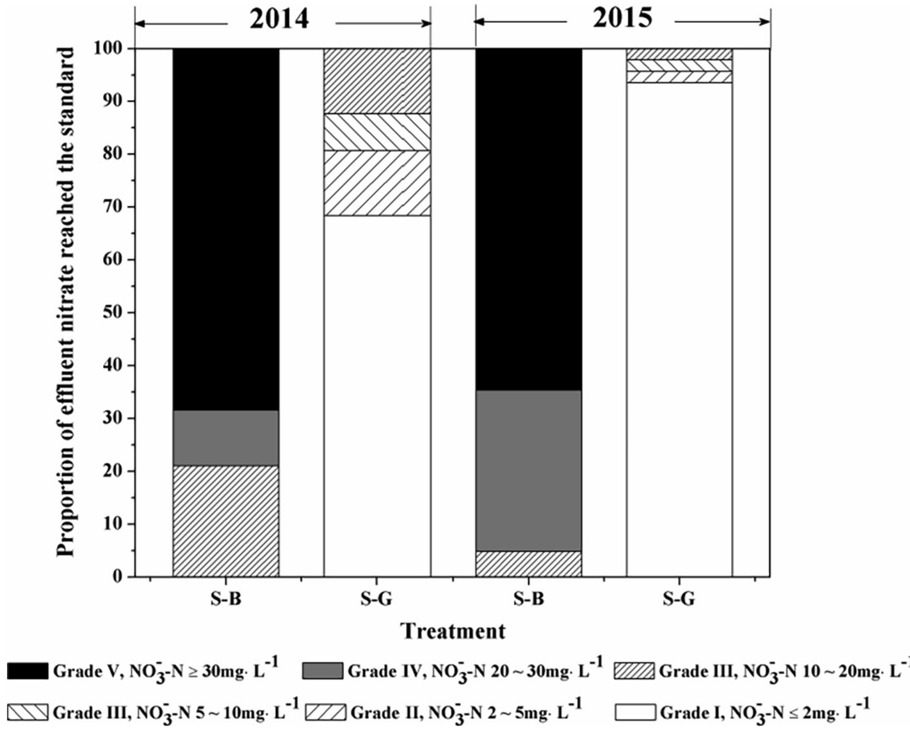

Fig. 6. Proportions of nitrate nitrogen concentration in effluent that satisfied the standards in 2014–2015.

national quality standard for groundwater (GB/T 14848-2017). The proportions of NO_3^--N concentration in effluents which met the standards are presented in Fig. 6. In the S-B treatment, none of the NO_3^--N concentrations met the international MCL during these two years. However, in the S-G treatment, the proportions of NO_3^--N concentrations in effluents which were lower than the international MCL of 10 mg L^{-1}, were 87.7% in 2014 and 97.9% in 2015, respectively, with an average of 92.8%. In addition, only 21.1% and 4.9% of the effluents of the S-B treatment were able to meet the Grade III of GB/T 14848-2017 for NO_3^--N in 2014 and 2015, respectively, whereas 100% of the effluents of the S-G treatment were below Grade III. Among these, the two-year average proportions of S-G, which met Grade I, II, and III of GB/T 14848-2017 for NO_3^--N, were 81.0%, 7.20% and 11.8%, respectively. The results showed that the S-G treatment significantly reduced the risk of environmental pollution of NO_3^--N in the SWIS effluents.

3.4. Nitrogen removal contribution of turfgrass

The dry weight, total nitrogen concentration, and nitrogen uptake quantities of turfgrass clippings in 2014–2015 are listed in Table 3. The total nitrogen concentration of turfgrass clippings was 35.2 g kg^{-1} and 36.5 g kg^{-1} in 2014 and 2015, respectively, which indicated a non-significant difference, whereas the dry weight of turfgrass clippings in 2015 (920 g m^{-2}) was significantly higher than that in 2014 (764 g m^{-2}). The annual difference of dry weight presented the difference of turfgrass growth in the two years, which was probably caused by the interannual variation of temperature and precipitation (Fig. 3). Additionally, this difference may also relate to the turfgrass maturity; that is, the turfgrass was newly planted in 2014 and had grown more mature in 2015. The nitrogen uptake quantities of turfgrass clippings in 2015 was significantly higher (32.4 g N m^{-2}) than that in 2014 (25.8 g N m^{-2}).

