Nitrogen removal and nitrous oxide emission in surface flow constructed wetlands for treating sewage treatment plant effluent: Effect of C/N ratios

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Abstract

In order to design treatment wetlands with maximal nitrogen removal and minimal nitrous oxide (N_2O) emission, the effect of influent C/N ratios on nitrogen removal and N_2O emission in surface flow constructed wetlands (SF CWs) for sewage treatment plant effluent treatment was investigated in this study. The results showed that nitrogen removal and N_2O emission in CWs were significantly affected by C/N ratio of influent. Much higher removal efficiency of NH_4^+-N (98%) and TN (90%) was obtained simultaneously in SF CWs at C/N ratios of 12:1, and low N_2O emission (8.2 mg/m^2/d) and the percentage of N_2O-N emission in TN removal (1.44 %) were also observed. These results obtained in this study would be utilized to determine how N_2O fluxes respond to variations in C/N ratios and to improve the sustainability of CWs for

wastewater treatment.

Keywords: Constructed wetlands; Wastewater treatment; C/N ratio; Nitrogen transformation; Nitrous oxide

1. Introduction

Constructed wetlands (CWs) are designed as an appropriate engineered systems for wastewater treatment. The use of this technology has grown increasingly over recent decades because of their low-cost, easy operation and maintenance, reliable efficiency and favorable environmental appearance compared with other conventional energy-intensive treatment technologies (Vymazal, 2007; Wu et al., 2011; Zhu et al., 2014). These systems mainly including surface flow (SF) and subsurface flow (SSF) CWs can remove various pollutants (e.g. organic matter and nutrients) by utilizing a variety of physical, chemical, and biological processes (Vymazal, 2007; Wu et al., 2015a). In the past several decades, CWs have been widely used for treating various types of wastewaters, such as domestic sewage, industrial drainage, stormwater runoff, animal wastewaters, leachates and polluted river water (Wu et al., 2009; Rai et al., 2013; Wu et al., 2016). However, nitrogen removal efficiency in common CWs exhibited substantial fluctuations, and was also far from satisfactory when CWs were designed to treating some types of wastewaters (such as the sewage treatment plant effluent) characterized by relatively low organic content and moderate nitrogen concentration or by varying organic loading rate (Wu et al., 2015b). Besides, nitrous oxide (N_2O) emissions originating from nitrogen removal in these systems recently attracted increasing high attention (Wu et al., 2009). Therefore, how to improve nitrogen removal efficiency and mitigate N_2O emission has become a research hotspot in the field of CW wastewater treatment.

Nitrogen in CWs are removed from wastewater mainly by classical nitrogen removal processes, known as nitrification-denitrification carried out by nitrifying and heterotrophic denitrifying bacteria (Saeed and Sun, 2012). Consequently, either nitrification or denitrification process suffocation can cause low total nitrogen (TN) removal efficiency. Moreover, numerous studies have demonstrated that the TN removal performance in CWs can be influenced by various designing parameters (e.g., plants and substrates); environmental parameters (e.g., temperature, pH and dissolved oxygen, etc.) and operational factors (e.g., influent C/N ratio, hydraulic loading rates, hydraulic retention time, etc.) (Saeed and Sun, 2012; Fan et al., 2013; Wu et al., 2015a). Particularly, the influent C/N ratio representing the relative amount of organic carbon source in a CW systerm, was recognized as the crucial factor in nitrogen transformation by affecting the microbial nitrification and heterotrophic denitrification significantly (Yan et al., 2012; Ding et al., 2012; Zhu et al., 2014; Shen et al., 2014). Recently, a plenty of investigations of CWs were carried out to study the impact of C/N ratios on nitrogen removal and greenhouse gas emission in wastewater treatments. Zhao et al. (2010) resulted that the highest TN removal efficiency was obtained at C/N ratio of 2.5-5. In addition, Zhu et al. (2014) found that the removal efficiency of TN was greatest at a C/N ratio of 5, and the removal efficiency rose with an increase of C/N ratio. However, another study by Fan et al. (2013) indicated that high removal rate of TN (90%) was obtained in aerated SSF CWs with influent C/N ratio of 10. The impacts of influent C/N ratios on greenhouse gas emission in CWs were also carried out in some other studies. The results by Yan et al. (2012) indicated that low and middle C/N ratios were most beneficial for reducing greenhouse gas emissions. As mentioned, various N removal performances were observed at different optimal influent C/N ratios in different type of CWs for various wastewaters. Actually, the higher TN removal efficiencies are always coupled to higher N/C, but the degradation of excess organic matter would consume the more dissolved oxygen in CWs, which would restrain the activity of nitrifying microorganisms (Zhu et al., 2014). Nevertheless, the optimum C/N ratio of SF CWs for maximal nitrogen removal capability and minimal N_2O emission still remains unclear especially for purifying the sewage treatment plant effluent. Therefore, more detailed investigation on the effect of incremental-increasing C/N ratios is necessary for a better understanding the influence of C/N ratio on these systems, especially on the simultaneous removal of nitrogen and reduction of N_2O.

