CONSTRUCTION AND APPLICATION OF CONTROL INDICATORS FOR DRY AND WET ALTERNATING ARTIFICIAL WETLAND SYSTEM

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Abstract. Dry and wet alternation is one of the most common aquatic ecological processes in nature. The alternation of water content is coupled with the cycling process of nutrients, which has a significant impact on the migration and transformation of nitrogen. Based on the concept of dry wet alternation and system control, this article constructs a three-level system control index for artificial wetland dry wet alternation. By designing dry and wet alternation (DWA) experiments in artificial wetlands, aerobic/anaerobic environment of natural wetlands is simulated, the regulation of wetland operating parameters (time T, water level H) was systematically studied, as well as the response relationship between key control parameters (pH, DO, carbon source) and nitrogen removal in wetlands. Under the influence of dry wet alternation in artificial wetlands, there is a significant correlation ($P < 0.05$) between the secondary indicators such as DO, pH, and TOC in each substrate and the dry wet alternation time (4 h, 8 h, 12 h) (primary indicators) to varying degrees ($P < 0.05$). Moreover, factors such as DO, pH, and TOC in various matrices have varying degrees of correlation with NH_3-N, NO_3-N, ON, and TN removal rates (tertiary indicators) ($P < 0.05$). By studying the control indicators of the three-level system of dry wet alternation established in this article, a technical basis is provided for achieving the effect of systematic regulation of the dry wet alternation operation of artificial wetlands.
Keywords: *dry and wet alternate; artificial wetland; a tri-grade index system; system control; nitrogen removal; correlation.*

Introduction

The dry and wet alternate operation mode of constructed wetland is gradually accepted and adopted (Kern et al., 1999; Zhang et al., 2011; Lv et al., 2017; Chen et al., 2021); however, most studies are limited to a single nitrification - denitrification removal process or a single influencing factor (temperature), and no holistic and systematic research theory has been formed (Butterworth et al., 2013; Fu et al., 2016; Alsaedi et al., 2018), especially in relation to the dry and wet alternations of constructed wetlands (Chen et al., 2022). Optimizing and coordinating the relationship between dry and wet alternations of constructed wetlands and influencing factors (temperature, DO, carbon source, microorganisms, etc.) and nitrogen removal effect (nitrifying - denitrification rate, anaerobic ammonia oxidation rate) in order to further explore the

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mechanism of dry and wet alternations in constructed wetlands, and to carry out the application of ecological model on this basis, have research significance.

Dry and Wet Alternate is one of the most common water ecological processes in nature, and the alternate change of water is coupled with the cycle of nutrient salts (Liu et al., 2007; Liu et al., 2014; Marcel et al., 2018). Dry and wet alternations had significant effects on nitrogen migration and transformation (Han et al., 2011; Jin et al., 2016), dry and wet alternation can improve the oxygen supply conditions of wetlands, promote the decomposition of wetland pollutants, and realize the purification capacity of regenerative wetlands. In constructed wetland systems, oxygen in the air can be dissolved in the wetland matrix through periodic flooding/drainage, so as to improve the dissolved oxygen of the wetland and thus realize the improvement of nitrogen removal efficiency (Hu et al., 2012; Chen et al., 2021, 2019).

An experiment of dry and wet alternate (DWA) in constructed wetland was designed, that simulated the aerobic/anaerobic environment of natural wetlands. Index system and their relationship were also studied including the following operation parameters of time T and water level H, the key control parameters temperature and DO, etc. and the nitrogen removal efficiency. In this paper, the concept of dry and wet alternating (DWA) system control for constructed wetlands was proposed, and a three-level control index of dry and wet alternating system was established. The relationship between dry and wet alternating operation state, key influencing factors and nitrogen removal efficiency was analyzed, which provided technical basis for systematically regulating the dry and wet alternating operation effect of constructed wetlands.

Materials and methods

Experimental design

The experimental device is desined by one raw water tanks and six reactor, which is placed in a constant temperature box for control (*Fig. 1*) (Chen et al., 2021, 2022).
Matrix: R1/R2/R3 is organic fiber material, R4 is gravel, R5 is zeolite, R6 is volcanic rock, R7 is control group.
Raw water: The tail water of a sewage treatment plant.
Time control: Dry and wet alternation time (DAWT) is 4 h/8 h/12 h.
Temperature control: The environment is 10°C.

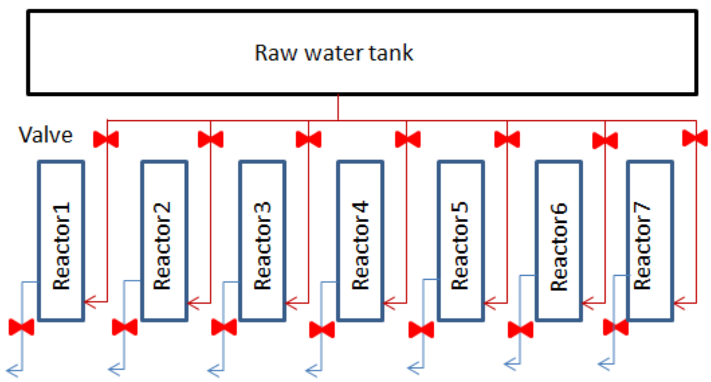

Figure 1. *Experimental apparatus*

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Analysis index and methods

Thermo Orion five star portable tester is used to monitor DO. Various nitrates and other chemical indexes are observed by the national standard method.
DO Sampling: Sampling port at 40 cm.
Water quality sampling: Sampling port at 40 cm.
Results analysis: Excel, Origin 8.0, SPSS20.0, etc.

