Assessment of Nutrient Usage and Discharge in Tomato Greenhouse

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Abstract. One of the contributors to eutrophication is from agricultural wastewater which contained nutrients such as nitrogen and phosphorus. The agricultural industry in Japan has practiced greenhouse plantation recently. In this study, the amount of nutrient concentration and load in the wastewater were investigated. Water samples from water supply, soil medium and effluent were collected at a greenhouse in Japan which cultivated tomato plants in coconut husk medium. The assessment was conducted every two weeks for regular monitoring for three months. The results showed that concentrations of all nutrients have same concentration level in the water supply samples from January 13\textsuperscript{th} to March 15\textsuperscript{th}. The concentration of supplied nutrient on March 29\textsuperscript{th} increased due to high concentration of nutrients in medium water samples which preventing the nutrient uptake by the plant. The nutrient uptake by the plants were in the same range which NH\textsubscript{4}-N was between 13.6 mg/L to 14.99 mg/L, NO\textsubscript{2}-N was between 2.3 to 2.5 mg/L, NO\textsubscript{3}-N was between 135.9 mg/L to 152.5 mg/L and PO\textsubscript{4}-P was between 70.12 to 76.64 mg/L.

The concentration of nutrients in drainage was below the permissible limit of Japan’s Effluent Standard. As a result, it can be concluded that using greenhouses as an alternative farming method contributes in reducing nutrient discharge by controlling the nutrient supply to the plants.

1. Introduction

Eutrophication is one of the environmental problems around the world that predicted to be increased every year. Increased usage of fertilizer in agricultural sector and waste discharge from industrial activities is mostly the cause of this phenomenon [1, 2]. Nutrient loading which are nitrogen and phosphorus from these activities into water bodies has trigger the growth of algae also known as algal bloom. Due to the algal bloom, the chemical properties of the water bodies have change which lead to the deterioration of water quality and destruction of aquatic ecosystem [3]. In Japan, one of the areas that had experience eutrophication in the past was Mikawa Bay.

Mikawa bay is semi-closed coastal area that located at Aichi prefecture. In 2004, about 700,000 people are living nearby this area and agricultural activity is the most practice industry at this area [4]. In the recent years, the increased number in the community influenced increased of human activities near the area. Due to the human activities, the water quality of the coastal area has experienced deterioration and affects the lives of aquatic organism. As Aichi prefecture is well-known of its agricultural practice, most of the agricultural fertilizers were flowed into river by surface run-off which then flowed to the bay. A lot of agricultural industry at Aichi prefecture has practice greenhouse plantation, especially in Toyohashi city. The open field cultivation was transitioned to greenhouse cultivation because of its benefit in lowering nutrient concentration of wastewater by controlling the
supplied nutrient to the plants. This study was conducted to investigate the nutrient usage of agriculture by analyzing the nutrient concentration in water supply, culture base and nutrient load in wastewater.

2. Materials and Methods

2.1. Sample collection
This study was conducted at tomato greenhouse in Toyohashi University of Technology. The greenhouse planted 192 tomatoes plant with soilless cultivation in coconut coir husk media. The sampling collection was conducted from January 13th until March 29th of 2021. The greenhouse was for research purpose thus, the concentration and amount of nutrient supplied to the crop are manually selected. The water supply was taken from raw water from municipal water supply. The fertilizers also applied together with supplied water. The temperature, humidity and shading were controlled automatically.

The sampling was conducted once every two weeks. Three sampling points were involved in sampling the water which are water supply, coconut medium and drainage as shown in Figure 1. Water supply samples was collected by putting the water supplier into 100ml sampling bottle until full. For coconut husk water samples, needle attached with syringe was injected into the medium to collect the water samples inside the medium and filled into 50 mL sampling bottle. The water samples were taken from 3 different points at the medium. For drainage, the water was collected two times from the drainage pipe and filled into 100 mL sampling bottle. The sampling bottles was capped and transferred to laboratory to be stored in refrigerator at 4°C.

2.2. Analytical methods
The analysis of water samples was conducted using Flow Injection Analyzer to measure the concentration of nutrients in the water samples which are nitrogen and phosphorus. The concentrations of nitrogen in water samples were determined by the concentration of nitrate nitrogen (NO\textsubscript{3}-N), nitrite nitrogen (NO\textsubscript{2}-N) and ammonia nitrogen (NH\textsubscript{4}-N) that present in the water samples. The concentration of phosphorus in the water samples was determined by the concentration of phosphate phosphorus (PO\textsubscript{4}-P) that present in the water samples. The method used in analysed all the nutrients in the samples were spectrophotometric method.

Figure 1. Collection of water samples in three sampling points: point 1 is the water supply, point 2 is the coconut medium and point 3 is the drainage.
Figure 2. Concentrations of ammonium in nutrient supply, growing medium, and wastewater drainage. The supply values were measured once while the medium values were the averages of triplicates, and the drainage values were the averages of duplicates.