The objectives of this study were (1) to evaluate the effect of influent C/N ratio on the nitrogen removal and N_2O emission in SF CWs for treating sewage treatment plant effluent; (2) to analyze the transformations of organics and nitrogen and variation of N_2O emission under different influent C/N ratios; and thus (3) to identify optimal C/N ratios for the most efficient nitrogen removal with the lowest N_2O emission rates

2. Material and Methods

2.1 Description of CW systems and operation

In this experiment, SF CWs were designed and set up with identical dimensions in Baihua Park in Jinan, northern China (36°40′36″N, 117°03′42″E) with the warm-temperature monsoonal climate. Figure S1 shows the profile of the experimental CW systems, and each CW system was made of the perspex tube with a diameter of 40 cm and depth of 50 cm. All system were filled with washed river sand (particle size: approximate 2 mm, porosity: 0.38) as the substrate with a depth of 25 cm, and were planted with the common wetland plant (*Phragmites australis)* at a density of twelve rhizomes per system. The influent wastewater was supplied manually from the upside of the system, and effluent was collected by an outlet installed at the bottom of the CW. Each system held a total volume of 20 L water when filled, and the water depth was maintained at 10 cm from the substrate surface of the CW system. After setting up the CW and planting the wetland plants, the synthetic sewage treatment plant effluent was fed in CW systems to allow the growth and development of plants and microbes in experimental systems, and then the experiment started.

After an acclimation period of one month, the systems were fed with synthetic wastewater to start the experiment, and all experimental CW systems operated for a period of four months. In order to minimize variability, synthetic wastewater was used in the experiment based on the water quality of the effluent of traditional sewage treatment plants, and was prepared by dissolving sucrose, $(NH_4)_2SO_4$, KH_2PO_4 and KNO_3 with tap water (Wu et al., 2011). To determine the influence C/N ratio on removal performance and N_2O emission, the COD/N (namely chemical oxygen demand/TN concentration) ratio of influent was manipulated by changing sucrose to create five C/N ratios (0:1, 1:1, 3:1, 6:1 or 12:1). Accordingly, synthetic wastewaters with different influent C/N ratios were composed of 0, 17.81, 53.44, 106.88, 213.75 mg/L sucrose, 37.71 mg/L $(NH_4)_2SO_4$, 50.51 mg/L KNO_3, 3.59 mg/L KH_2PO_4. The characteristics of the influents with different influent C/N ratios are shown in Table 1. Sequencing fills-and-draw batch mode was used in the operating period, and the hydraulic retention time (HRT) was 10 d (Wu et al., 2011). Each system was manually drained after a cycle (10 d), and then re-filled with the wastewater immediately after drainage (Wu et al., 2009).

2.2 Experimental sampling and analysis

2.2.1 Water sampling and analysis

Water samples of influent and effluent in all systems were taken every 10 d to evaluate the treatment performance, and water samples in systems were also collected at intervals (2 d and 5 d) to analyze the transformation of organics and nitrogen in an operation cycle within 10 d of HRT. According to standard methods (APHA, 2005), all samples were transferred immediately to the lab and analyzed immediately for chemical oxygen demand (COD; HACH DR 2008^{TM} Spectrophotometer, USA), ammonia nitrogen (NH_4^+-N) nitrate (NO_3^--N), nitrite (NO_2^--N), TN and total phosphorus (TP). The other parameters, such as dissolved oxygen (DO), pH, and water temperature, were measured in situ by a DO meter (HQ 30d 53LED^{TM} HACH, USA) and a glass pH meter (SG2-T SevenGo pro™ MTD, Switzerland).

2.2.2 Gas collection and measurement

Gas sampling was done at intervals (2 d and 5 d) using the static-stationary chamber to determine N_2O fluxes from all systems during the whole experimental period. Gas samples were collected at 0, 20, 40 and 60 min between 8:00 and 10:00 am of the sampling day, and the details about steps of gas sampling were described in the previous studies (Wu et al., 2009). The N_2O concentration was analyzed using the gas chromatography (SP-3410, China) with an electron capture detector (ECD) and a Poropak Q column. N_2O fluxes (mg/m^2/d) were calculated by the change in concentration in the chambers over time with linear regression analysis according to the method in the previous studies (Wu et al., 2009).

2.3 Statistical analysis

All experimental data were expressed as means of triplicates with standard deviation. Software SPSS 21.0 (SPSS Inc., Chicago, USA) was used for all statistical analyses, including analysis of variance (ANOVA), Bartlett's and Levine's test for homogeneity of variance and normality, and Duncan's multiple range test for differences between means. In all analyses, differences and correlations were considered statistically significant when $P < 0.05$.

