Chapter 9

A Study and Analysis on the Physical Shading Effect of Water Quality Control in Constructed Wetlands

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Additional information is available at the end of the chapter

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1. Introduction

Eutrophication of water bodies has been studied since 1970. It is an urgent water pollution issue that needs to be addressed. In the past, eutrophication often occurred in reservoirs, lakes, or watersheds where water bodies have a slow flowing speed. Eutrophication or hypertophication refers to the accumulation of nutrients due to the addition of external nutrients into the water system (lakes, reservoirs, and wetlands) [7]. Eutrophication, according to nutrient concentration, can be divided into four types: oligitrophic, mesotropic, eutrophic, and hypertrophic [9].

In recent years, eutrophication in water bodies mainly was the result of excessive human activities such as overdevelopment of watersheds, agricultural irrigation, and recreation that cause the addition of exogenous nutrients to local water bodies that sped up the eutrophication of the water bodies and caused serious damage (Wu et al., 2006). The eutrophication phenomena include an increase of nutrient concentration and a rapid increase in the number of algae. However, Carlson Tropic State Index (CTSI), this is a measure of the trophic status of a body of water using several measures of water quality including: transparency or turbidity (using Secchi disk depth recordings), chlorophyll-a concentrations (algal biomass), and total phosphorus levels (usually the nutrient in shortest supply for algal growth).

Generally, the treatment technologies of eutrophic water bodies can be classified into physical, chemical, and eco-technology. Commonly used technologies include aeration at the bottom layer to increase dissolved oxygen concentrations in the deeper layers, addition of an algae inhibitor called copper sulfate that inhibits the growth of algae by increasing the concentration of Cu^{2+}, or the construction of wetlands that remove the carbon source and nutrients in the water [3, 7]. Among them, physical treatment requires huge amounts of energy to be effective and the addition of chemical agents increases treatment costs. Therefore, eco-technology treatment, a green technology, has gained high public support and at the same time, it requires lower amounts of energy, lower costs, and easy technological operations.

Eutrophication includes an increase in nutrient concentration as well as an increase in the number of algae (algal bloom). The extensive results of eutrophication are the death of a large number of animals, plants, and plankton, dramatic changes in dissolved oxygen concentration, changes in the eco-system and foul odors in the water bodies. Thus, if the nutrient concentration in water bodies can be controlled or algal bloom can be avoided, issues caused by eutrophication can be effectively rendered to prevent water quality and eco-system problems and to further achieve the purpose of water quality control.

Treatments for eutrophication mostly aim to remove the nutrients, such as nitrogen and phosphorus, in the water in order to improve eutrophication in water bodies. The mechanism of a constructed wetland system to treat eutrophication lies in the absorption of nitrogen and phosphorus nutrients by aquatic plants in the wetland system as well as the competition for the absorption of nutrients between aquatic plants and algae in water in order to control algae concentrations in water effectively. Algae in water, however, can use photosynthesis to convert light energy into chemical energy for self growth and aquatic plants can prevent the sun's ray from entering the water bodies as they grow, thereby creating the physical shading effect [5].

2. Experimental materials and methods

This study utilized model basins (as shown in Fig. 1) and in the beginning, wetland plants were collected from the wild for cultivation. Tests were started after the adaptation period of the plants. The basin size is in the dimension of L*W*H:50*35*27 cm and for each batch test, a point in each basin was used. Each day samples were collected four times; water resources came from the ecological pond of the National University of Kaohsiung. The initial nutrient concentration was also measured.

Figure 1. Module Basin Tests and Physical Shading Effect

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To conduct the physical shading test, this study fixed an opaque board on the lateral side of the basins to prevent exposure to sunrays. Shading rates refers to the surface area shaded and were set as 0, 30, 50, 70, and 100%; the 100% shading rate, based on oxygen transmission, was divided into two types: sealed shading and vented sealing. Due to the shading effect developed by the different growth types of plants and the oxygen transmission to water bodies by aquatic plants, vented sealing was selected to simulate the shading effect of wetland plants.

The test interval lasted for five days and there were six points where we collected samples of shading rate every day at three time periods, every four hours from 9:00 in the morning to 5:00 in the afternoon.

Water quality parameters are used mainly for sample analysis including DO, pH, ORP, temperature, electric conductivity, and luminance, which were measured on site as well as nitrogen and phosphorous contents, Chlorophyll a, turbidity, SS, transparency, which were analyzed at the lab.