3. Results and Discussions

Based on the analysis of water sample taken from the greenhouse, the data obtained show that there is significant presence of nutrient which are phosphate phosphorus (PO\(_4\)-P), nitrate nitrogen (NO\(_3\)-N), nitrite nitrogen (NO\(_2\)-N) and ammonia nitrogen (NH\(_4\)-N). The samples were collected from January 13\(^{th}\) to March 29\(^{th}\) with five sampling times.

3.1. Ammonia nitrogen (NH\(_4\)-N)

Based on Figure 2, NH\(_4\)-N concentration in the water samples showed decreasing trends. The supplied nutrient from January 13\(^{th}\) until March 15\(^{th}\) was 13.63 mg/L. On January 13\(^{th}\), the concentrations of NH\(_4\)-N in medium and drainage water samples were 0.01 mg/L and 0.006 mg/L respectively. This shows that the amount of supplied nutrient on this sampling period was higher than in medium and drainage water samples. On February 12\(^{th}\), both concentration of NH\(_4\)-N in the medium and drainage water sample was decreased to 0.0035 mg/L and 0.002 mg/L respectively. The concentration of NH\(_4\)-N in medium water samples on February 24\(^{th}\) dropped continuously to 0.0024 mg/L. However, the NH\(_4\)-N concentration in drainage water samples of the same sampling day has increased to 0.003 mg/L. The concentration of medium and drainage on March 15\(^{th}\) kept increased to 0.0069 mg/L and 0.0039 mg/L. On March 29\(^{th}\), the supplied nutrient has increased to 15 mg/L. Both medium and drainage water samples of the same day also increased to 0.015 mg/L and 0.0097 mg/L respectively. This shows that March 29\(^{th}\) has the highest concentration of NH\(_4\)-N in all samples.

The concentration of NH\(_4\)-N that absence in drainage water samples on January 13\(^{th}\), February 12\(^{th}\), February 24\(^{th}\), March 15\(^{th}\) and March 29\(^{th}\) were 13.624 mg/L, 13.628 mg/L, 13.627 mg/L, 13.626 mg/L and 14.99 mg/L respectively. There are two factors that can be assumed due to the loss of nutrient. The first factor is plant growth phase. It is assuming that the plants were in growth phase during the sampling period. Thus, the amount of nutrient needed for the growth is high. During growth phase, plants have high tendency to absorbed ammonia more than nitrate [5, 6]. By taking ammonia, it has decreased the energy needed by plants to reduce nitrate to ammonia [7]. Second factor is nitrification process. Nitrification is an oxidation process of ammonia to nitrite and nitrate in two processes. The first process involved the oxidation of ammonia to nitrite by ammonia-oxidizing bacteria and followed with the second process that involved the oxidation of nitrite to nitrate by nitrite-oxidizing bacteria [8].
Figure 3. Concentrations of nitrite in nutrient supply, growing medium, and wastewater drainage. The supply values were measured once while the medium values were the averages of triplicates, and the drainage values were the averages of duplicates.

Due to this process, the amount of ammonia in drainage water samples is lower. The amount of ammonia building up in the medium also needs to take attention. It can be seen that on Figure 2 that the ammonia in coconut medium increased dramatically from February 24th to March 29th. The trends show that it will be increased by time. Excessive amount of ammonia can harm the plant growth. Excessive quantities of ammonia can cause inhabitation of root and plant growth [9]. Thus, the nutrient supplied to the plants need to be lowered to prevent from ammonia poisoning by the plants.

3.2. Nitrite nitrogen (NO$_2$-N)

Figure 3 showed the concentration of NO$_2$-N in the tomato greenhouse did not experience extreme changes during the first four month while on March 29th, the supplied nutrient increased to 2.64 mg/L. The supplied nutrient from January 13th to March 15th was 2.4 mg/L. The amount of NO$_2$-N in the medium and drainage water samples on January 13th was 0.024 mg/L and 0.037 mg/L respectively. The concentration of medium and drainage on February 12th has increased to 0.026 mg/L and 0.063 mg/L respectively. On February 24th, the concentration of medium water samples has increased dramatically to 0.129 mg/L while the concentration in drainage water sample has decreased to 0.037 mg/L. On March 15th, both the concentration in medium and drainage water samples has decreased to 0.031 mg/L and 0.0326 mg/L respectively. However, the amount of NO$_2$-N in both medium and drainage water samples has increased drastically to 0.42 mg/L and 0.10 mg/L respectively.