3. Results and Discussion

3.1 Overall treatment performance and N_2O emission

3.1.1 Removal performance

The difference in removal performance of SF CWs under different influent C/N ratios could be revealed from the varied effluent quality with the identified influent characteristics. Table 2 gives the average effluent concentrations of COD, NH_4^+-N, NO_3^--N, NO_2^--N, TN, and removal efficiencies (rates) of COD, NH_4^+-N and TN in SF CWs with different influent C/N ratios during the experimental period. On the whole, there were significant variations and differences removal performance of SF CWs with various C/N ratios. Specifically, the removal efficiency of COD in all the treatments was greater than 60% except for the systems with an influent C/N ratio of 0 which had no organic carbon input. Accordingly, average COD removal rates at different C/N conditions were 0.35-4.21 g/m^2/d with average COD concentration of 8.17-10.68 mg/L. Moreover, it was observed that COD removal performance was increased with the rising of C/N ratios. The removal efficiency of NH_4^+-N in SF CWs under different influent C/N ratios was greater than 80%, and removal rates of NH_4^+-N ranged between 0.14 and 0.16 g/m^2/d. NH_4^+-N removal efficiency increased significantly with an increase in C/N ratio from 0 to 3, but there was little decrease in NH_4^+-N removal when C/N ratio varied from 6 to 12. When concerning TN removal, there were no significant differences among the systems under C/N ratio = 0 and 3 with lower TN removal efficiency of 14.34-15.29%. However, significant increase of TN removal efficiency (from 14.34 to 89.81%) was detected when C/N ratio increased from 3 to 12. Accordingly, TN removal rates at different C/N conditions were 0.07-0.36 g/m^2/d. The transformation of NO_3^--N and NO_2^--N are important processes for the nitrification and denitrification. The concentration of NO_3^--N in effluent under different influent C/N ratios decreased from 21.82 to 2.55 mg/L with an increase in C/N from 0 to 12. Compared with the influent NO_3^--N concentration, the effluent NO_3^--N concentration in SF CWs at influent C/N = 0, 1 and 3 accumulated significantly for lack of organic carbon that caused denitrification did not occur. But the effluent NO_3^--N concentration under influent C/N = 6 and 12 was relatively lower due to enough carbon source supporting denitrification process in SF CWs. Besides, an accumulation of NO_2^--N concentration was not observed in the effluent of all treatments with different influent C/N ratios during the experimental period. There were no significant differences in DO concentration and pH in different SF CWs (Table 2). Specifically, DO concentration was similar at different C/N conditions, and generally ranged between 5.46 and 7.01 mg/L with the pH ranging from 7.87 to 8.17.

It was known that nitrification and denitrification are considered to be the major nitrogen removal mechanisms in CW wastewater treatments, and carbon source is a key factor for denitrification (Saeed and Sun, 2012; Wu et al., 2015a; He et al., 2016). Thus, the low C/N ratio characterizing a lack of carbon source would restrain the denitrification process in CW systems, and TN removal in CWs increased with increasing of C/N ratio due to the promoted the denitrification (Yan et al., 2012; Ding et al., 2012; Zhu et al., 2014; He et al., 2016). The results obtained in the present study indicated that with the increase of C/N ratio, more carbon source was supplied for the system, which obviously enhanced denitrification of nitrogen. It is found that the most efficient performance for TN removal in this research achieved at the C/N ratio of 12:1, at which high removal efficiencies of COD and NH_4^+-N were obtained simultaneously in SF CWs. When the carbon source was low (C:N ratio = 6:1), control of the C/N ratio in the influent by supplementation of the carbon may be important for optimizing nutrient removal in SF CWs treating the effluent of sewage treatment plant. A similar result of optimal C/N ratio for nitrogen removal in CWs has also been reported in other studies, which showed that the highest TN removal (90%) was obtained at influent COD/N ratio of 10 (Fan et al., 2013). However, the results by Zhu et al. (2014) indicated that the optimal quantity of C/N ratio was 5 for the greatest TN removal which did not increase when the C/N ratio exceeded the optimal value. Zhao et al. (2010) resulted that the highest TN removal efficiency was obtained at COD/N ratio of 2.5-5. There was significant difference in the results the optimal C/N ratio for TN removal found in previous and present studies, which may be explained by the following reasons. A proper C/N ratio for microorganism reproduction and nitrogen removal could be directly affected by the design parameters such as structure and size of CWs, macrophyte species and the type of substrate. It would also be partially related to differences in the mode of operation of CWs, wastewater types, retention times, loading rates, etc. (Vymazal, 2007; Wu et al., 2011; Zhu et al., 2014; Wu et al., 2015b). Furthermore, TN removal performance in CWs can be influenced by other environmental parameters such as air/water temperature, pH and dissolved oxygen (Saeed and Sun, 2012; Fan et al., 2013; Wu et al., 2015a).