Dry and wet alternating system control concept

(1) Basis of the dry and wet alternation theory

As the most basic feature of wetlands, Dry and Wet Alternate changes in soil/sediment/substrate water are coupled with nutrient enrichment and removal (Liu et al., 2007). Usually, in natural wetlands, due to the influence of natural vegetation, substrate and water level fluctuations, the interior of the wetland can alternately present an aerobic/anaerobic environment or an aerobic environment, creating the survival conditions of nitrogen removing microbial flora, promoting the nitrification and denitrification. Based on the structural characteristics of natural wetlands and the principle of nitrogen removal, this paper designs a DWA test for constructed wetlands. Through water inlet regulating valve and water level controller, the water level of the test device can fluctuate up and down according to Dry and Wet Alternate Time (DWAT). Make it run alternately dry and wet to simulate the changing environment of natural wetland aerobic/anaerobic:

(1) Control half of the water level and maintain it for 4 h/8 h/12 h time, etc., showing an aerobic state, then the lower half is anaerobic or facultative. Through the aerobic state to achieve nitrification conditions, NH_3 in sewage into NO_2N and NO_3N, this process must have the participation of oxygen.

(2) Control the full water level and maintain it for 4 h/8 h/12 h time, etc., where the upper part of the wetland is anaerobic or facultative, then the lower part of the matrix is anaerobic. The reduction of NO_2N and NO_3N to N_2, and the anaerobic environment can promote denitrification.

(3) The dry and wet alternate (DWA) can meet the above conditions and systematically control the key influencing factors.

(2) Dry and wet alternating system control concept

On the theory of dry and wet alternation and system control, this paper puts forward the concept of dry and wet alternation system control of constructed wetland: By adjusting the operation control parameters of the constructed wetland, the anaerobic/oxygen-consuming environment of the natural wetland is simulated alternately, and the key influencing parameters are regulated, and then the nitrogen removal effect parameters of the constructed wetland are adjusted to achieve the best nitrogen removal effect.

Dry and wet alternating system control index

In order to express the relationship between the control parameters of the dry and wet alternating experiment operation on the influence parameters of wetland nitrogen removal and the final effect of nitrogen removal, this paper established a three-level control index of the dry and wet alternating system of constructed wetland on the

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concept of dry and wet alternating, so as to reflect the control operation effect of the wetland system.

The first index is the control index of dry and wet alternate (DWA) operation state of constructed wetland (water level H, dry and wet time T). The initial setting is DWA (Hm, Tn), where Hm indicates the water level indicator and Tn indicates the time indicator. For example, H1 means the full water level of the test device, H2 means 1/2 water level, H3 means 1/3 water level, and so on. T1 indicates that the dry/wet interval of the test device is 1 h, that is, the first 1 h is filled with water, the second 2 h is filled with water, the 3 h is filled with water, the 3 h is filled with water, the 4 h is filled with water, the 5 h is filled with water, and so on.

The second index is the control and influence of the key influencing factors, such as substrate, temperature, DO, etc. On the basis of the first index (water level H, time T). The initial setting is DWA (Hm, Tn, Fs). Hm and Tn are the same as previously mentioned, and Fs represents the key influencing factor indicator. For example, F1 represents the rubble/volcanic rock matrix, F2 represents dissolved oxygen, F3 represents temperature, and so on.

The third level index, that is, based on the second level index, further analyzed the relationship between the key influencing factors of constructed wetlands and nitrogen removal efficiency and its influencing mechanism. Initially set as DWA (Hm, Tn, Fs, Ni), Hm, Tn, Fs as mentioned above, Ni represents the nitrogen element index. For example, N1 means NH_3-N, N2 means NO_2-N, N3 means NO_3-N, N4 means TN, and so on.

Based on the above analysis, this paper preliminarily established a three-level control index of the constructed wetland alternating between dry and wet, as shown in *Table 1*.