Table 3
Dry weight, nitrogen concentration and nitrogen uptake quantity of turfgrass clippings in S-G.

Treatment	Year	Dry weight (g m^{-2})	Nitrogen concentration (g kg^{-1})	Nitrogen uptake quantity (g N m^{-2})
S-G	2014	764 ± 24.5B	35.2 ± 1.20A	25.8 ± 0.34B
	2015	920 ± 31.3A	36.5 ± 0.66A	32.4 ± 0.13A

Note that different capital letters indicate significant differences between 2 years.

The nitrogen inputs of SWIS were mainly from sewage and rainwater. As displayed in Table 4, the total quantity of nitrogen input was 50.1 g N m^{-2} in 2014, with 49.9 g N m^{-2} from sewage and 0.23 g N m^{-2} from rainwater. The quantity of nitrogen in the S-G effluent was 1.00 g N m^{-2}, and nitrogen uptake quantity of the turfgrass clippings was 25.8 g N m^{-2}. According to formula (6), nitrogen removal contribution by the turfgrass clippings accounted for 52.5%. Moreover, in 2015, the total quantity of nitrogen input was 53.6 g m^{-2}, including 50.1 g N m^{-2} from sewage and 3.48 g N m^{-2} from rainwater. The quantity of nitrogen in S-G effluent was 0.49 g N m^{-2} and the nitrogen uptake quantity of turfgrass clippings increased to 32.4 g N m^{-2} in 2015. Hence, the turfgrass clipping contribution efficiency of nitrogen increased to 61.0% in 2015 in the S-G system.

The results indicated that the turfgrass clipping contribution efficiency of nitrogen found in this study was very high, reaching 52.5–61.0%. In short, the turfgrass uptake was able to contribute more than half of the nitrogen removal in SWIS, whereas the contribution efficiency of other nitrogen removal mechanisms including nitrification-denitrification, ammonia volatilization and soil adsorption was less than 47.5%. The effect of nitrification-denitrification in nitrogen removal was far less than that of the turfgrass uptake. The results also indicated that in two years, the total nitrogen concentration of turfgrass clippings showed a non-significant difference, thus the difference in nitrogen uptake quantity mainly depended on the biomass of the turfgrass clippings. Therefore, it is feasible to enhance the turfgrass uptake contribution efficiency in SWIS by increasing the turfgrass biomass as much as possible.

Table 4
Turfgrass contribution to nitrogen removal of SWIS.

Treatment	Year	TN input ($g\,N\,m^{-2}$)		TN output ($g\,N\,m^{-2}$)		Efficiency (%)	
		Domestic sewage	Rainwater	Turfgrass uptake	Effluent output	Removal efficiency	Turfgrass contribution efficiency
S-G	2014	49.9	0.23	25.8 ± 0.34	1.00 ± 0.17	98.1 ± 0.34	52.5 ± 0.82
	2015	50.1	3.48	32.4 ± 0.13	0.49 ± 0.02	99.1 ± 0.0004	61.0 ± 0.24

4. Discussion

4.1. Optimal indicator evaluation

Ammonia-nitrogen is the main form of nitrogen in sewage (Li et al., 2013). In this study, the sewage influent of SWIS was taken from a septic tank, in which NH_4^+-N accounted for 82.2% of the total nitrogen. The NH_4^+-N removal in SWIS may follow several pathways, including ammonia volatilization, plant uptake, soil adsorption and nitrification. Ammonium ions are adsorbed easily by the soil particles, which are negative in charge (Li et al., 2013). Some of the soil-fixed NH_4^+-N are absorbed by plants, and some of them are oxidized into nitrate by nitrifying bacteria (Llorens et al., 2015). Ammonia-nitrogen was almost completely removed from the soil depth of 40–60 cm, and the removal efficiency of SWIS was up to 90% (Van cuyk et al., 2001; Fei et al., 2016). The NH_4^+-N removal efficiency was more than 99% in both the S-B treatment and S-G treatment in the two-year study, which was consistent with previous researches (Fei et al., 2016; Pan et al., 2016). These results indicated that most of the NH_4^+-N in the influent was removed by SWIS, thus SWIS performed well in NH_4^+-N removal in both the S-B and S-G treatments. Whether there were plants covering the SWIS had no significant effect on NH_4^+-N removal.

