Nutrient uptake from liquid digestate using ornamental aquatic macrophytes (*Canna indica*, *Iris pseudacorus*, *Typha latifolia*) in a constructed wetland system

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Abstract. Indonesia has implemented energy recovery from organic (food) waste by anaerobic digestion method, but the digestate was commonly treated only by composting, and still as a separated treatment (not integrated into a resource recovery system). Whilst not getting any pretreatment, the digestate was disposed to the environment and then act as a pollutant. Yet it contains nutrients which could be recovered as a nutrient source for plants. The study was about how ornamental aquatic macrophytes could uptake nitrogen from liquid digestate in a constructed wetland method. *Canna indica*, *Iris pseudacorus*, and *Typha latifolia* were the experimented ornamental aquatic macrophytes used to uptake the nutrient (nitrogen—N) from liquid digestate. The study showed that the highest N uptake was done by *C. indica* (25.1%) which has the highest biomass increment as well (80.5%). Effluent quality improvement also shown by N removal by *C. indica* (68.5—76.4% TN), *I. pseudacorus* (61.8—71.3% TN), and *T. latifolia* (61.6—74.5%). This research proved that *C. indica* has the performance for the N uptake, best N removal efficiency, with a great growth rate as well. This system using *C. indica* could also improve the water quality of the effluent and add the aesthetic of environment.

1. Introduction

Organic (food) waste has been treated for recovering energy using the technology of anaerobic digestion (AD). This technology is quite well-known in developed countries such as Indonesia, which is also one of the problem solvers of food waste generation. Despite the role of treating waste and recovering energy, AD even puts another problem on the environment by producing end-of-waste, known as digestate [1]. Digestate in both forms, solid (fibre) and liquid (liquor), still contains high nutrient content which makes it as a pollutant if it’s not treated before disposal. Liquid fraction/liquor has higher nutrient content than solid fraction/fiber; Total Nitrogen (TN) of solid digestate range from 8.8—13.0 kg/t dry solids (DS), while the liquid fraction contains 4,000—6,000 mg/l [2]. Due to the high nutrient content of digestate, it must be treated before disposing to prevent unwanted matter on the environment.

The characteristic of digestate made it as a valuable nutrient source, yet not many technologies are friendly enough to the user. One way to treat digestate is by using a nutrient recovery method, which not only could recover nutrients from digestate by plant uptake, but also create a cleaner environment by making a friendly post-treatment product (low nutrient, BOD, and COD content). Nutrient recovery of digestate that has been done was only up to composting (biofertilizer), mostly on solid form, but it was not good enough to compete with synthetic fertilizers [3] unless it is integrated with an agriculture industry which uses AD technology as well [2].

Another method of nutrient recovery is by using plants, particularly aquatic macrophytes. Aquatic macrophytes are the type of plants which has a macro (can be seen; big) form, and lives in a wet
ecosystem [4]. It is known that this vegetation has a reputation in nutrient removal system, such as a constructed wetland. The vegetation that are quite popular in here is *Canna indica*, *Iris pseudacorus*, and *Typha latifolia*. Each of these ornamental aquatic macrophytes recovered the nutrients from liquor state as nutrient uptake which will be the source of their development.

*C. indica* is one of the most popular ornamental aquatic macrophyte used in the wastewater treatment in a wetland system. As for treating domestic wastewater, *C. indica* could be used as an efficient nutrient removal up to 84% for nitrogen removal and 92% for phosphorus removal, which could create a healthier environment at the end of the treatment [5]. With those capabilities, *C. indica* could be more likely used as a nutrient recovery agent for substances such as liquid products of organic waste treatment which has similarities with domestic wastewater; high nutrient content. In this study, *C. indica* was compared to two other ornamental aquatic macrophytes, *I. pseudacorus* and *T. latifolia*, to see if how much does the ornamental aquatic macrophytes could make use liquid digestate as a nutrient source, especially nitrogen.

2. Methods

2.1 Operation

The operation flow started from the AD reactor to the influent storage, and the influent later will be distributed to three beds (Figure 3). The operational time was done in 70 days; acclimatization (A) and feeding (F) stage. Both stages (A and F) started in the morning (10 AM); flowing the influent inside the bed. Sampling was done three times a week (every two days) after the acclimatization stage. As for laboratory test needed 14 days for liquid samples, and 20 days for plants and sediments (count on work days).