Table 1. *Control Index of dry-wet alternate system in constructed wetland*

The first index	**The second index**	**The third level index**
Operating status control indicators (water level H, dry and wet time T)	Indicators of influencing factors (temperature, DO, carbon source)	Concentration or removal rate indicators (NH_3-N, NO_2-N, NO_3-N, TN)
(H_1, T_1)	(H_1, T_1, F_1)	(H_1, T_1, F_1, N_1)
		(…, …, …, …)
		(H_1, T_1, F_1, N_i)
	(..., …, …)	(…, …, …, …)
	(H_1, T_1, F_s)	(H_1, T_1, F_s, N_1)
		(…, …, …, …)
		(H_1, T_1, F_s, N_i)
(…, …)	(..., …, …)	(…, …, …, …)
(H_m, T_n)	(H_m, T_n, F_1)	(H_m, T_n, F_1, N_1)
		(…, …, …, …)
		(H_m, T_n, F_1, N_i)
	(..., …, …)	(…, …, …, …)
	(H_m, T_n, F_s)	(H_m, T_n, F_s, N_1)
		(…, …, …, …)
		(H_m, T_n, F_s, N_i)

Dry and wet alternating system operation process

Based on the establishment of the above indicator system, how do the three level indicators influence each other and what is the relationship between them?

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Firstly, in this three-level control system, the alternating dry and wet time (4 h/8 h/12 h) and the amplitude of water level change (only 50% change is considered in the text) are regulated, and then the changes of other indicators are observed.

Then, pay attention to the changes in secondary indicators of key influencing factors such as DO, PH, TOC, and establish a relationship between this secondary indicator and the primary indicators (T, H), and analyze whether there is a significant correlation?

Furthermore, detect changes in nitrogen indicators, analyze the impact of secondary indicators on nitrogen, and establish whether there is a significant correlation between the tertiary indicators and secondary indicators?

Finally, what is the significant correlation between primary indicators and secondary and tertiary indicators? By establishing a three-level indicator system for artificial wetlands, the regulation of nitrogen in the three-level indicator can be achieved through the alternation of dry and wet operation of the primary indicator.

Results

The influence of dry and wet alternation on key factors

(1) Change in dissolved oxygen

Figure 2 shows that DO concentration presents a “V”-shaped trend with the DWAT time in each substrate at a low temperature of 10℃. The DO was lower at 8 h than that of 4 h/12 h (the value < 4 mg/L) (*Table 2*). It means that under the alternating condition of dry and wet, the reoxygenation capacity in constructed wetland can be changed.

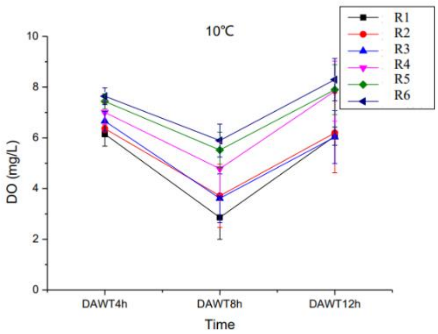

Figure 2. *DO changes with dry/wet alternate time (DWAT)*

Table 2. *Statistical analysis results of DO, pH, TOC*

T	DAWT 4 h		
ST	**DO /mg/L**	**pH**	**TOC /mg/L**
R1	4.25 ± 1.36	7.70 ± 0.14	67.01 ± 2.54
R2	4.44 ± 1.07	7.60 ± 0.04	68.06 ± 3.57
R3	4.72 ± 1.39	7.53 ± 0.06	71.22 ± 2.41
R4	4.93 ± 1.05	7.57 ± 0.02	67.34 ± 3.52
R5	5.57 ± 0.99	7.64 ± 0.02	67.99 ± 3.07
R6	5.50 ± 0.96	7.59 ± 0.05	65.42 ± 2.15

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T	DAWT 8 h		
ST	DO /mg/L	pH	TOC /mg/L
R1	5.33 ± 2.14	7.37 ± 0.02	69.62 ± 1.98
R2	5.25 ± 2.16	7.36 ± 0.01	70.01 ± 1.44
R3	5.26 ± 2.04	7.28 ± 0.02	74.42 ± 0.81
R4	6.74 ± 1.26	7.33 ± 0.02	68.28 ± 1.70
R5	6.96 ± 1.28	7.47 ± 0.13	67.62 ± 1.28
R6	6.99 ± 1.20	7.42 ± 0.05	66.89 ± 1.18
T	DAWT 12 h		
ST	DO /mg/L	pH	TOC /mg/L
R1	4.59 ± 1.04	7.48 ± 0.18	68.82 ± 1.12
R2	4.54 ± 0.67	7.61 ± 0.10	70.25 ± 2.12
R3	5.17 ± 0.59	7.47 ± 0.09	74.80 ± 1.43
R4	5.90 ± 0.42	7.59 ± 0.11	68.69 ± 1.49
R5	6.47 ± 0.29	7.66 ± 0.16	66.05 ± 2.04
R6	6.84 ± 0.30	7.49 ± 0.18	66.40 ± 1.03

(2) Carbon source change

Figure 3 shows that TOC concentration value presents a decreasing trend with the increase of DWAT time in each substrate at a low temperature of 10℃. The TOC concentration in the alternating wet and dry group was slightly higher than that in the control group (the value < 5 mg/L).

(3) The pH value changes

Figure 4 shows that pH value presents a “V”-shaped trend with the increase of DWAT time in each substrate at a low temperature of 10℃. On the whole, the pH values in the dry-wet alternating group were slightly lower than those in the control group (pH < 1.0).