Nitrate-nitrogen has a negative effect on human health (USEPA, 2010). The nitrate concentration of the effluent was higher than that of sewage influent in SWIS, which indicated that NH_4^+-N in the influent was transformed into NO_3^--N via nitrosation and nitrification by microorganisms in the upper soil (Beal et al., 2005). According to formula (3), the NO_3^--N removal efficiency presented negative values, which indicated that it is meaningless to evaluate the removal effect of nitrogen by NO_3^--N removal efficiency. Nitrate-nitrogen can be removed by plant uptake, and it can also be converted to N_2 and N_2O via denitrification in SWIS (Li et al., 2013). Compared with the S-G system, the NO_3^--N removal of the S-B system was only able to rely on denitrification, not including plant uptake. As the sewage influent with nutrient distributed into the system continuously, there appeared an amount of nitrogen residue in the soil in S-B system. Due to negative charge, nitrate was not easily adsorbed by the soil, and thus the residual nitrate nitrogen was easily leached out of the system when the influent was fed into the system, which could lead to the pollution of groundwater (Sevostianova and Leinauer, 2014). This might be the reason why TN concentration of the S-B system in effluent reached the peak value of 139 $mg\,L^{-1}$ in November 2014. Therefore, the NO_3^--N concentration of effluent in the S-B system was significantly higher than that of the S-G system, increasing the risk of groundwater pollution drastically.

Nitrogen can exist in many forms (Pan et al., 2016). In the wastewater treatment process, what we need to remove is nitrogen, not just ammonia-nitrogen. In this study, the NH_4^+-N removal efficiency in the S-B system and S-G system were both high, reaching more than 99%. However, this did not mean that nitrogen was completely removed. If using NH_4^+-N as the main evaluating indicator, the results indicated a low NH_4^+-N concentration and a high NH_4^+-N removal efficiency, so the removal performance of the S-B system was also very good. However, as a matter of fact, the TN concentration in the S-B system did not decrease, and a large amount of NO_3^--N in the effluents posed a serious environmental risk. The NO_3^--N concentration of the S-B system was significantly higher than that of the S-G system, and the TN removal efficiency of the S-B system was significantly lower than that of the S-G system, which illustrated that a majority of the nitrogen in the S-B system was not removed but was transformed into another forms. This indicated that TN, rather than NH_4^+-N or NO_3^--N, is the only appropriate evaluating indicator for the removal of nitrogen.

Most of the wastewater treatment studies adopted NH_4^+-N as the evaluating indicator, and the water environment assessment indicators in China are NH_4^+-N and COD (Yang et al., 2016; MEPPRC, 2015). Nevertheless, the results of this study showed that although the concentration of NH_4^+-N was very low, the TN concentration was not, and so the environmental quality was still not improved. Therefore, it is not appropriate to characterize the nitrogen removal ability by either NO_3^--N or NH_4^+-N removal efficiency, but it is more reasonable to use the TN removal quantity and efficiency to evaluate the nitrogen removal performance. Therefore, for the removal of nitrogen, TN should be the primary evaluating indicator, while NH_4^+-N can only serve as a reference indicator. The current environmental evaluation indicator in China is therefore defective, and this study has a positive impact on the improvement of the water environment assessment system in China.

4.2. Contribution of plant to nitrogen removal

Vegetation is an important component of land sewage treatment systems (Tzanakakis et al., 2009; Hallin et al., 2015). Plants have mechanisms for transporting oxygen to the rhizosphere, which can improve the growth conditions for microbial communities and be conducive to the degradation of pollutants (Shimp et al., 1993). Moreover, nitrogen is absorbed by roots and transported to the aboveground parts during the growth of plants, and then removed by harvesting plants periodically (Keizer-Vlek et al., 2014; Zheng et al., 2015; Pavlineri et al., 2017).