3. Results and discussion

3.1. Influence of different shading rates on dissolved oxygen concentration

Table 1 shows daily dissolved oxygen concentration at different shading rates. On Day 1 after the model basin system was built, the initial concentration level of dissolved oxygen for each group was between 5-7 mg/L while the final concentration of dissolved oxygen of the 100 (aerobic), 100 (anaerobic), 70, 50, 30, and 0% groups was, respectively, 12.00±1.26, 8.08±0.10, 22.00±0.00, 13.28±0.18, 14.77±0.36 and 14.36±0.38 mg/L. Among them, the 70, 50, 30, and 0% groups showed a significant increase of dissolved oxygen concentration.

Testing time	100% (aerobic)	100%(anaerobic)	70%	50%	30%	0%
Day 1	6.51±0.17	5.91±0.08	6.57±0.24	6.12±0.42	6.43±0.37	6.73±0.37
Day 2	7.38±0.17	6.66±0.1	8.25±0.52	8.58±0.97	8.83±1.04	9.62±1.6
Day 3	8.11±0.32	6.94±0.07	10.79±1.34	13.28±2.85	14.45±3.43	17.04±4.53
Day 5	9.22±1.24	8.54±1.23	18.8±3.74	21.71±0.41	22±0.00	22±0.00
Day 7	12.00±1.26	8.08±0.10	22±0.00	13.28±0.18	14.77±0.36	14.36±0.38

Table 1. Average Daily Dissolved Oxygen Concentration Levels at Different Shading Rates (mg/L)

Figure 2 indicates the trend of dissolved oxygen concentration at different shading rates where the 70, 50, 30 and 0% groups had significantly increased concentration levels from Day 2 to Day 5; the 50, 30, and 0% groups had decreased concentration levels from Day 5 to Day 7. The 70% group had an increased concentration level. For the 100% (aerobic) and 100% (anaerobic) groups, dissolved oxygen concentration increased during the tests but they were small changes.

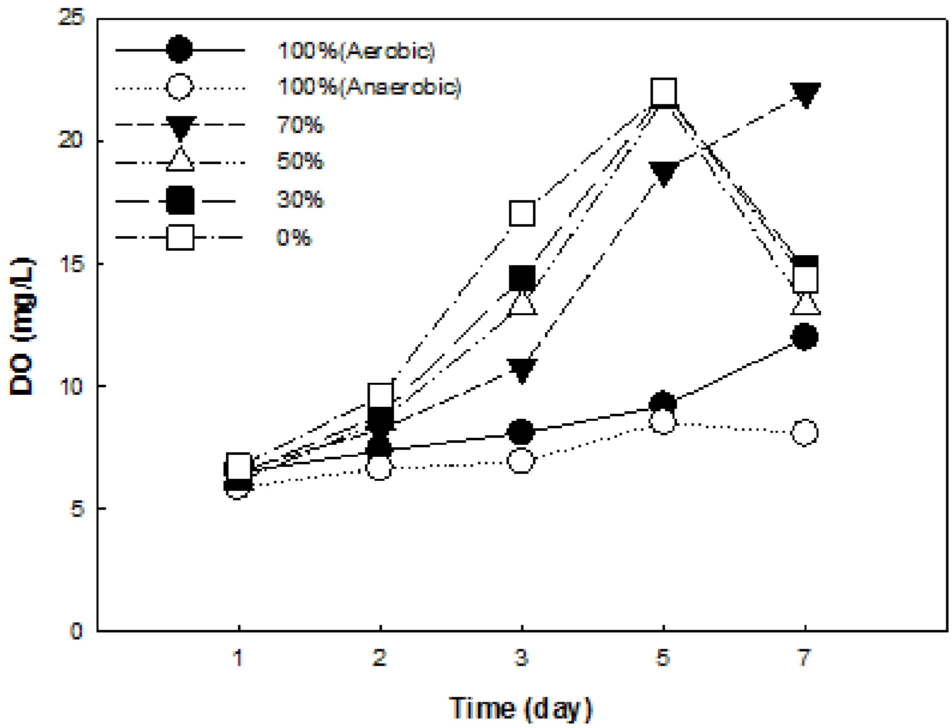

Figure 2. Dissolved Oxygen Concentration Trends at Different Shading Rates

Overall, the 70, 50, 30, and 0% groups were influenced by the photosynthesis of algae, resulting in a more significant change of dissolved oxygen concentration in water bodies. The concentration level decreases along with the increase in shading rate. For the 50, 30, and 0% groups, due to the reduced concentration level of algae, dissolved oxygen concentration decreased at the latter stage.