Effects of dry and wet alternations on nitrogen

(1) Removal of ammonia nitrogen

Figure 5 shows that, the ammonia nitrogen presents a downward trend with the increase of DWAT time in each matrix at a temperature of 10℃, (the change value of NH_3-N < 0.05 mg/L); The removal rate of ammonia nitrogen Showed a downward trend. Also, the ammonia nitrogen removal rate is higher at 12 h, but not at 4 h/8 h (*Table 3*). Then we could make a conclusion, it will improve the removal capacity of ammonia nitrogen (NH_3-N) by reducing the frequency of rapid increase.

(2) Removal of nitrate nitrogen

Figure 6 shows that, the nitrate nitrogen presents a linear trend with the increase of DWAT in each matrix at a temperature of 10℃, but not the removal rate of nitrate nitrogen (NO_3-N). So, it will improve the removal capacity of nitrate nitrogen (change value > -20%) by reducing the frequency of rapid increase.

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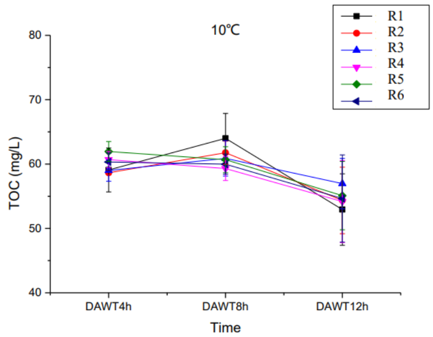

Figure 3. *TOC varies with DWAT*

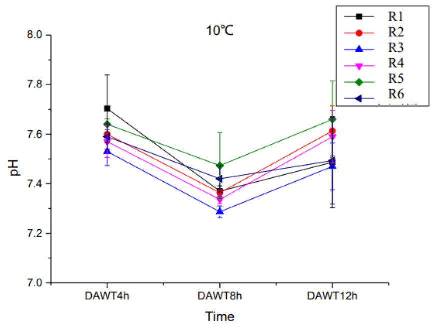

Figure 4. *pH varies with DWAT*

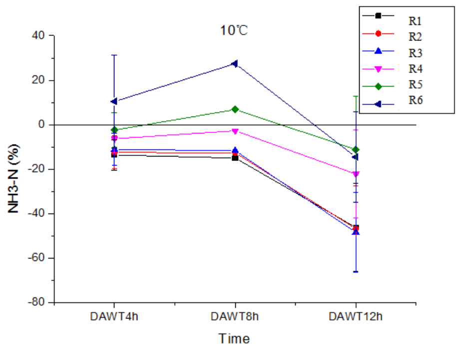

Figure 5. *NH_3-N varies with DWAT*

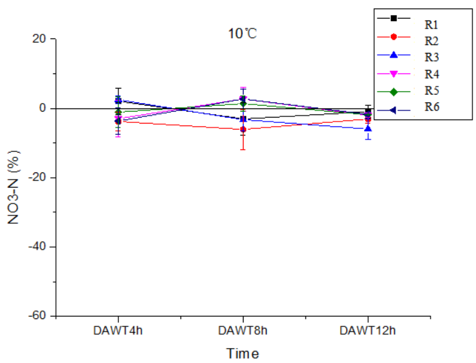

Figure 6. *NO_3-N varies with DWAT*

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Table 3. *Statistical analysis results of nitrogen*

T	DAWT 4 h				
ST	**NH_3-N/mg/L**	**NO_2-N/mg/L**	**NO_3-N/mg/L**	**ON/mg/L**	**TN/mg/L**
R1	0.10 ± 0.03	0.05 ± 0.02	2.84 ± 0.08	9.95 ± 0.39	11.95 ± 0.44
R2	0.10 ± 0.02	0.06 ± 0.02	2.68 ± 0.05	10.20 ± 0.52	12.04 ± 0.54
R3	0.10 ± 0.02	0.05 ± 0.02	2.85 ± 0.04	10.08 ± 0.45	12.10 ± 0.42
R4	0.10 ± 0.02	0.05 ± 0.02	2.70 ± 0.0.15	10.28 ± 0.82	13.15 ± 0.76
R5	0.11 ± 0.02	0.05 ± 0.02	2.75 ± 0.09	10.64 ± 0.31	13.56 ± 0.37
R6	0.12 ± 0.01	0.05 ± 0.02	2.68 ± 0.11	10.62 ± 0.65	13.48 ± 0.56
T	**DAWT 8 h**				
ST	**NH_3-N/mg/L**	**NO_2-N/mg/L**	**NO_3-N/mg/L**	**ON/mg/L**	**TN/mg/L**
R1	0.07 ± 0.01	0.21 ± 0.11	2.59 ± 0.09	8.04 ± 0.17	11.72 ± 0.17
R2	0.07 ± 0.02	0.28 ± 0.14	2.51 ± 0.13	9.01 ± 0.12	12.18 ± 0.13
R3	0.07 ± 0.01	0.21 ± 0.09	2.59 ± 0.08	9.37 ± 0.26	12.75 ± 0.32
R4	0.08 ± 0.02	0.07 ± 0.01	2.75 ± 0.03	10.29 ± 0.37	13.21 ± 0.40
R5	0.09 ± 0.01	0.08 ± 0.01	2.71 ± 0.01	10.59 ± 0.24	13.48 ± 0.23
R6	0.10 ± 0.01	0.08 ± 0.01	2.75 ± 0.02	10.58 ± 0.53	13.52 ± 0.53
T	**DAWT 12 h**				
ST	**NH_3-N/mg/L**	**NO_2-N/mg/L**	**NO_3-N/mg/L**	**ON/mg/L**	**TN/mg/L**
R1	0.04 ± 0.01	0.07 ± 0.01	7.60 ± 0.27	1.58 ± 0.37	9.29 ± 0.63
R2	0.03 ± 0.01	0.06 ± 0.01	7.44 ± 0.23	2.89 ± 0.41	10.44 ± 0.76
R3	0.04 ± 0.01	0.07 ± 0.01	7.22 ± 0.33	2.84 ± 0.51	10.18 ± 0.71
R4	0.06 ± 0.01	0.06 ± 0.01	7.52 ± 0.16	3.25 ± 0.64	10.90 ± 0.71
R5	0.08 ± 0.01	0.06 ± 0.01	7.53 ± 0.11	3.45 ± 0.57	11.13 ± 0.72
R6	0.06 ± 0.01	0.06 ± 0.01	7.54 ± 0.15	3.52 ± 0.63	11.20 ± 0.81