As the turfgrass grows on the SWIS soil column, its roots and rhizomes are embedded in these materials and cannot be easily extracted for analysis. To test root mass distribution by depth and nitrogen accumulation in the roots, the soil column should be broken. For the continuity of the long-term experiment, the present study didn't break the experimental device to test turfgrass root. Thus, the assessment of turfgrass uptake by harvests is important to clarify the plant contribution in SWIS. The turfgrass clipping contribution efficiency, which refers to the proportion of nitrogen nutrient uptake of the turfgrass clippings to the pollutant removal quantity, was 52.5–61.0% in this study. The results suggested that turfgrass plays an important role in SWIS. The present results were consistent with the results in slow rate systems that were founded by Paranychianakis et al. (2006) and Tzanakakis et al. (2009).

Plant uptake in land treatment systems is affected by many factors, including plant species, sewage characteristics, soil matrix and climate conditions (Tzanakakis et al., 2003; Huett et al., 2005; Keizer-Vlek et al., 2014; Pavlineri et al., 2017). In the present study, Tall Fescue (*Festuca arundinacea*) was chosen as the plant covered on SWIS. *Festuca arundinacea* is one of the most widely used cool-season turfgrass in Beijing. It is adapted to the climate in northern China and has strong resistance and tolerance to environmental factors. *Festuca arundinacea* can be planted in parks, recreational facilities, and residential areas and it is easy for maintenance and management (Emmons, 2007). Compared with the warm-season turfgrass (*Zoysia japonica)*, *Festuca*

Table 5
Research progress on contribution of plants in land sewage treatment systems.

TN pollution load ($kg\,ha^{-1}\,y^{-1}$)	Nitrogen contribution (%)	Plant species	References
2600	17[a]	*Kentucky bluegrass*	Zhang et al., 2002
1032	21 [a]	*Ryegrass*	Zhang et al., 2005
370	94 [a]	*Banagrass (Pennisetum purpureum)*	Valencia-Gica et al., 2012
	59 [a]	*Stargrass (Cynodon nlemfuensis)*	
1200	48 [a]	*Banagrass (Pennisetum purpureum)*	
	37 [a]	*Stargrass (Cynodon nlemfuensis)*	
500	89 [a]	*Bermudagrass–rye (BR)*	Woodard et al., 2002
	63 [a]	*Corn–forage sorghum–rye (CSR)*	
690	73 [a]	*Bermudagrass–rye (BR)*	
	48 [a]	*Corn–forage sorghum–rye (CSR)*	
910	60 [a]	*Bermudagrass–rye (BR)*	
	41 [a]	*Corn–forage sorghum–rye (CSR)*	
2444	14.5 [a]	*Ryegrass*	Duan et al., 2015
213	64 [a]	*Bermudagrass*	Adeli et al., 2003
660	40 [a]		
600	53–61[b]	*Tall fescue*	This study

Note that lowercase “a” represents the proportion of nitrogen nutrient uptake by plants to the applied nitrogen, while lowercase “b” represents the proportion of nitrogen nutrient uptake by plants to the pollutant removal quantity.

arundinacea had the longer green period, and nitrogen concentration of *Festuca arundinacea* was significantly higher than that of *Zoysia japonica* (Zhang et al., 2011). Compared with other cool-season turfgrasses (e.g. *Poa pratensis* and *Lolium perenne*), the annual biomass of *Festuca arundinacea* was the biggest and its root was the deepest, which could remove more nitrogen by the harvest of turfgrass (Liu et al., 2008).

The plant uptake contribution to sewage nitrogen removal varies depending on the nitrogen pollution load in the influent (Woodard et al., 2002; Adeli et al., 2003). Valencia-Gica et al. (2012) reported that under a nitrogen pollution load of $370\,kg\,N\,ha^{-1}\,yr^{-1}$, the nitrogen removal by *Banagrass* and *Stargrass* represented 94% and 59% of the TN applied respectively, whereas these percentages decreased by almost half when the nitrogen load reached $1200\,kg\,N\,ha^{-1}\,yr^{-1}$. The nitrogen removal contributions of *Bermudagrass* were 64% and 40% of the TN applied respectively under the pollution loads of $213\,kg\,N\,ha^{-1}\,yr^{-1}$ and $660\,kg\,N\,ha^{-1}\,yr^{-1}$ (Adeli et al., 2003). According to the studies above (Table 5), it can be concluded that different plants have different abilities on nitrogen removal in land wastewater treatment systems, and the plant uptake contributions to nitrogen removal would be decreased with the increasing of the nitrogen pollution loads.