The concentration of NO$_2$-N that absence in drainage water samples on January 13th, February 12th, February 24th, March 15th and March 29th were 13.624 mg/L, 13.628 mg/L, 13.627 mg/L, 13.626 mg/L and 14.99 mg/L. The factor that can be considered affecting the nitrite loss in the drainage was due to the nitrification and denitrification process. Nitrites act as intermediary product in both denitrification and nitrification process [10]. In nitrification process, ammonia is converted to nitrites by Nitrosomonas bacteria before it was converted to nitrates by Nitrobacter bacteria. In denitrification process, nitrate is converted to a series of conversion where nitrite is produced in the series before it is achieved final product which is nitrogen gas (N$_2$). However, some of nitrite compounds are not able to be processed to end product due to several factor. The first factor that affect the lack of bacterial communities on the site is the accumulation of nitrite in coconut medium and wastewater [11]. This make the process of nitrite conversion to nitrate and nitrogen gas was disturbed. the accumulation of nitrite occur in medium and drainage water samples was due to several factors which are the medium characteristics, type of fertilization, nitrification activity, pH of medium and soil [12].
Figure 4. Concentrations of nitrate in nutrient supply, growing medium, and wastewater drainage. The supply values were measured once while the medium values were the averages of triplicates, and the drainage values were the averages of duplicates.

3.3. Nitrate nitrogen (NO$_3$-N)

Figure 4 showed the trend of NO$_3$-N concentration in tomato greenhouse water samples from January 13$^{th}$ until March 29$^{th}$. It can be seen that the supplied nutrient on the first four months was 141.2 mg/L while on March 29$^{th}$, the amount of NO$_3$-N supplied to the plant was 155.3 mg/L. The medium and drainage water samples contain 0.623 mg/L and 0.069 mg/L of NO$_3$-N concentration respectively. On February 12$^{th}$, the concentration of medium water samples decreased to 0.3 mg/L while the concentration of drainage water samples on the same day increased to 0.343 mg/L. On February 24$^{th}$, the concentration of NO$_3$-N in both medium and drainage water samples increased drastically to 6.07 mg/L and 4.98 mg/L respectively. However, the concentration of medium on March 24 decreased to 3.38 mg/L. While the concentration of drainage water samples on the same day increased to 5.28 mg/L. On March 29$^{th}$, the concentration in medium water samples was increased to 3.81 mg/L while in drainage, the concentration decreased to 2.8 mg/L.

The amount of nitrate absent in the drainage water samples of January 13$^{th}$, February 12$^{th}$, February 24$^{th}$, March 15$^{th}$ and March 29$^{th}$ were 141.13 mg/L, 140.85 mg/L, 136.22 mg/L, 135.92 mg/L and 152.53 mg/L respectively. This can be assumed that most of the nitrate has been taken up by the plants as nitrate is one of the essential elements along with ammonium for plant growth. The nitrification processes that occur in the medium also affect the amount of nitrate presence in the medium and drainage water samples. On February 24$^{th}$, the medium contained high concentration of NO$_3$-N because the rate of nutrient uptake by the plant was decreased. It is assumed that the plant has reached the peak of growth phase. It is also can be assumed that the denitrification activity during this time is decrease. Denitrifying bacteria such as Pseudomonas stutzeri C3 helps in reduced a great number of nitrate concentration in denitrification process [13]. Thus, the concentration of NO$_3$-N in medium was low. The concentration of nitrate in the drainage water samples were within the range of 0.068 mg/L to 5.27 mg/L. The concentration of NO$_3$-N of this study was compared with Japan’s Effluent Standard [16]. From the comparison, it shows that the NO$_3$-N concentration in discharge water samples was below the permissible level which is 120 mg/L. Thus, it can be assumed that the discharge water from this greenhouse might be less likely to contribute to eutrophication.
Figure 5. Concentrations of phosphate in nutrient supply, growing medium, and wastewater drainage. The supply values were measured once while the medium values were the averages of triplicates, and the drainage values were the averages of duplicates.

3.4. Phosphate phosphorus (PO$_4$-P)

For the first four months, the concentration of supplied nutrient was 72.72 mg/L. However, on March 29$^{th}$, the supplied nutrient increased to 80 mg/L. The medium and drainage concentration on January 13$^{th}$ was 1.46 mg/L and 1.85 mg/L respectively. On February 12$^{th}$, medium concentration decreased. For the first two months, the concentration of PO$_4$-P uptake by the plants were high which are 70.87 mg/L for January 13$^{th}$ and 70.86 mg/L for February 12$^{th}$. This can be assumed that during this time, the plant undergoes reproduction phase where the amount of PO$_4$-P needed was high. This is because PO$_4$-P is important for plant reproduction, cell growth and plant metabolism [14]. Some of the PO$_4$-P was assumed to undergo several chemical reactions to be assimilated into organic compound such as adenosine triphosphate (ATP) which is important for photosynthesis process [15]. On February 24$^{th}$, the amount of PO$_4$-P uptake by plant decreased to 70.12 mg/L. Although the PO$_4$-P uptake is still high, there was accumulation of PO$_4$-P in the coconut medium. This accumulation kept increased by 7.34 mg/L on March 15$^{th}$ and decreased to 3.74 mg/L on March 29$^{th}$. The excess PO$_4$-P was assumed to be washed out to the drainage system which increases the concentration of PO$_4$-P in wastewater. The highest concentration of PO$_4$-P in drainage water sample is on March 15$^{th}$ which is 5.69 mg/L.