(3) Removal of nitrite nitrogen

Figure 7 shows that the nitrite nitrogen concentration present an inverted “V”-shaped trend in each matrix increases with DWAT at 10℃. Compared with the control group, the value has increased, while the removal rate of nitrite nitrogen as a whole showed a downward trend. So, the removal rate of nitrite nitrogen (NO_2-N) and the concentration value is increased.

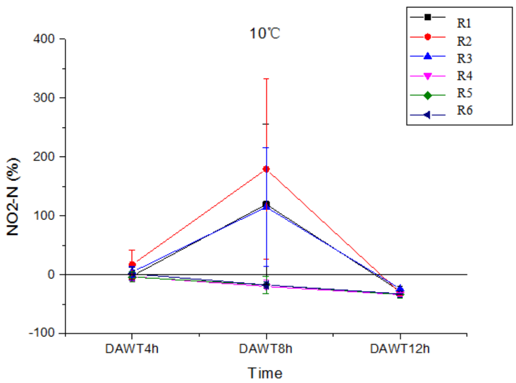

Figure 7. *NO_2-N varies with DWAT*

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(4) Removal of organic nitrogen

Figure 8 shows that, the organic nitrogen (ON) presents a downward trend in each matrix with the increase of DWAT at 10℃, and a decreasing trend with the removal rate. Also, the concentration of nitrite nitrogen is significantly lower at 12 h. Then, the removal rate of nitrite nitrogen in R1/R2/R3 is higher than that in R4R4/R6, that the change value is more than -40%.

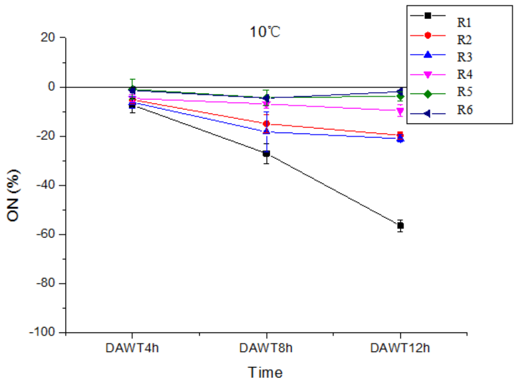

Figure 8. *ON varies with DWAT*

(5) Removal of total nitrogen

Figure 9 shows that, the Total nitrogen (TN) presents a downward trend in each matrix with the increase of DWAT time at 10℃, where the change value is less than 5 mg/L. Also, the removal rate of Total nitrogen presents an “L”-shaped downward trend, where the change value is more than -22%. Then, the removal rate of Total nitrogen (TN) in R1/R2/R3 is higher than that in R4R4/R6.

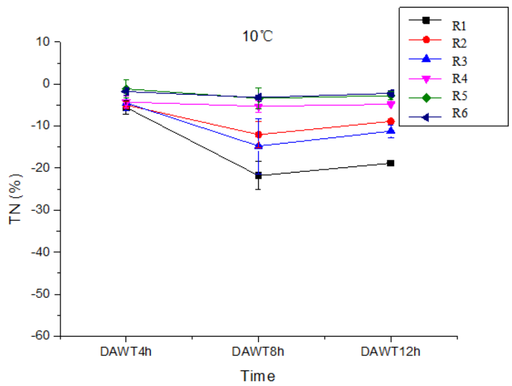

Figure 9. *TN varies with DWAT*

Discussion

Response of dry and wet alternation to key influencing factors

Pearson correlation analysis was used to analyze the correlation between DO, PH, TOC and various matrices at different dry wet alternation times. *Table 4* shows that, there is a significantly correlation (P = 0.01) between DO and 12 h interval in each

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matrix under wetting and drying, also DO and 4 h interval in biological carbon matrix 2, gravel, zeolite and volcanic rock matrix, but little correlation in other circumstances. So, the DO content can be improved with dry and wet alternations in wetland matrix (do increased by 1.5-4.0 mg/L), which can achieve artificial oxygen enhancement (Liu, 2017; Huang, 2018; Kang, 2019); This result was significantly higher than that of Chen Tao et al., whose DO concentration was higher than 1.0 mg/L by adjusting water level + covering + airway (Chen et al., 2019).