3.2. Influence of different shading rates on algae concentration

Table 2 shows daily algae concentration at different shading rates. As shown in the table, the initial algae concentrations of the 100 (aerobic), 100 (anaerobic), 70, 50, 30 and 0% groups were, respectively, 5.27±0.93, 5.92±0.00, 7.90 ±5.59, 5.92±0.00, 7.90±5.59, and 13.82±2.79 μg/L while the final algae concentrations of 100 (anaerobic), 100 (anaerobic), 70, 50, 30 and 0% were, respectively, 140.86±58.94, 15.8±2.79, 15.8±2.79, 53.32±4.84, 55.29±2.79 and 49.37±26.64 μg/L. For the 70, 50, 30 and 0% groups, from Day 1 to Day 7, algae concentration significantly increased.

Figure 3 shows the algae concentration trend at different shading rates in water bodies. As shown in this figure, the 70, 50, 30 and 0% groups from Day 2 to Day 5 had significantly increased concentration levels while between Day 5 and Day 7, they decreased. For the 100% (anaerobic) and 100% (anaerobic) groups, due to the shading effect, algae could not use photosynthesis and therefore, the concentration was lower.

Testing time	100%(aerobic)	100%(anaerobic)	70%	50%	30%	0%
Day 1	5.27±0.93	5.92±0	7.9±5.59	5.92±0	7.9±5.59	13.82±2.79
Day 2	1.97±2.79	15.14±9.17	19.75±7.39	15.8±7.39	21.72±12.17	25.67±21.81
Day 3	19.75±5.59	7.9±2.79	49.37±14.78	102.68±43.62	130.33±58.04	152.05±60.48
Day 5	57.27±11.17	9.87±2.79	244.86±50.34	280.4±32.92	329.77±15.55	250.78±32.21
Day 7	140.86±58.94	15.8±2.79	177.72±17.44	53.32±4.84	55.29±2.79	49.37±26.64

Table 2. Daily Algae Concentration Levels at Different Shading Rates in Water Bodies (μg/L)

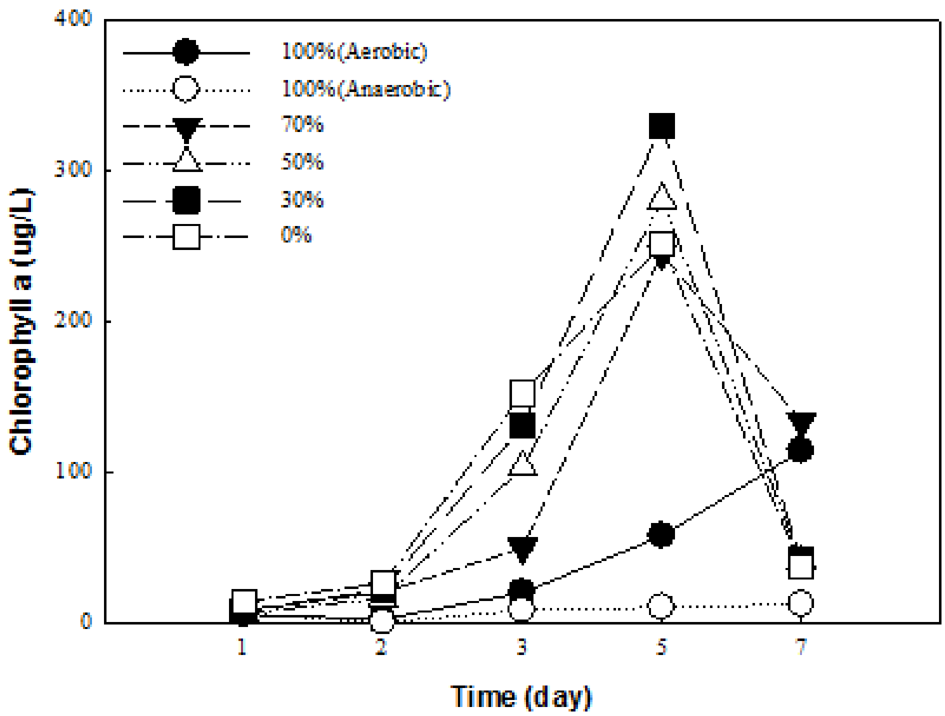

Figure 3. Algae Concentration Trends at Different Shading Rates in Water Bodies

3.3. Influence of nutrients at different shading rates

Tables 3-5, respectively, show the daily concentration of ammonia nitrogen, nitrate nitrogen, and nitrite nitrogen. Results indicate that the initial concentration levels of ammonia nitrogen for the 100 (aerobic), 100 (anaerobic), 70, 50, 30 and 0% groups were, respectively, 3.07±0.68, 2.69±0.24, 2.64±0.32, 2.69±0.41, 2.5±0.16 and 2.52±0.23 mg/L while the final concentration levels of ammonia nitrogen of the 100 (aerobic), 100 (anaerobic), 70, 50, 30 and 0% group were, respectively, 0.20±0.08, 0.40±0.08, 0.10±0.03, 0.08±0.04, 0.29±0.23, and 0.08±0.06 mg/L. Each group on Day 7 had significantly reduced concentrations of ammonia nitrogen.