![Figure 1. Operation Flow](image)

2.2 Influent Characteristic

The constructed wetland influent was from an anaerobic digester which treats food waste [6, 7]. Effluent from the digester was pretreated by dilution to provide an influent with a BOD₅ characteristics ± 400 mg/L (Table 2). This characteristic must be reached for the survival of the macrophyte itself [8].

2.3 CW Design

The constructed wetland for the research was designed in a horizontal subsurface flow [9]. This system was chosen since the constructing area are located near the campus so it could prevent the smell from the influent (flows in the subsurface), near from water and energy source, and fairly manageable. The site was also for adding the aesthetic view. As for the land used for each bed is 170 × 80 × 70 cm (length : width : depth), with planting area 120 × 60 cm (length : width). *C. indica*, *I. pseudacorus* and *T. latifolia* were the experimented object in the study. The selection of the vegetation was based on literature (the most effective vegetation in nutrient removal), availability in the country, price and aesthetic [10]. Sediments were put in layers with clay as the top layer (20 cm), sandy loam as the middle layer (15 cm), and coarse sand at the bottom (15 cm). Each inlet and outlet were given gravel (15 cm).
2.4 Data Analysis

The data which were gained from the study will be analyzed later on by statistical analysis using ANOVA and Duncan Multiple Range Test (DMRT) to compare the effect of digestate on plant growth (height, shoots, and leaves). Calculating the nutrient removal by each plant was using an efficiency equation:

\[
\text{%Efficiency} = \left( \frac{\text{input-output}}{\text{input}} \right) \times 100\%
\]

(1)

TN content by each plant used the equation as followed:

\[
\text{%N uptake} = \left( \frac{\text{total nutrient content}_F - \text{total nutrient content}_A}{\text{total nutrient content}_F} \right) \times 100\%
\]

(2)

Calculating total biomass increment using equation is:

\[
\text{Total biomass (g/m}^2\text{)} = \frac{\text{biomass (F-A) (g)}}{\text{planting area (m}^2\text{)}}
\]

(3)

and measuring the growth rate of each plants using kinetics from the order of 0 to 2.
3. Result and Discussion

The statistic shows that the type of the macrophyte which used digestate as the nutrient source has a significant effect for each variable (Table 1). *C. indica* was the most improved macrophyte in plant height, and the least improvement of it was shown by *T. latifolia*. *T. latifolia* had a stagnant height situation on the feeding stage; barely add a milimeter of height, while *C. latifolia* could rise 1—4 cm height per week, and *I. pseudacorus* could add 0.5—2 cm per week.

| Variable          | *C. indica* | *I. pseudacorus* | *T. latifolia* |
|-------------------|-------------|------------------|----------------|
| Plant height      | 131.500a    | 59.972b          | 14.199c        |
| Number of leaves  | 9.222a      | 4.278b           | 4.833b         |
| Number of shoots  | 1.1111a     | -                | 0.5556b        |

Letters (a-c) are indicate homogeneous subsets (p < 0.05)

Number of leaves also improved the best on *C. indica* which has lush leaves, while the other two had the same growth performance being in the same group that explain how small the growth of leaves of each macrophytes. *I. pseudacorus* didn’t have shoots for growth, so the variable was compared between *C. indica* and *T. latifolia*. *C. indica* leads the performance by having lots of shoots growth every week since acclimatization until feeding ended. The parent plant of *T. latifolia* withered several days after acclimatization started, but showing shoots number increment two weeks before the study ended.

![Figure 4](image_url)

*Figure 4. Growth Rate Kinetics of C. indica using order 2 (a), I. pseudacorus using order 1, and T. latifolia (c) using the order 0 which the R^2's are the closest to 1*
C. indica 2\textsuperscript{nd} Order

\[
\frac{1}{Ca} = -0.002 x + 0.0237 \quad (4)
\]

I. pseudacorus 1\textsuperscript{st} Order

\[
\frac{\ln Ca}{Ca} = 0.001 x + 0.0965 \quad (5)
\]

T. latifolia 0\textsuperscript{th} Order

\[
Ca = 14.809 x + 109.92 \quad (6)
\]

Ca is the height of the plant and x is number of the day.