3.1.2 N_2O emission

The C/N ratio of the influent caused the significant difference in N_2O emission, and as shown in Figure 1a, the average N_2O fluxes from SF CWs with different influent C/N ratios ranged from 3.11 to 13.61 mg/m^2/d, which indicated that the influent C/N ratio had a significant impact on N_2O emission. Average N_2O fluxes under different influent C/N ratios represented a gradual increase when C/N ratio increased from 0 to 3; but N_2O fluxes decreased suddenly with an increase in C/N from 3 to 12. The N_2O emission occurred in the system with the influent having a C/N ratio of 3 was significantly higher ($P < 0.05$) than others. The N_2O emission was lower when the C/N ratio was 0 and 1, and no statistical significant difference was found between them. Meanwhile, there was no statistical significant difference between N_2O fluxes at C/N ratio = 0 and 1. On the whole, average N_2O emission under C/N ratio of 3 was approximately 4 times greater than that measured under the C/N ratio of 0 and 1, and was also twice as high as N_2O emission at C/N ratio of 6 and 12. Figure 1b presents the percentage of N_2O-N emission in total nitrogen removal in different SF CWs during the study period, which showed a similar trend to the average N_2O fluxes in CWs. When the emission of N_2O-N is compared to removed N by the wetlands treating wastewaters with different C/N ratios, it was found that N_2O-N emission was only a small portion of the removed N. Specifically, the percentage of N_2O-N emission in total nitrogen removal ranged from 1.44 % at the influent C/N ratio of 12 to 5.08% at the influent C/N ratio of 1. Based on the results in this study, it can be demonstrated that the SF CWs had lowest N_2O fluxes and the optimal TN removal at C/N ratios of 12:1, which can be utilized to determine how N_2O fluxes respond to variations in C/N ratios and to improve the sustainable operation of CWs (Yan et al., 2012; Wu et al., 2016).

In previous studies examining the N_2O fluxes in CWs treating wastewater, emission range of -8.32 mg/m^2/d to 170.4 mg/m^2/d were reported (Johansson et al., 2003). The results of N_2O fluxes measured in this study agree with results mentioned above. However, the maximum N_2O emission fluxes in this study is lower than the values reported in a current literature review which shows that average values of N_2O emissions in various types of CWs are 52.1-74.4 mg/m^2/d (Mander et al., 2014). When concerning the effects of C/N ratios, Wu et al. (2009) showed the N_2O fluxes of ranging from 0.03 mg/m^2/d to 134.2 mg/m^2/d, and successful treatment performance and low N_2O emission were obtained in the microcosm wetland at the C/N ratio of 5. Similarly, Yan et al. (2012) concluded that the optimum C/N ratio for simultaneously achieving the best treatment efficiency and lowest greenhouse gas (GHG) fluxes was around C:N = 5:1. These results were not consistent with the results in the present study that lowest GHG fluxes and the optimal TN removal were achieved at C/N ratios of 12:1. This difference is hypothesized to be due to the effect of TN content in the influent and NO_3^--N accumulation in wetland systems. On the other hand, N_2O production is closely correlated to the conditions of pH, temperature and especially oxygenation (Beline et al. 2001; Wu et al., 2009).

3.2 Nitrogen transformations in the typical operating period

3.2.1 Variation of temperature, pH, DO and COD concentration

The variation of average temperature, pH, DO and COD concentration in SF CWs under different influent C/N ratios in the typical cycle is shown in Figure 2. Average temperature and pH in different systems generally ranged in 26.2-27.3 ℃ and 7.5-8.1, respectively. DO concentration in SF CWs under different influent C/N ratios exhibited similar changing trend. A sharp decrease of DO concentration was observed in systems at initial stage of the cycle, then DO increased gradually. At the end of the cycle, the concentration of DO in all SF CWs could reach to above 4 mg/L. However, some differences were detected in DO concentration in different SF CWs on the second day. Specifically, DO concentration was ranging 1.8-4.5 mg/L at C/N ratio = 0, 1 and 3, but the lower DO concentration (below 0.5 mg/L) was found at C/N ratio = 6 and 12, which was be attributed to the biodegradation of more organic source (Wu et al., 2015b). Moreover, it is indicated that cyclic anaerobic and aerobic conditions favoring nitrification and denitrification was formed in the systems especially at C/N ratio = 6 and 12. The degradation of organic matter in CWs is correlated with the change of DO concentrations in the system. As shown in Figure 2, the COD profiles in different SF CWs except for C/N ratio of 0 was similar to the DO profile, and the COD concentration decreased rapidly in CWs immediately after feeding. In the SF CW with an influent C/N ratio of 0, average effluent COD concentration was about 8 mg/L, which may be due to the release of carbon source from the rhizosphere of plants (Zhang et al., 2014). The increasing of influent C/N ratio from 1 to 12 did not affect the efficiency of organic matters degradation. It is known that organic matters can be degraded aerobically and anaerobically in CWs (Saeed and Sun, 2012). Tao et al. (2007) also demonstrated that a higher influent strength did not show a significant inhibition on heterotrophic activity in mesocosm CWs.