There is a significantly correlation (P = 0.01) between pH and 4 h interval in each substrate under wetting and drying, and between pH and 12 h interval in crushed stone and zeolite. Dry and wet alternations can affect the pH value in wetlands (pH 7.2-7.8), and can provide suitable pH values for wetlands (pH 6.5-8.5 for ammonification, 7.5-8.6 for nitrification, 7-8 for denitrification) (Abbas et al., 2003).

There is a significantly correlation (P = 0.01) between TOC and 12 h interval in all matrices with the dry and wet, while TOC and 8 h interval in biological carbon matrix 2. The analysis shows that the content of TOC is affected by the alternations of dry and wet in wetland, increased the electron donor required for microbial metabolism, and improved the efficiency of nitrogen removal (Wei, 2010; Wang et al., 2016).

Talbe 4. *Correlation between dry-wet alternation and key influencing factors*

Key influencing factors	Dry and wet alternate time (DWAT)	Matrix type					
		R1	R2	R3	R4	R5	R6
DO	4 h	-0.578	-0.753*	-0.624	-0.667*	-0.741*	-0.794*
	8 h	0.111	-0.006	0.054	-0.178	0.067	0.088
	12 h	-0.908**	-0.794*	-0.814*	-0.923**	-0.760*	-0.701*
pH	4 h	-0.853**	-0.839**	-0.930**	-0.912**	-0.893**	-0.880**
	8 h	0.038	0.168	0.090	0.011	0.009	0.065
	12 h	0.009	-0.507	-0.395	-0.694*	-0.730*	-0.409
TOC	4 h	0.430	0.480	0.562	0.350	0.289	0.262
	8 h	0.352	0.509	0.727*	0.546	0.442	0.455
	12 h	0.797*	0.824**	0.906**	0.727*	0.693*	0.683*

N = 9; *, there was a significant correlation at 0.05 level (bilateral); **, there was a significant correlation at 0.01 level (bilateral), the same as below

Response of influencing factors to nitrogen removal efficiency

(1) DO effect

Pearson correlation analysis was used to analyze the correlation between DO and different nitrogen at different dry wet alternation times. *Table 5* showed that, there was a significant correlation (P = 0.05) between DO and NH_3-N removal rate in biological carbon matrix 1 under DAWT for 12 h. At DAWT 4 h and DAWT 12 h, there was a significant correlation (P = 0.05) between DO and NO_3-N removal rate in biological carbon matrix. But no correlation between DO and NO_2-N removal rate in each matrix. DAWT 12 h, DO and ON removal rates in bio-carbon matrix 3 and macadam matrix were significantly correlated (P = 0.05). DAWT 4 h, DO and TN removal rate in zeolite matrix were significantly correlated (P = 0.05). DAWT 12 h, DO was significantly correlated (P = 0.01) with TN removal rate in biological carbon matrix 3.

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So, we can see that the DO was related to nitrogen removal efficiency in alternating wet and dry wetlands. (Gao et al., 2008; Dessureault-Rompre et al., 2010), the DO content was affected with the alternations of dry and wet in the matrix, meet the demand for oxidative decomposition of pollutants (Wu et al., 2010), and facilitate ammoniation reaction (Liu et al., 2017). Then the alternations of dry and wet can affect the nitrification and denitrification rates directly or indirectly (Verhoeven et al., 1999; Zhang et al., 2015). Therefore, DO content is significantly related to nitrogen removal effect in wetland system.

Table 5. *Correlation between DO and nitrogen removal rate*

Nitrogen	**Dry and wet alternate time (DWAT)**	**Matrix type**					
		R1	**R2**	**R3**	**R4**	**R5**	**R6**
NH_3-N	4 h	0.061	0.405	0.545	-0.407	-0.382	0.655
	8 h	-0.650	-0.486	-0.736*	0.174	-0.266	0.005
	12 h	-0.792*	-0.469	-0.474	-0.143	-0.017	-0.146
NO_3-N	4 h	0.688*	0.622	0.632	0.479	0.491	0.259
	8 h	-0.148	0.350	0.548	-0.210	-0.512	-0.358
	12 h	-0.568	0.364	0.675*	0.386	-0.601	-0.483
NO_2-N	4 h	-0.277	-0.209	-0.377	-0.273	-0.092	0.108
	8 h	-0.372	-0.344	-0.511	-0.527	-0.062	-0.245
	12 h	0.277	-0.276	-0.217	-0.425	0.224	0.395
ON	4 h	0.376	0.201	0.556	0.598	0.530	0.394
	8 h	-0.276	0.269	0.582	0.664	0.632	0.003
	12 h	0.222	0.560	0.737*	0.759*	0.630	0.544
TN	4 h	0.421	0.377	0.655	0.594	0.698*	0.200
	8 h	0.242	0.514	0.658	0.525	0.041	0.150
	12 h	0.001	0.546	0.837**	0.735*	0.556	0.615