Thus, the nutrient supplied has been lowered from March 15$^{th}$ to avoid PO$_4$-P build up in the future which will be washed out to the drainage. This will cause eutrophication to occur if it is released to the surface water. This is because PO$_4$-P is one of the important elements that needed by algae to growth. However, high concentration of PO$_4$-P will trigger the algal bloom which will deteriorate the water body [16]. The concentration of PO$_4$-P in the drainage water samples were within the range of 1.85 mg/L to 5.69 mg/L. When compared the concentration of PO$_4$-P in drainage with the Japan’s Effluent Standard, it showed that the concentration was below the permissible limit of PO$_4$-P which is 16 mg/L [16]. From the comparison, it can be said that the drainage from this greenhouse was less likely to contribute to eutrophication.

4. Conclusion

The study showed that the uptake of nutrient supplied to the tomato plants was at maximum concentration in all sampling periods. Due to the maximum level of uptake, the concentrations of studied nutrients in the wastewater were small and did not exceed the permissible limit of Japan’s Effluent Standard. Thus, it can be said the application of greenhouses as alternative agriculture cultivation helps in lowering the concentrations of nutrient in the greenhouse wastewater by managing the supplied nutrient to the targeted plants. This assessment needs further research to analyse the amounts of nutrient
loads in the discharge samples and to investigate the factors affecting the level of nutrient loads in the drainage samples.

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References
[1] Withers P, Neal C, Jarvie H and Doody D 2014 Agriculture and Eutrophication: Where Do We Go from Here? Sustainability 6 5853-5875
[2] Le C, Zha Y, Li Y, Sun D, Lu H and Yin B 2010 Eutrophication of Lake Waters in China: Cost, Causes, and Control Environ. Manage. 45 662-668
[3] Bhagowati B and Ahamad K.U 2019 A review on lake eutrophication dynamics and recent developments in lake modeling Ecohydrol. Hydrobiol. 19 155-166
[4] Anggara Kasih G A and Kitada T 2004 Numerical simulation of water quality response to nutrient loading and sediment resuspension in Mikawa Bay, central Japan: quantitative evaluation of the effects of nutrient-reduction measures on algal blooms Hydrol. Process. 18 3037-3059
[5] Ferrón-Carrillo F, da Cunha-Chiamolera T P L and Urrestarazu M 2021 Effect of ammonium nitrogen on pepper grown under soilless culture J. Plant Nutr. 194348
[6] Howitt S M and Udvardi M K 2000 Structure, function and regulation of ammonium transporters in plants Biochim. Biophys. Acta Biomembr. 1465 152-170
[7] Hachiya T and Sakakibara H 2016 Interactions between nitrate and ammonium in their uptake, allocation, assimilation, and signaling in plants J. Exp. Bot. 68 2501-2512
[8] van Kessel M, Speth D and Albertsen M et al 2015 Complete nitrification by a single microorganism Nature 528 555-559
[9] Liu Y and von Wirén N 2017 Ammonium as a signal for physiological and morphological responses in plants J. Exp. Bot. 68 2581-2592
[10] Su H et al. 2011 Soil Nitrite as a Source of Atmospheric HONO and OH Radicals Science 333 1616-1618
[11] Sun H et al 2009 Nitrite Accumulation during the Denitrification Process in SBR for the Treatment of Pre-treated Landfill Leachate Chin J. Chem. Eng. 17 1027-1031
[12] Du R, Peng Y, Cao S, Li B, Wang S and Niu M 2015 Mechanisms and microbial structure of partial denitrification with high nitrite accumulation Appl. Microbiol. Biotechnol. 100 2011-2021
[13] He T, Xie D, Li Z, Ni J and Sun Q 2017 Ammonium stimulates nitrate reduction during simultaneous nitrification and denitrification process by Arthrobacter arilaitensis Y-10 Bioresour. 239 66-73
[14] Razaq M, Zhang P, Shen H and Salahuddin 2017 Influence of nitrogen and phosphorus on the growth and root morphology of Acer mono PLoS One 12 e0171321
[15] McClain A M and Sharkey T D 2019 Triose phosphate utilization and beyond: from photosynthesis to end product synthesis J. Exp. Bot. 70 1755-1766
[16] Ministry of the Environment Government of Japan 2015 National effluent standards JP. MOE. https://www.env.go.jp/en/water/wq/nes.html