3.2.2 Dynamic transformations of nitrogen and N_2O fluxes

In CW treatments, the complete nitrogen removal should be firstly dependent on complete nitrification, and then the nitrified nitrogen would be permanently removed via denitrification (Saeed and Sun, 2012). These anaerobic and heterotrophic microbial processes could be limited by insufficient organic carbon source and excess oxygen (Fan et al., 2013). The time-profiles of the NH_4^+-N, NO_3^--N and NO_2^--N concentrations in different SF CWs at different influent C/N ratios during the typical cycle are graphically represented in Figure 3. In the systems with C/N ratio = 6 and 12, an immediate NH_4^+-N decrease was observed during the 2 d after feeding, and a further progressive reduction of NH_4^+-N was obtained in just 5 d. At the end of the cycle, the effluent concentration of NH_4^+-N decreased to below 0.1 mg/L. A similar trend of NO_3^--N concentration reducing rapidly was also observed in different CW systems during the cycle. Moreover, the effluent NO_3^--N concentration under influent C/N ratio = 6 and 12 was relatively lower, which suggested that alternative aerobic and anaerobic conditions were well developed for nitrification and denitrification simultaneously at these conditions (Fan et al., 2013; Wu et al., 2015b). Thus, a peak of N_2O fluxes from SF CWs under these conditions was observed at the beginning, and then N_2O fluxes exhibited a gradual decreasing trend. On the contrary, the NH_4^+-N concentration especially influent C/N ratio of 0 and 1stabilized at 1-2 mg/L by the end of the cycle although a significant removal of NH_4^+-N could be found at influent C/N ratio of 0, 1 and 3 during the typical cycle. Furthermore, because of the insufficient carbon source supply, the significant accumulation of NO_3^--N was found in SF CWs under influent C/N ratio = 0, 1 and 3 in the later stage of the cycle, which indicated that full denitrification could not be achieved due to carbon deficiency. Therefore, a peak of N_2O fluxes was observed at the second day especially in the system at influent C/N ratio = 3. The results obtained in this study demonstrated that the existence of adequate organic matters were needed for effective nitrogen removal in CWs, which is in accordance with other previous studies indicating influent C/N ratios would significantly influence the TN removal rates in CWs (Wu et al., 2009; Zhao et al., 2010; Fan et al., 2013; Zhu et al., 2014). The above results could be also explained by the relationship between nitrogen transformation rates and nitrogen functional genes in CW under C/N ratios in the previous study by Zhi and Ji (2014). It was found that aerobic ammonia oxidation was the dominant NH_4^+-N removal pathway when the C/N ratio was less than or equal to six, however, when the C/N ratio was greater than six, anammox was notably enhanced (Zhi and Ji, 2014).

4. Conclusions

In this study, the effect of influent C/N ratios on nitrogen removal and N_2O emission in SF CWs for sewage treatment plant effluent treatment was investigated to improve the sustainable operation of CW wastewater treatment. The results showed that the maximal nitrogen removal efficiency (NH_4^+-N 98% and TN 90%) and low N_2O emission (8.2 mg/m^2/d) accounting for 1.44 % of TN removal were obtained at C/N ratio of 12:1. The results from this study would be useful for improving the sustainability of design, operation and removal performance of treatment wetlands.

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Figure Captions:

Figure 1 The average N_2O fluxes (a) and the percentage of N_2O-N emission (b) in total N removal in CW systems at different C/N rates (0:1, 1:1, 3:1, 6:1 and 12:1) during the experimental period.

Figure 2 The variation of DO, pH, temperature and COD concentration in CW systems at C/N rate = 0:1 (a), 1:1 (b), 3:1 (c), 6:1 (d) and 12:1 (e) during the typical operating period.

Figure 3 Dynamic transformations of nitrogen (NH_4^+-N, NO_3^--N and NO_2^--N) and N_2O emission in CW systems at C/N rate = 0:1 (a), 1:1 (b), 3:1 (c), 6:1 (d) and 12:1 (e) during the typical operating period.