4.3. The appropriate pollution load of SWIS for engineering applications

The study conducted by Zhang et al. (2002) indicated that the uptake of nitrogen by *Kentucky bluegrass* accounted for no more than 17% of the TN applied when the nitrogen pollution load was equivalent to $2600\,kg\,N\,ha^{-1}\,yr^{-1}$. Under this pollution load, the nitrate concentration of effluent is approximately $24.5\,mg\,L^{-1}$, which not only exceeds the Grade III ($20\,mg\,L^{-1}$) of Quality Standard for Groundwater but also fails to reach the limit value (MCL $10\,mg\,L^{-1}$) of the international drinking water standard for nitrate. Seepage control measures and effluent collection systems should be needed in the construction stage with such a pollution load so as not to contaminate groundwater, but this will increase the cost of construction. In this way, the advantages of easy construction and low cost are reduced, and the prospect of engineering applications will be weakened correspondingly. In fact, the most practical engineering application mode of SWIS is that the system effluent is finally recharged with groundwater (USEPA, 2002)). Zheng et al. (2016) noted that the environmental carrying capacity of nitrogen in the SWIS was in a range of $600–1200\,kg\,N\,ha^{-1}\,yr^{-1}$ when using $20\,mg\,L^{-1}$ of the nitrate concentration as the evaluation criterion. Under TN pollution load of $600\,kg\,N\,ha^{-1}\,yr^{-1}$, the proportion of effluent that satisfied the Grade III ($20\,mg\,L^{-1}$) of Quality Standard for Groundwater was 100%.

The effect of plant uptake is usually ignored in the SWIS, when using a high pollution load (Zhang et al., 2002; Zhang et al., 2005; Li et al., 2011). In addition, the construction of seepage control measures and effluent collection systems in SWIS also restricts its broad engineering application (Zhang et al., 2002). In contrast, the SWIS system used in the present study was intended to recharge effluent directly to groundwater. The turfgrass uptake contribution reached approximately 52.5–61.0% under the nitrogen pollution load of $600\,kg\,N\,ha^{-1}\,yr^{-1}$. It is indicated that the plant uptake effects on nitrogen removal in SWIS are indispensable when operating under a suitable nitrogen pollution load. Therefore, plant cover is needed in the engineering application of SWIS, and the maintenance and management of plants should be strengthened to enhance the overall nitrogen removal efficiency. This long-term study which conducted in optimum conditions presented a positive effect of turfgrass on sewage nitrogen removal in the SWIS, which provided a scientific basis for better performance of the engineering applications of SWIS.

4.4. The operation of SWIS in winter

In the present experiment, the SWIS operation period didn’t include winter. However, in the large-scale application of SWIS, wastewater treatment in winter should be considered in the design and construction stage. In winter, the removal efficiency for nitrogen is inhibited because of the decrease of microbial activity and the senescence of plant (Yan and Xu, 2014). To enhance winter treatment effectiveness in constructed wetland wastewater treatment systems, some measures are used, including internal improvement and optimization in system design, setup and operation, and external methods of pretreatment and post-treatment technologies (Gao et al., 2014; Qin et al., 2013; Yan and Xu, 2014). Similarly, some of these measures are also suitable for SWIS when running in winter. In addition, it is feasible for wastewater in winter to be stored temporarily or treated by using other disposal techniques.

5. Conclusion

Plant uptake is an effective approach to enhance the nitrogen removal in SWIS under a suitable pollution load. The two-year results indicated that both turfgrass-covered system (S-G) and bare soil system (S-B) can have positive effects on NH_4^+-N removal. The concentrations of NO_3^--N in the effluent of the S-G system were significantly lower than that of the S-B treatment. Correspondingly, compared with S-B, the TN removal efficiency and quantity of S-G were significantly higher. The S-G system significantly reduced environmental risk of NO_3^--N in the SWIS effluents. 87.7% and 97.9% of NO_3^--N concentrations in the S-G effluent satisfied the international standard for drinking water ($10\,mg\,L^{-1}$ NO_3^--N) in 2014 and 2015 respectively, whereas none of NO_3^--N concentrations in S-B effluent reached the standard. The turfgrass uptake contribution to nitrogen removal reached 52.5–61.0% under a nitrogen pollution load of $600\,kg\,N\,ha^{-1}\,yr^{-1}$. The obtained results proved that plant uptake in SWIS plays an important role in removing nitrogen. Therefore, plant cover is needed in the engineering application of SWIS, and the maintenance and management of plants should be strengthened to enhance the overall nitrogen removal efficiency.