Testing Time	100%(aerobic)	100%(anaerobic)	70%	50%	30%	0%
Day 1	3.07±0.68	2.69±0.24	2.64±0.32	2.69±0.41	2.5±0.16	2.52±0.23
Day 2	3.22±0.66	2.81±0.08	2.86±0.3	2.34±0.26	2.69±0.1	2.61±0.25
Day 3	0.44±0.33	0.26±0.08	0.06±0.04	0.23±0.22	0.03±0.05	0.1±0.05
Day 5	0.07±0.05	0.04±0.03	0.07±0.05	0.04±0.06	0.34±0.26	0.04±0.06
Day 7	0.2±0.08	0.4±0.08	0.1±0.03	0.08±0.04	0.29±0.23	0.08±0.06

Table 3. Daily Ammonia Nitrogen Concentration Levels at Different Shading Rates in Water Bodies (mg/L)

Testing time	100%(aerobic)	100%(anaerobic)	70%	50%	30%	0%
Day 1	1.07±0.05	1.19±0.06	1.21±0.06	1.16±0.04	1.14±0.12	1.36±0.07
Day 2	1.27±0.12	1.32±0.04	1.32±0.14	1.12±0.17	1.24±0.07	1.37±0.03
Day 3	0.9±0.08	1.07±0.03	0.87±0.05	0.87±0.17	0.76±0.04	1.01±0.34
Day 5	0.96±0.15	1.14±0.18	0.51±0.06	0.22±0.03	0.23±0.05	0.29±0.08
Day 7	0.86±0.15	1.24±0.18	0.41±0.06	0.32±0.03	0.33±0.05	0.39±0.08

Table 4. Daily Nitrate Nitrogen Concentration Levels at Different Shading Rates in Water Bodies (mg/L)

Testing time	100%(aerobic)	100%(anaerobic)	70%	50%	30%	0%
Day 1	0.09±0	0.09±0	0.08±0	0.08±0	0.08±0	0.08±0
Day 2	0.13±0.01	0.14±0.02	0.1±0	0.07±0.02	0.09±0	0.09±0
Day 3	0.18±0.01	0.25±0.02	0.11±0	0.09±0	0.09±0	0.08±0
Day 5	0.23±0.00	0.34±0.00	0.1±0	0.01±0	0.01±0	0.01±0
Day 7	0.24±0.00	0.35±0.00	0.08±0	0.01±0	0.01±0	0.01±0

Table 5. Daily Nitrite Nitrogen Levels at Different Shading Rates in Water Bodies (mg/L)

The initial concentration levels of nitrate nitrogen of the 100 (aerobic), 100 (anaerobic), 70, 50, 30 and 0% groups were, respectively, 1.07±0.05, 1.19±0.06, 1.21±0.06, 1.16±0.04, 1.14±0.12, and 1.36±0.07 mg/L while the final nitrate nitrogen concentration levels of the 100 (aerobic) and 100 (anaerobic), 70, 50, 30 and 0% groups were, respectively, 0.86±0.15, 1.24±0.18, 0.41±0.06, 0.32±0.03, 0.33±0.05, and 0.39±0.08 mg/L. On Day 7, the 70, 50, 30, and 0% groups did not have significantly reduced concentration levels of nitrate nitrogen.

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Testing time	100%(aerobic)	100%(anaerobic)	70%	50%	30%	0%
Day 1	0.19±0.01	0.19±0.01	0.22±0.04	0.19±0.00	0.19±0.00	0.18±0.03
Day 2	0.19±0.00	0.19±0.00	0.18±0.00	0.18±0.01	0.18±0.00	0.18±0.01
Day 3	0.18±0.00	0.18±0.00	0.15±0.01	0.12±0.01	0.12±0.01	0.1±0.02
Day 5	0.16±0.01	0.18±0.00	0.05±0.01	0.02±0.00	0.02±0.01	0.03±0.00
Day 7	0.14±0.01	0.18±0.00	0.01±0.00	0.01±0.00	0.01±0.00	0.02±0.00

Table 6. Daily Orthophosphate Concentration Trends at Different Shading Rates in Water Bodies (mg/L)