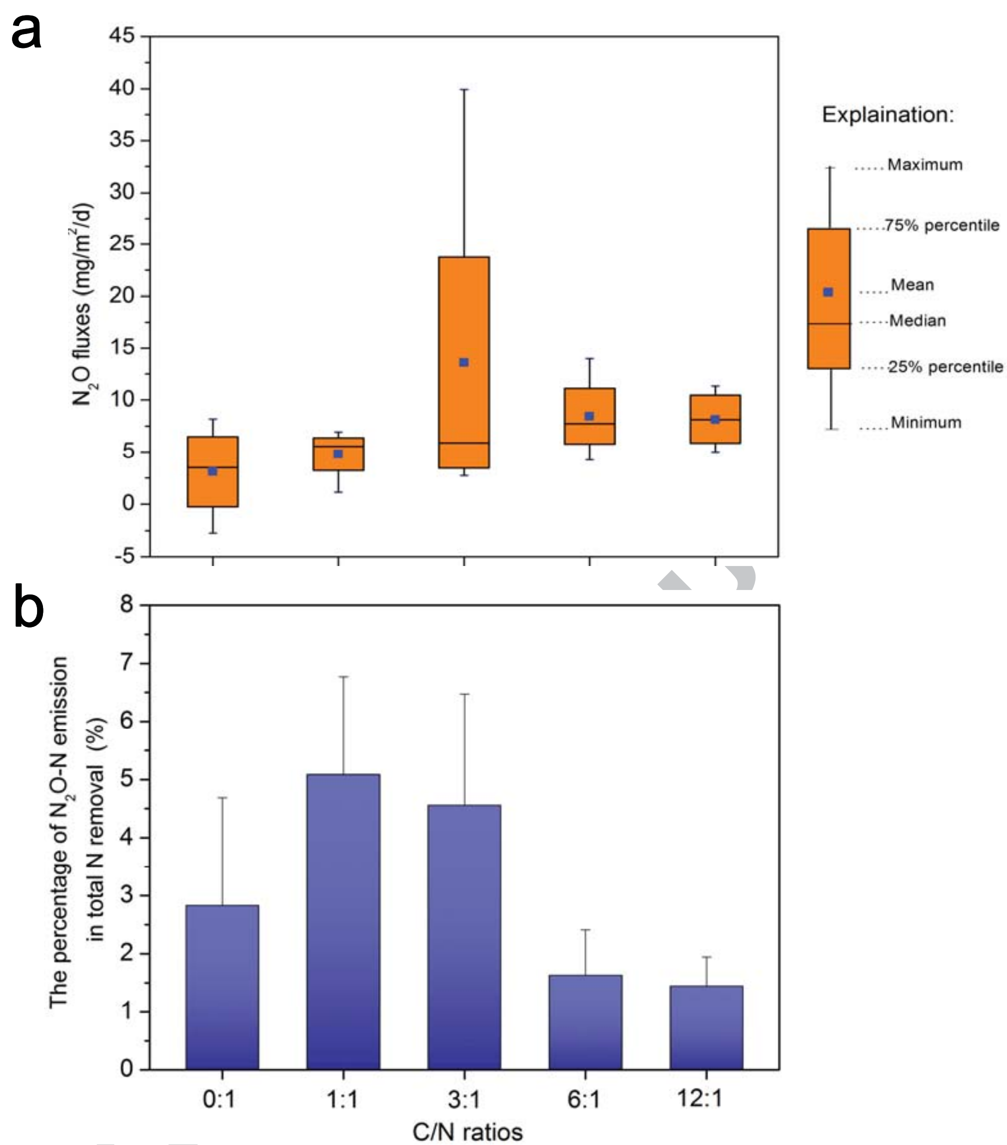


Figure 1 The average N_2O fluxes (a) and the percentage of N_2O-N emission (b) in total N removal in CW systems at different C/N rates (0:1, 1:1, 3:1, 6:1 and 12:1) during the experimental period.

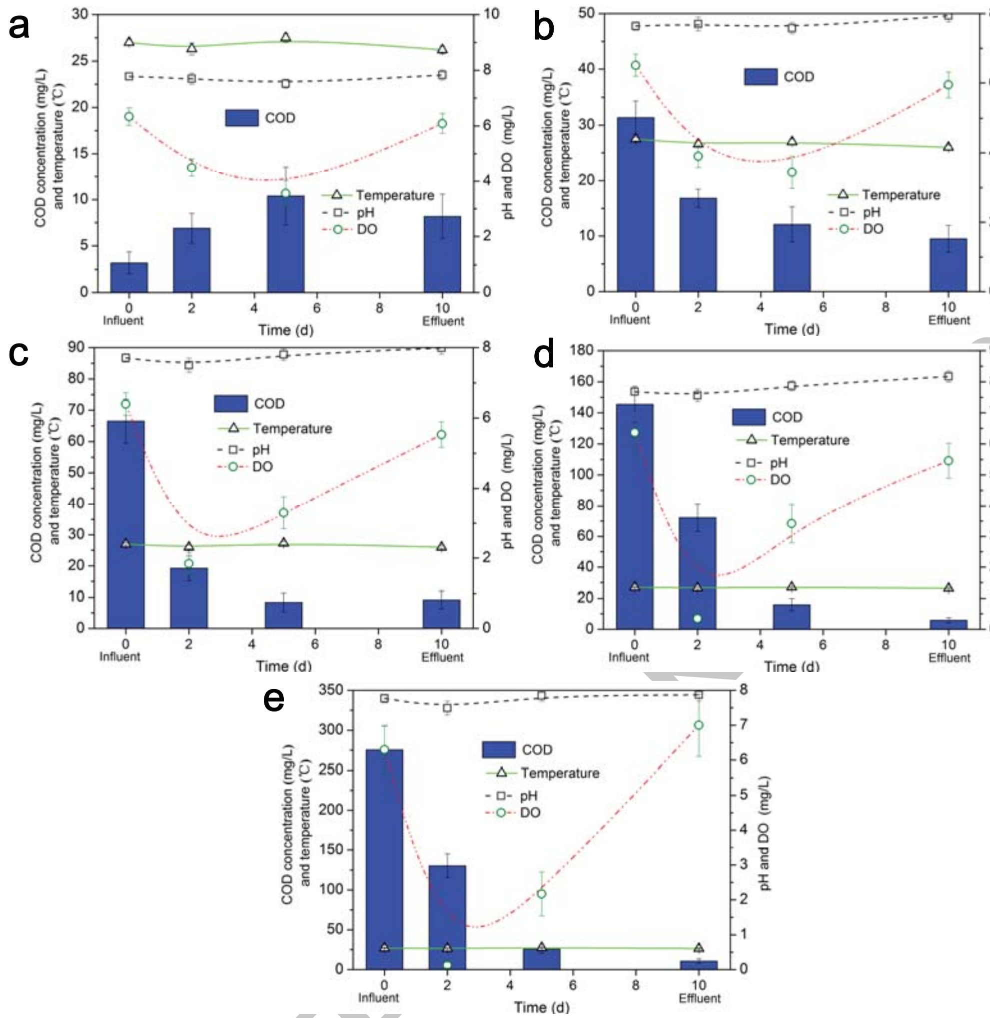


Figure 2 The variation of DO, pH, temperature and COD concentration in CW systems at C/N rate = 0:1 (a), 1:1 (b), 3:1 (c), 6:1 (d) and 12:1 (e) during the typical operating period.