The significant relationship is the same as above

(2) pH effect

Pearson correlation analysis was used to analyze the correlation between pH and different nitrogen at different dry wet alternation times. *Table 6* showed that, under the influence of alternate wetting and drying of constructed wetland, DAWT 4 h, pH value was significantly correlated ($P = 0.05$) with NH_3-N removal rate (biological carbon matrix, zeolite and volcanic rock). But no significant correlation between pH value and the removal rate of NO_3-N and NO_2-N. At DAWT 8 h, the pH was significantly correlated ($P = 0.01$) with ON removal rate in zeolite and volcanic rocks, respectively. DAWT 12 h, the pH in zeolite was significantly correlated ($P = 0.05$) with the removal rate of ON. DAWT 12 h, there was a significant correlation ($P = 0.05$) between pH and TN removal in zeolite and volcanic rocks.

Significance analysis showed that pH value had a certain influence ON the removal of NH_3-N, ON and TN (Verhoeven et al., 1999; Dessureault-Rompre et al., 2010; Ding et al., 2015; Huang et al., 2018), but the effect of pH on the removal of NO_3-N and NO_2-N was not significant.

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Table 6. *Correlation between pH and nitrogen removal rate*

Nitrogen	Dry and wet alternate time (DWAT)	Matrix type					
		R1	**R2**	**R3**	**R4**	**R5**	**R6**
NH_3-N	4 h	0.382	0.116	0.770*	-0.087	-0.722*	-0.737*
	8 h	0.262	0.075	-0.442	0.039	-0.625	-0.075
	12 h	0.083	-0.338	-0.162	-0.060	0.247	0.119
NO_3-N	4 h	0.317	0.016	0.317	-0.157	0.058	-0.287
	8 h	0.183	0.042	0.393	-0.276	-0.345	-0.373
	12 h	0.553	0.154	0.423	0.192	-0.078	-0.317
NO_2-N	4 h	-0.444	-0.558	-0.659	0.211	0.177	0.159
	8 h	-0.412	-0.168	-0.349	-0.439	0.039	-0.376
	12 h	-0.465	-0.249	-0.351	-0.250	-0.222	-0.039
ON	4 h	0.330	0.326	0.457	0.208	0.357	0.169
	8 h	-0.092	0.034	0.481	0.826**	0.720*	0.501
	12 h	-0.377	0.148	0.327	0.449	0.697*	0.635
TN	4 h	0.303	0.091	0.382	0.117	0.384	0.183
	8 h	0.306	0.056	0.387	0.446	0.204	0.039
	12 h	0.387	0.118	0.402	0.443	0.720*	0.719*

The significant relationship is the same as above

(3) TOC effect

Pearson correlation analysis was used to analyze the correlation between TOC and different nitrogen at different dry wet alternation times. *Table 7* showed that, under the influence of alternating wetting and drying in constructed wetlands, TOC and NH_3-N removal rates in volcanic rocks at DAWT 8 h were significantly correlated (P = 0.05). At DAWT 4 h, there was a significantly correlated (P = 0.05) between TOC and NO_3-N removal rate in biological carbon matrix 2, zeolite and volcanic rock, respectively. DAWT 8 h, TOC in biological carbon matrix 2(P = 0.05) and 3(P = 0.01) was significantly correlated with NO_3-N removal rate, respectively. DAWT 4 h, TOC and NO_2-N removal rate in biological carbon matrix 3 were significantly correlated (P = 0.05). At DAWT 4 h, TOC and ON removal rate were significantly correlated. DAWT 8 h, biological carbon matrix 3, TOC and ON removal rate were significantly correlated (P = 0.01); DAWT 4 h, TOC and TN removal rates in rubble, zeolite and volcanic rocks were significantly correlated (P = 0.05). DAWT 8 h, TOC and TN removal rate in biological carbon matrix 3 were significantly correlated (P = 0.01).

The significance analysis showed that TOC had a significant effect ON the removal of NO_3-N, ON and TN. Because TOC content is higher, it is conducive to the growth of denitrifying bacteria, especially the biocarbon matrix contains more decompostable cellulose, which is easy to release carbon sources (Lin et al., 2002; Huang et al., 2018) provided electron donors for the denitrification process, improved the denitrification rate (Ding et al., 2015), and increased the removal rate of NO_3-N and TN.

This study found that TOC did not significantly remove NH_3-N and NO_2-N, possibly because TOC was related to ON, and ON converted to NH_3-N through ammonification, resulting in poor removal effect of NH_3-N.