The initial concentration levels of nitrite nitrogen for the 100 (aerobic), 100 (anaerobic), 70, 50, 30 and 0% groups were, respectively, 0.09±0.00, 0.09±0.00, 0.08±0.00, 0.08±0.00, 0.08±0.00 and 0.08±0.00 mg/L while the final concentration levels of nitrite nitrogen of the 100 (aerobic), 100 (anaerobic), 70, 50, 30 and 0% groups were, respectively, 0.24±0.00, 0.35±0.00, 0.08±0.00, 0.01±0.00, 0.01±0.00 and 0.01±0.00 mg/L. On day 7, the concentration levels of nitrite nitrogen for the 100% (aerobic) and 100% (anaerobic) groups increased while that of the 70, 50, 30 and 0% groups decreased.

Testing time	100%(aerobic)	100%(anaerobic)	70%	50%	30%	0%
Day 1	0.23±0.02	0.22±0.01	0.24±0.03	0.22±0.01	0.21±0.01	0.23±0.00
Day 2	0.18±0.00	0.18±0.00	0.18±0.01	0.17±0.01	0.18±0.01	0.18±0.01
Day 3	0.2±0.00	0.2±0.00	0.18±0.01	0.15±0.01	0.16±0.01	0.15±0.01
Day 5	0.18±0.01	0.2±0.01	0.1±0.01	0.04±0.01	0.05±0.01	0.05±0.00
Day 7	0.19±0.11	0.25±0.09	0.03±0.00	0.03±0.00	0.02±0.00	0.04±0.00

Table 7. Daily Total Phosphorous Contents at Different Shading Rates in Water Bodies (mg/L)

Figures 4 to 6 show the concentration trends of ammonia nitrogen, nitrate nitrogen, and nitrite nitrogen at different shading rates. Results indicate that for each group the ammonia nitrogen concentration significantly decreased on Days 2 and 3 and between Days 3 and 7, there was no significant change.

The nitrate nitrogen concentration levels of the 100% (aerobic) and 100% (anaerobic) groups decreased between Day 1 and Day 3 and from Day 3 to Day 7, they increased. The levels in the 70, 50, 30 and 0% groups decreased from Day 2 to Day 5. However, the levels for the 50, 30 and 0% groups increased between Day 5 and Day 7. The 70% group showed a continuous decrease.

The concentration levels of nitrite nitrogen, for the 100% (aerobic) and 100% (anaerobic) groups, showed an increasing trend during the tests while that of the 70, 50, 30 and 0% groups decreased along with time.

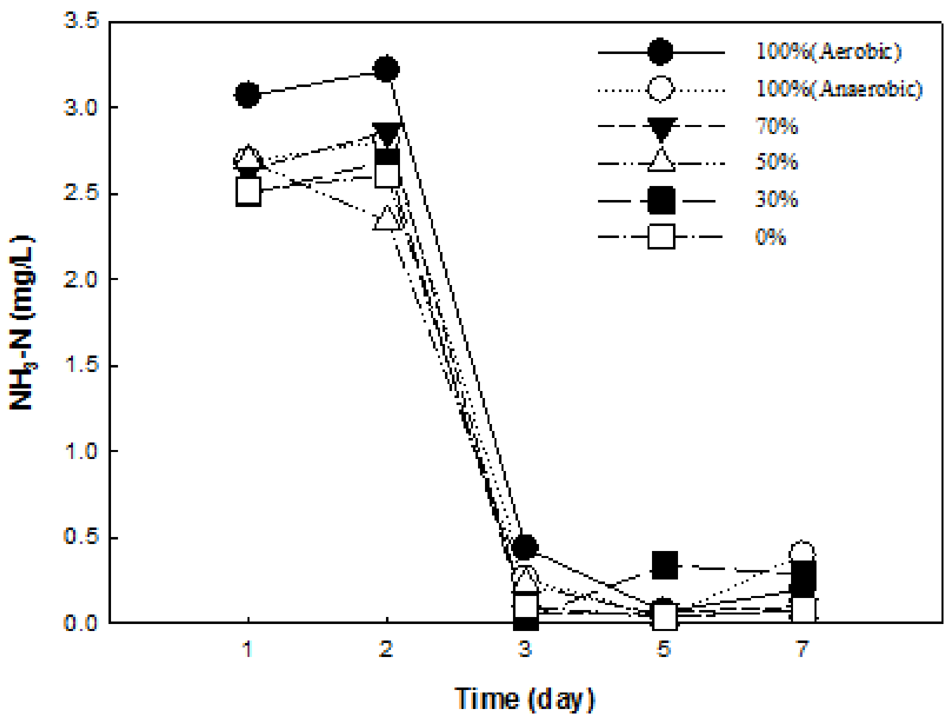

Figure 4. Ammonia Nitrogen Concentration Trends at Different Shading Rates in Water Bodies