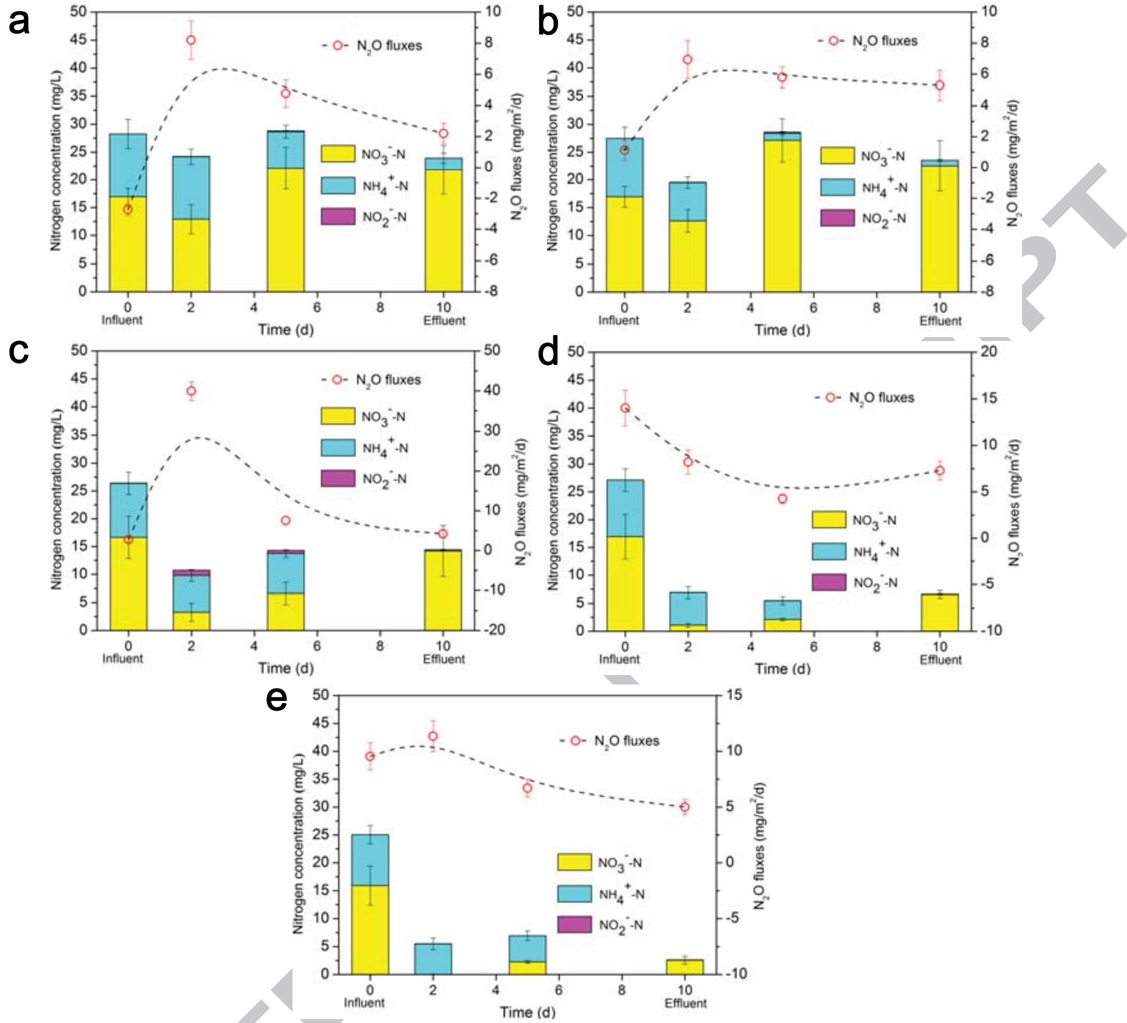


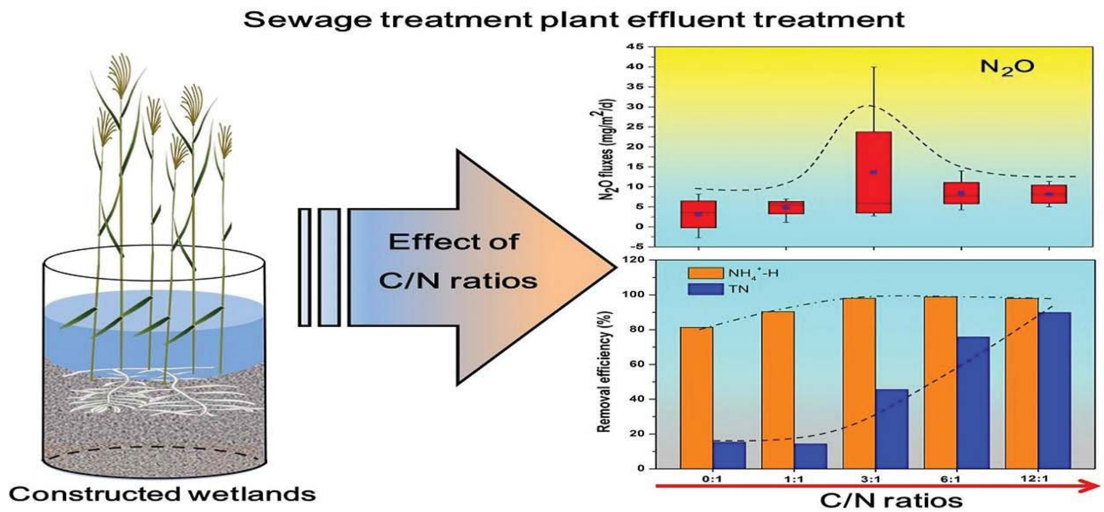
Figure 3 Dynamic transformations of nitrogen (NH_4^+-N, NO_3^--N and NO_2^--N) and N_2O emission in CW systems at C/N rate = 0:1 (a), 1:1 (b), 3:1 (c), 6:1 (d) and 12:1 (e) during the typical operating period.

Table 1 Characteristics of influents (Mean ± SD, n=12)

Parameters	C/N ratios of influent				
	0:1	1:1	3:1	6:1	12:1
COD (mg/L)	3.12±1.09	31.38±5.24	66.51±8.43	145.48±16.24	275.35±18.26
NH_4^+-N (mg/L)	11.32±2.15	10.55±1.48	9.72±1.88	10.19±1.55	9.15±1.75
NO_3^--N (mg/L)	16.93±2.49	16.95±1.45	16.64±2.35	16.93±1.58	15.92±1.68
TN (mg/L)	28.25±2.32	27.75±2.12	26.36±2.15	27.12±2.14	25.07±2.02
TP (mg/L)	2.05±0.32	1.89±0.23	1.90±0.22	1.92±0.21	1.85±0.31
pH	7.78±0.38	7.64±0.32	7.71±0.45	7.68±0.38	7.69±0.36
DO (mg/L)	6.34±0.61	6.51±0.59	6.41±0.66	6.37±0.55	6.32±0.61
COD/TN	0.11+0.09	1.13±0.19	2.53±0.28	5.38±0.45	11.02±0.32

Table 2 Characteristics of effluent and respective removal performance (Mean ± SD, n=12)

Parameters	C/N ratios of influent				
	0:1	1:1	3:1	6:1	12:1
COD (mg/L)	8.17±3.11	9.51±4.68	9.17±3.26	5.88±4.81	10.68±5.13
Removal	-	69.67±2.62	86.21±4.32	95.96±1.69	96.12±3.31
Removal	-	0.35±0.01	0.91±0.02	2.22±0.03	4.21±0.04