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Table 7. *Correlation between TOC and nitrogen removal rate*

Nitrogen	**Dry and wet alternate time (DWAT)**	**Matrix type**					
		R1	**R2**	**R3**	**R4**	**R5**	**R6**
NH_3-N	4 h	-0.388	-0.542	-0.475	-0.304	-0.532	0.243
	8 h	0.092	-0.060	0.016	-0.554	-0.169	-0.769*
	12 h	0.440	0.431	0.650	0.435	0.094	-0.289
NO_3-N	4 h	0.561	0.695*	0.687	0.783	0.777*	0.789*
	8 h	-0.082	-0.710*	-0.954**	0.023	0.546	0.306
	12 h	0.550	-0.257	-0.684	-0.266	0.157	0.317
NO_2-N	4 h	0.259	0.632	0.732*	0.152	0.110	0.301
	8 h	0.084	0.527	0.590	0.536	0.097	0.009
	12 h	0.252	0.347	0.574	0.324	0.223	-0.039
ON	4 h	0.482	0.447	0.457	0.761*	0.568	0.587
	8 h	0.478	-0.349	-0.956**	0.864**	-0.661	-0.445
	12 h	0.129	-0.437	-0.657	0.324	-0.423	0.635
TN	4 h	0.568	0.680	0.664	0.834**	0.669*	0.826**
	8 h	0.248	-0.772*	-0.957**	-0.586	0.107	0.146
	12 h	0.360	-0.436	-0.650	-0.297	-0.372	0.719

The significant relationship is the same as above

Response relationship of three control indexes of alternating dry and wet

It can be seen above that, the DO content can be improved in constructed wetland matrix by the alternation of dry and wet (Liu, 2017; Huang, 2018; Kang, 2019), satisfied the oxidative decomposition of matrix trapped pollutants (Wu et al., 2010), increased the ammoniation rate of ON in wetland systems (Liu et al., 2017), and affected the nitrification and denitrification rates (Verhoeven et al., 1999; Zhang et al., 2015). At the same time, the addition of carbon source can improve the denitrification rate. Therefore, the dry-wet alternation can promote and improve the removal rate of organic nitrogen (ON), ammonia nitrogen (NH_3-N) and total nitrogen (TN).

In summary, dry and wet alternations were significantly correlated with key influencing factors (DO, TOC, etc.) and nitrogen removal ($P < 0.05$), as shown in *Figure 10*. Through the research of three-level control index of alternating dry and wet system established in this paper, the operation state and nitrogen removal effect of constructed wetland can be regulated.

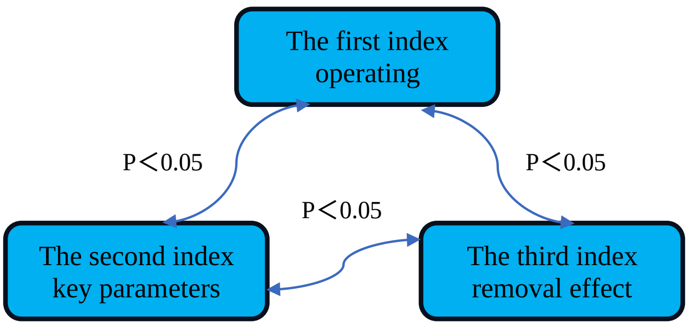

Figure 10. *The relationship between the three indexes of dry-wet alternation*

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Conclusion

(1) The concept of dry and wet alternation is put forward, and on this basis, a three-level system control index (operation control parameter, key influence parameter, nitrogen removal effect parameter) is established.

(2) At low temperature of 10°C, under different DWAT conditions of 4 h, 8 h and 12 h, the reoxygenation capacity and carbon source content can be improved by reducing the dry and wet alternating time (rapid increase frequency) in wetland, but not pH value. In other words, the key parameters of the secondary indexes are influenced by the control parameters of the operation of the primary indexes of alternate wet and dry wetlands.

(3) At a low temperature of 10°C, the removal effect of ammonia nitrogen, nitrate nitrogen, organic nitrogen and total nitrogen were improved by reducing the dry and wet alternating time (rapid addition frequency) in the constructed wetland under the condition of dry and wet alternating. In other words, through the control parameters of the operation of the primary index of the constructed wetland alternating dry and wet, the influence of the key parameters of the secondary index and the third-level nitrogen removal effect parameters was realized.

(4) Under the influence of dry and wet alternations, DO, pH, TOC and other influencing factors (secondary indexes) in each matrix were significantly correlated with dry and wet alternations (4 h, 8 h, 12 h) (primary indexes) ($P < 0.05$). However, DO, pH, TOC and other influencing factors in each matrix were correlated with the removal rates of NH_3-N, NO_3-N, ON and TN (tertiary indexes) to varying degrees ($P < 0.05$). In other words, through the research of the three-level control index of alternating dry and wet system established in this paper, the operation effect of regulating the constructed wetland ecosystem can be realized.

Author contributions. All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Jing Zhu, Xinyong Chen, Jianjian Lu, Zhongxu Wang, Xiangyu Zhang. The first draft of the manuscript was written by Xinyong Chen and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data and material availability. The datasets generated and/or analyzed and material and software used during the current study are available from the corresponding author on reasonable request.

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