N removal by each macrophyte on the digestate was proved by the TN content on the effluent from every bed are lower than the influent (Table 2). However, there was an anomaly result on period A3; TN content of C. indica’s bed effluent was too high compared to other samples. The efficiency calculation shows that C. indica could remove nitrogen up to 72.19%, the highest N removal efficiency among the other macrophytes in the study. Even though the influent’s nitrogen content wasn’t as high as the literature mentioned, but C. indica has the performance to improve the quality of the effluent. I. pseudacorus and T. latifolia show similar efficiency performance, lower than C. indica. However, it still shows improvement in the effluent quality.

| Table 2. BOD and N Concentration in Influent and Each Effluent (mg/L) |
|-----------------|-----------------|-----------------|-----------------|
| Periode          | BOD\textsubscript{5} of the Influent | TN content of the Influent | TN content of the Effluent |
|                 | C. indica | I. pseudacorus | T. latifolia | C. indica | I. pseudacorus | T. latifolia |
| A1              | 420       | 617            | 195           | 224       | 236           |
| A2              | 275       | 659            | 177           | 223       | 242           |
| A3              | 255       | 581            | 1205          | 222       | 188           |
| F1              | 530       | 670            | 158           | 192       | 257           |
| F2              | 520       | 649            | 189           | 238       | 165           |

| Table 3. N Removal Efficiency by Each Macrophyte (%) |
|-----------------|-----------------|-----------------|
| Periode          | Bed             |
|                 | C. indica | I. pseudacorus | T. latifolia |
| A1              | 68.5       | 63.8           | 61.8          |
| A2              | 73.1       | 66.1           | 63.3          |
| A3              | -          | 61.8           | 67.7          |
| F1              | 76.4       | 71.3           | 61.6          |
| F2              | 70.8       | 63.3           | 74.5          |
| Min-Max         | 68.5—76.4   | 61.8—71.3      | 61.6—74.5     |
| Average         | 72.2       | 65.3           | 65.8          |

C. indica shows the best result in N uptake and biomass increase. C. indica gains 25.1% TN during the study, and increase 80.5% of the plant biomass. Meanwhile, I. pseudacorus lost 9.7% of TN content and T. latifolia lost 62% of TN content, while both still having an increment in their biomass (gain 68.8% and 72.4% biomass, respectively). This result matches the situation presented in Table 1, when C. indica has the fastest height growth and the most number of leaves.
Table 4. N Uptake and Biomass Increase by Each Macrophyte

|    | Period  | C. indica | I. pseudacorus | T. latifolia | C. indica | I. pseudacorus | T. latifolia |
|----|---------|-----------|----------------|--------------|-----------|----------------|--------------|
|    | TN content (g/kg) |    |                |              |    |                |              |
| A  | 1,652   | 1,319     | 1,319          | 12,430       | 11,110    | 12,100         |
| F  | 2,207   | 1,203     | 920            | 63,590       | 35,630    | 43,860         |
| %  | +25.1%  | -9.7%     | -62%           | 80.5%        | 68.8%     | 72.4%          |

4. Conclusions
Ornamental aquatic macrophyte in a constructed wetland system could be a solution for treating liquid digestate. Using a horizontal subsurface flow constructed wetland, the highest nutrient uptake performance from liquid digestate was done by C. indica which has 25.1% N uptake to the plant during the study, and has the highest biomass increase for 80.5%, which was shown by the growth performance as well to be significantly high than the two other experimental macrophytes. I. pseudacorus and T. latifolia had a lower number of TN content in the plant (loss 9.7% and 62%, respectively), but the biomass shows increment number up to 68.8% for I. pseudacorus and 72.4% for T. latifolia. Effluent quality improvement also shown by N removal by C. indica (68.5—76.4% TN), I. pseudacorus (61.8—71.3% TN), and T. latifolia (61.6—74.5%). With this result, all of the experimented plants could use liquid digestate as a nutrient source, but the best performance goes to C. indica. Besides of the nitrogen uptake value, it could also improve the quality of the effluent before disposal. Nonetheless, the ornamental aquatic macrophyte also has an aesthetic value to the environment.

5. References
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