NH_4^+-N	2.11±0.52	1.02±0.34	0.19±0.23	0.12±0.14	0.19±0.12
Removal	81.34±1.32	90.34±5.17	98.09±1.98	98.82±4.64	97.92±2.14
Removal	0.15±0.01	0.15±0.02	0.15±0.03	0.16±0.02	0.14±0.02
NO_3^--N	21.82±3.61	22.54±4.06	14.21±2.35	6.58±2.05	2.55±2.21
NO_2^--N(mg/L)	0.01±0.01	0.01±0.01	0.01±0.02	0.01±0.01	0.01±0.02
TN (mg/L)	23.93±3.86	23.56±3.15	14.39±3.28	6.58±2.65	2.55±1.32
Removal	15.29±2.63	14.34±2.35	45.43±4.21	75.74±7.22	89.81±7.58
Removal	0.07±0.02	0.06±0.02	0.19±0.03	0.33±0.05	0.36±0.06
TP (mg/L)	1.98±0.32	1.54±0.40	1.28±0.33	1.32±0.53	0.54±0.25
pH	7.83±0.11	7.94±0.32	7.99±0.28	8.17±0.22	7.87±0.24
DO (mg/L)	6.09±1.08	5.92±0.52	5.53±0.42	5.46±0.53	7.01±1.38


Sewage treatment plant effluent treatment
Constructed wetlands
Effect of C/N ratios
N2O
N2O fluxes (mg/m2/d)
Removal efficiency (%)
NH4+-H
TN
0:1
1:1
3:1
6:1
12:1
C/N ratios

Research Highlights

1) Effect of influent C/N ratios on nitrogen removal and N_2O emission was studied.

2) Higher removal of NH_4^+-N (98%) and TN (90%) was achieved at C/N ratio of 12.

3) Low N_2O emission accounting for 1.44 % of TN removal was found at C/N ratio of 12.

4) Results would be useful for improving the sustainability of CW treatments.