References

Adeli, A., Varco, J.J., Rowe, D.E., 2003. Swine effluent irrigation rate and timing effects on bermudagrass growth, nitrogen and phosphorus utilization, and residual soil nitrogen. J. Environ. Qual. 32, 681–686.

American Public Health Association (APHA), 2012. Standard Methods for the Examination of Water and Wastewater, twenty-second ed. American Public Health Association/American Water Works Association/Water Environment Federation, Washington, DC.

Beal, C.D., Gardner, E.A., Menzies, N.W., 2005. Process, performance, and pollution potential: a review of septic tank–soil absorption systems. Aust. J. Soil Res. 43, 781–802.

Degen, M.B., Reneau Jr., R.B., Hagedom, C., Martens, D.C., 1991. Denitrification in onsite wastewater treatment and disposal systems. Virginia Water Resour. Res. Center Bull. 171, 1–113.

Chen, P.Z., Cui, J.Y., Hu, L., Zheng, M.Z., Cheng, S.P., Huang, J.W., Mu, K.G., 2014. Nitrogen removal improvement by adding peat in deep soil of subsurface wastewater infiltration system. J. Integr. Agric. 13, 1113–1120.

Duan, R., Fedler, C.B., 2010. Performance of a combined natural wastewater treatment system in West Texas. J. Irrig. Drain. Eng. 136, 204–209.

Duan, J.J., Geng, C.G., Li, X., Duan, Z.Q., Yang, L.Z., 2015. The treatment performance and nutrient removal of a garden land infiltration system receiving dairy farm wastewater. Agric. Water. Manage. 150, 103–110.

Emmons, R.D., 2007. Turfgrass Science and Management, 4th ed. Delmar, Albany, NY.

Fei, H.X., Tong, D., Pan, J., Zhang, Y., Huang, L.L., Cheng, F., Zheng, F.P., 2016. Pollutant removal in subsurface wastewater infiltration systems with/without intermittent aeration under different organic pollutant loadings. Water. Sa 42, 595–599.

Gao, J.Q., Wang, W.L., Guo, X., Zhu, S.F., Chen, S.H., Zhang, R.Q., 2014. Nutrient removal capability and growth characteristics of Iris sibirica in subsurface vertical flow constructed wetlands in winter. Ecol. Eng. 70 (9), 351–361.

Gao, Z.M., Li, X.F., 1991. Manual for Land Treatment of Municipal Wastewater. Standards Press of China, Beijing (in Chinese).

GB/T 14848-2017, 2017. Quality standard for ground water. Standardization administration of the People's Republic of China. (in Chinese).

Hallin, S., Hellman, M., Choudhury, M.I., Ecke, F., 2015. Relative importance of plant uptake and plant associated denitrification for removal of nitrogen from mine drainage in sub-arctic wetlands. Water. Res. 85, 377–383.

Huett, D.O., Morris, S.G., Smith, G., Hunt, N., 2005. Nitrogen and phosphorus removal from plant nursery runoff in vegetated and unvegetated subsurface flow wetlands. Water. Res. 39, 3259–3272.

Kadam, A.M., Nemade, P.D., Oza, G.H., Shankar, H.S., 2009. Treatment of municipal wastewater using laterite-based constructed soil filter. Ecol. Eng. 35, 1051–1061.

Keizer-Vlek, H.E., Verdonschot, P.F.M., Verdonschot, R.C.M., Dekkers, D., 2014. The contribution of plant uptake to nutrient removal by Floating treatment wetlands. Ecol. Eng. 73, 684–690.

Li, Y.H., Li, H.B., Sun, T.H., Wang, X., 2011. Study on nitrogen removal enhanced by shunt distributing wastewater in a constructed subsurface infiltration system under intermittent operation mode. J. Hazard. Mater. 189, 336–341.

Li, Y.H., Li, H.B., Wang, H., Wang, X., Yi, Z., Sun, T.H., 2013. Comparison of the treatment performance of bio-substrate based and meadow brown soil based subsurface infiltration systems for domestic wastewater treatment. Water. Sci. Technol. 67, 506–513.