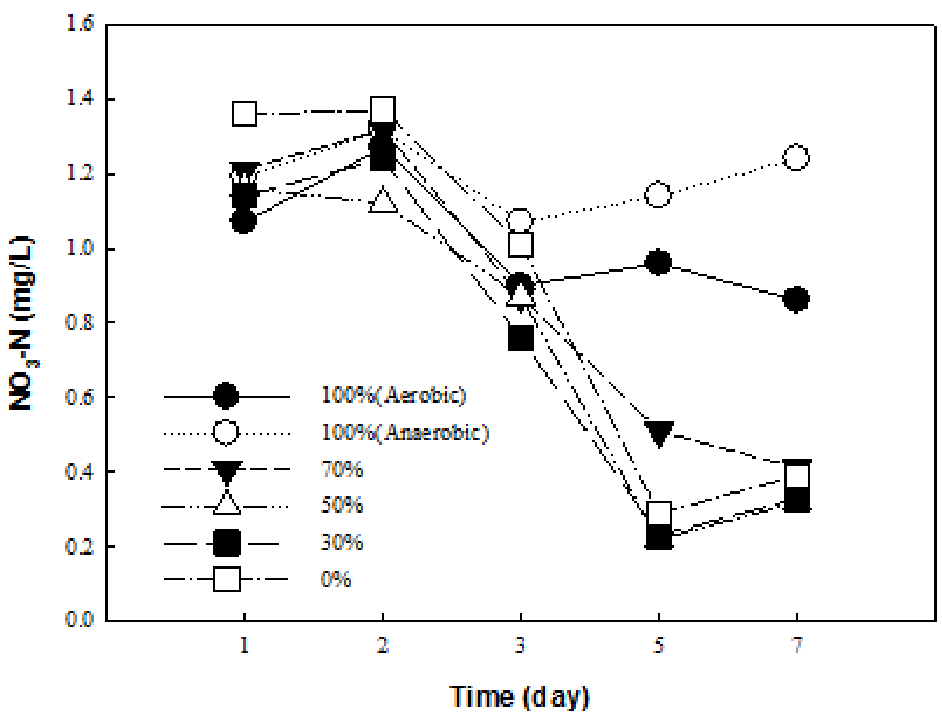

Figure 5. Nitrate Nitrogen Concentration Trends at Different Shading Rates in Water Bodies

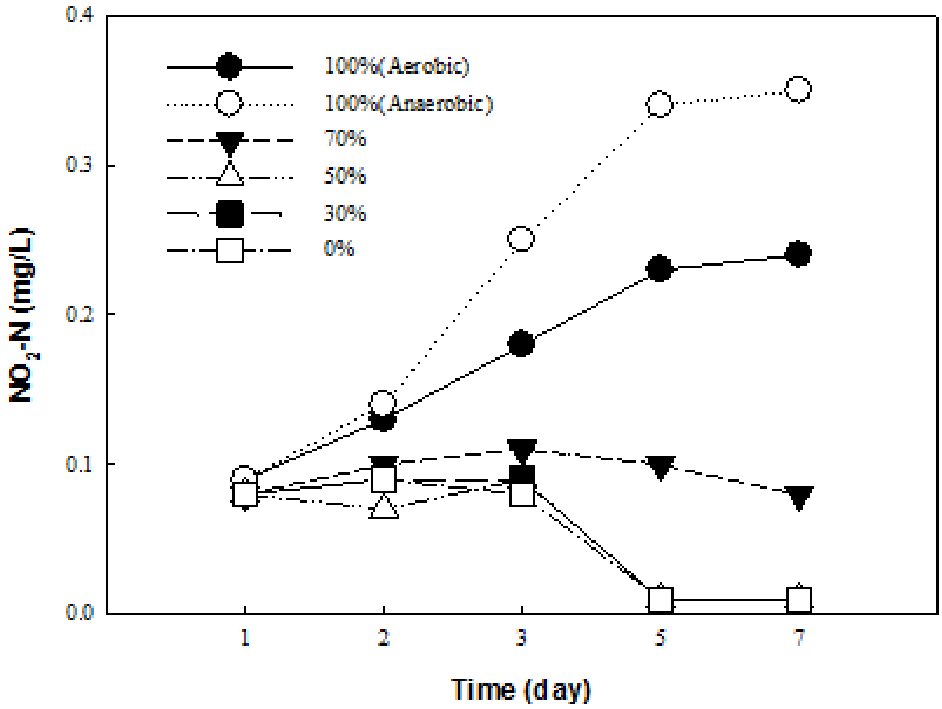

Figure 6. Nitrite Nitrogen Concentration Trends at Different Shading Rates in Water Bodies