Liu, Y.S., Liu, Z.X., Li, X.G., Zhang, Z.H., 2008. Study on biomass and nutrient uptake dynamics of three cold-season turfgrass species in Beijing. Pract. Sci. 25 (4), 88–94 (in Chinese).

Llorens, M., Perez-Marin, A.B., Aguilar, M.I., Saez, J., Ortuno, J.F., Meseguer, V.F., 2011. Nitrogen transformation in two subsurface infiltration systems at pilot scale. Ecol. Eng. 37, 736–743.

Llorens, M., Pérez-Marín, A.B., Sáez, J., Aguilar, M.I., Ortuño, J.F., Meseguer, V.F., Ruiz, J.A., 2015. Sewage treatment with a hybrid constructed soil filter. Int. J. Chem. React. Eng. 13, 161–168.

Luo, P., Liu, F., Zhang, S., Li, H.F., Yao, R., Jiang, Q.W., Xiao, R.L., Wu, J.S., 2018. Nitrogen removal and recovery from lagoon-pretreated swine wastewater by constructed wetlands under sustainable plant harvesting management. Bioresour. Technol. 258, 247–254.

Ministry of Environmental Protection of the People's Republic of China (MEPPRC), 2015. China Environmental State Bulletin, Beijing, (in Chinese).

Pan, J., Yuan, F., Yu, L., Huang, L.L., Fei, H.X., Cheng, F., Zhang, Q., 2016. Performance of organics and nitrogen removal in subsurface wastewater infiltration systems by intermittent aeration and shunt distributing wastewater. Bioresour. Technol. 211, 774–778.

Paranychianakis, N.V., Angelakis, A.N., Leverenz, H., Tchobanoglous, G., 2006. Treatment of wastewater with slow rate systems: a review of treatment processes and plant functions. Crit. Rev. Environ. Sci. Technol. 36, 187–259.

Pavlineri, N., Skoulikidis, N.T., Tsihrintzis, V.A., 2017. Constructed floating wetlands: a review of research, design, operation and management aspects, and data meta-analysis. Chem. Eng. J. 308, 1120–1132.

Qin, W., Dou, J.F., Ding, A.Z., Xie, E., Zheng, L., 2014. A study of subsurface wastewater infiltration systems for distributed rural sewage treatment. Environ. Technol. 35, 2115–2121.

Qin, X.D., Sun, Y.C., Li, L., Shao, X.L., Yu, D., Liu, Q.Q., Liu, H.L., Han, L., 2013. Study on winter operation process of the surface flow constructed wetland in Tianjin area. Meteor. Environ. Res. 4 (7), 43–46.

Saeed, T., Sun, G., 2012. A review on nitrogen and organics removal mechanisms in subsurface flow constructed wetlands: dependency on environmental parameters, operating conditions and supporting media. J. Environ. Manage. 112, 429–448.

Seguí, M.D.M.B., Hess, T., Sakrabani, R., Tyrrel, S., 2017. Long-term phosphorus removal in land treatment systems: evaluation, experiences, and opportunities. Crit. Rev. Environ. Sci. Technol. 47 (5), 314–334.

Sevostianova, E., Leinauer, B., 2014. Subsurface-applied tailored water: combining nutrient benefits with efficient turfgrass irrigation. Crop. Sci. 54, 1926–1938.

Shimp, J.F., Tracy, J.C., Davis, L.C., Lee, E., Huang, W., Erickson, L.E., Schnoor, J.L., 1993. Beneficial effects of plants in the remediation of soil and groundwater contaminated with organic materials. Crit. Rev. Environ. Sci. Technol. 23, 41–77.

Tzanakakis, V.A., Paranychianakis, N.V., Angelakis, A.N., 2009. Nutrient removal and biomass production in land treatment systems receiving domestic effluent. Ecol. Eng. 35, 1485–1492.

Tzanakakis, V.E., Paranychianakis, N.V., Kyritsis, S., Angelakis, A.N., 2003. Wastewater treatment and biomass production by slow rate systems using different plant species. Water. Sci. Tech.-W. Sup. 3, 185–192.