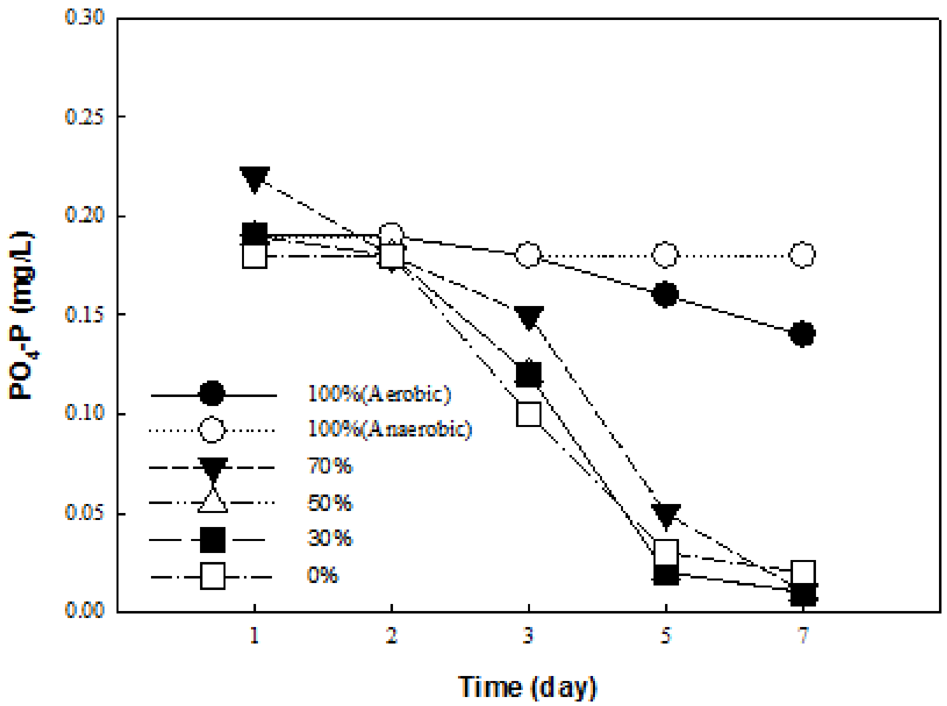

Figure 7. Orthophosphate Concentration Trends at Different Shading Rates in Water Bodies

Figure 7 and Fig. 8 show daily orthophosphate concentration and total phosphorous contents at different shading rates in water bodies. The results indicate that the initial orthophosphate concentration of the 100 (aerobic), 100 (anaerobic), 70, 50, 30 and 0% groups were, respectively, 0.19±0.01, 0.19±0.01, 0.22±0.04, 0.19±0.00, 0.19±0.00, and 0.18±0.03 mg/L while the final concentration levels of the 100 (aerobic), 100 (anaerobic), 70, 50, 30 and 0% groups were, respectively, 0.14±0.01, 0.18±0.00, 0.01±0.00, 0.01±0.00, 0.01±0.00 and 0.02±0.00 mg/L. For the 70, 50, 30, and 0% groups, there were significantly reduced concentrations from Day 1 to Day 7.

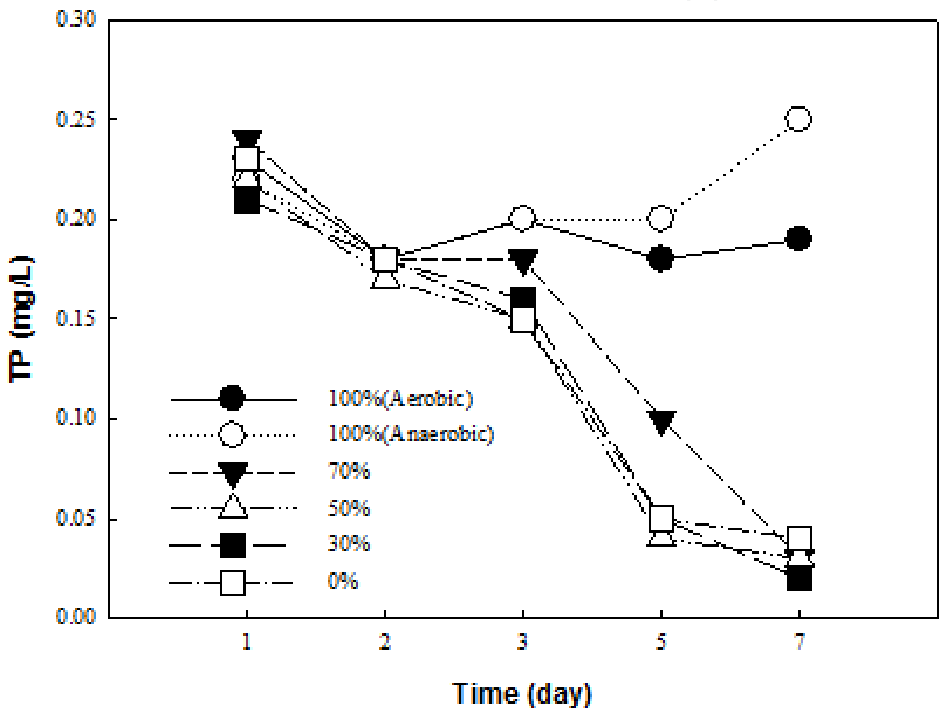

Figure 8. Total Phosphorous Content Trends at Different Shading Rates in Water Bodies

The initial total phosphorous contents of the 100 (aerobic), 100 (anaerobic), 70, 50, 30 and 0% were, respectively, 0.23±0.02, 0.22±0.01, 0.24±0.03, 0.22±0.01, 0.21±0.01 and 0.23±0 mg/L and the final total phosphorous contents of the 100 (aerobic), 100 (anaerobic), 70, 50, 30 and 0% groups were respectively 0.19±0.11, 0.25±0.09, 0.03±0.00, 0.03±0.00, 0.02±0.00 and 0.04±0.00 mg/L. The 70, 50, 30 and 0% groups, from Day 1 to Day 7, had significantly reduced total phosphorous content.

Figure 7 and 8, respectively, show the orthophosphate concentration trends and total phosphorous contents at different shading rates in water bodies. The results indicate that for each group during the tests, the orthophosphate concentration gradually decreased and among them, the 70, 50, 30, and 0% groups showed the most significant changes of orthophosphate

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concentrations while the 70, 50, 30 and 0% groups showed the most significant reduction of orthophosphate concentrations during the tests.

In general, due to the rapid increase in the number of algae, the 70, 50, 30 and 0% groups were found to have a significant reduction in orthophosphate concentrations and total phosphorous content. Higher shading rates resulted in higher orthophosphate concentrations and total phosphorous content.

4. Conclusion

As shown in the results of the physical shading rates, along with an increase in shading rates, dissolved oxygen concentration decreases. When the shading rate reaches 100%, there is the smallest change in dissolved oxygen concentration and water temperature decreases along with the increase of shading ratios. Algae concentration in water bodies decreases significantly along with the increase in water temperature and on Day 5, water bodies that are partially shaded has algae concentrations five times higher than that of the completely shaded water bodies. Results indicate that it is important to control algae growth in water bodies by blocking sunrays to prevent algae from having the energy, through photosynthesis, to rapidly grow in number.

There was relatively no correlation between changes in ammonia nitrogen concentrations and the physical shading effect. Nitrate nitrogen was found on Day 3 to have increased in concentration along with the increase of the physical shading rate; nitrate nitrogen was found on Day 2 to have increased in concentration along with an increase in shading rate. Orthophosphate concentrations were discovered on Day 3 to increase along with the shading ratio and total phosphorous contents were found on Day 3 to increase according to shading rates. Overall, water bodies completely shaded on Day 7 had concentration levels of nitrate nitrogen and nitrate nitrogen two times higher than that of partially shaded water bodies and seven times higher orthophosphate concentrations and phosphorous contents than that of partially shaded water bodies.

In conclusion, the above two points find that the use of the physical shading effect prevents algae from using photosynthesis to convert the light energy that is used for self growth and proliferation and the resulting rapid growth in the number of algae. The physical shading effect, however, cannot reduce nutrients in order to provide beneficial functions and that results in high nutrient levels in water bodies in the latter part of the test. After the introduction of the Carlson Tropic State Index (CTSI), the completely shaded water bodies at the initial stage of the test are mesotrophic water bodies that had neutral nutrients and partially shaded ones are eutrophic water bodies. In the latter stage of the test, the former turned into eutrophic water bodies while the latter turned into mesotrophic water bodies. The main cause lies in the relatively higher weight that CTSI places on total phosphorous content.

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