United States Environmental Protection Agency (USEPA), 2002. Onsite wastewater treatment systems manual. United States Environmental Protection Agency, Washington, DC, EPA/625/R-00/008.

United States Environmental Protection Agency (USEPA), 2010. Source water protection practices bulletin. Managing agricultural fertilizer application to prevent contamination of drinking water, Washington, DC.

Valencia-Gica, R.B., Yost, R.S., Porter, G., 2012. Biomass production and nutrient removal by tropical grasses subsurface drip-irrigated with dairy effluent. Grass. Forage. Sci. 67, 337–349.

Van Cuyk, S., Siegrist, R., Logan, A., Masson, S., Fischer, E., Figueroa, L., 2001. Hydraulic and purification behaviors and their interactions during wastewater treatment in soil infiltration systems. Water. Res. 35, 953–964.

Vymazal, J., 2007. Removal of nutrients in various types of constructed wetlands. Sci. Total Environ. 380, 48–65.

Vymazal, J., 2011. Plants used in constructed wetlands with horizontal subsurface flow: a review. Hydrobiologia 674 (1), 133–156.

Vymazal, J., 2013. Emergent plants used in free water surface constructed wetlands: a review. Ecol. Eng. 61 (19), 582–592.

Woodard, K.R., French, E.C., Sweat, L.A., Graetz, D.A., Sollenberger, L.E., Macoon, B., Portier, K.M., Wade, B.L., Rymph, S.J., Prine, G.M., Van Horn, H.H., 2002. Nitrogen removal and nitrate leaching for forage systems receiving dairy effluent. J. Environ. Qual. 31, 1980–1992.

World Heath Organization (WHO), 2011. Guidelines for drinking water quality, 4th ed. ISBN 978 92 4 154815 1 http://apps.who.int/iris/bitstream/10665/44584/1/9789241548151_eng. pdf.

Yan, Y.J., Xu, J.C., 2014. Improving winter performance of constructed wetlands for wastewater treatment in northern China: a review. Wetlands 34 (2), 243–253.

Yang, L.P., Tian, N.N., Chu, F.C., 1999. Study on sewage purification and green-land-utilization based on soil capillary percolation. Urb. Environ. Urban Ecol. 12, 4–7 (in Chinese).

Yang, Q., Chen, Z.H., Zhao, J.G., Gu, B.H., 2007. Contaminant removal of domestic wastewater by constructed wetland: effect of plant species. J. Integr. Plant Biol. 49, 437–446.

Yang, Y.Q., Zhan, X., Wu, S.J., Kang, M.L., Guo, J.N., Chen, F.R., 2016. Effect of hydraulic loading rate on pollutant removal efficiency in subsurface infiltration system under intermittent operation and micro-power aeration. Bioresour. Technol. 205, 174–182.

Zhang, J., Huang, X., Liu, C.X., Shi, H.C., Hu, H.Y., 2005. Nitrogen removal enhanced by intermittent operation in a subsurface wastewater infiltration system. Ecol. Eng. 25, 419–428.

Zhang, J., Huang, X., Wei, J., Hu, H.Y., Shi, H.C., 2002. Nitrogen and phosphorus removal mechanism in subsurface wastewater infiltration system, China. Environ. Sci. 22 (5), 438–441 (in Chinese).

Zhang, X.H., Cui, J.Y., Zheng, M.Z., Lan, Y., Zhao, Y.Y., Hu, L., 2011. Removal effects of N and P in subsurface wastewater infiltration system by *Festuca aroundinaces Schres.* and *Zoysia japonica Steud.*. In: Proc. Int. Conf. Computer Distribute Control and Intelligent Enviromental Montioring (CDCIEM), Changsha, China, pp. 934–937.

Zheng, P., Cui, J.Y., Hu, L., Chen, P.Z., Huang, J.W., Cheng, S.P., Mu, K.G., 2016. Effect of long-term operation of a subsurface wastewater infiltration system (SWIS) based on the limiting value of environmental carrying capacity. Ecol. Eng. 92, 190–198.

Zheng, Y.C., Wang, X.C.C., Ge, Y., Dzakpasu, M., Zhao, Y.Q., Xiong, J.Q., 2015. Effects of annual harvesting on plants growth and nutrients removal in surface-flow constructed wetlands in northwestern China. Ecol. Eng. 83, 268–275.