Characteristic Analysis of the Organic Substance and Nutrient Removal and the Green House Gas Emission in the Soil Treatment Systems with Aquatic Plants

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Abstract

In this study, characteristic analysis of the organic substance and nutrient removal and the green house gas emission in the soil treatment systems with aquatic plants was evaluated. From this study various outcomes were obtained: Soil treatment systems using aquatic plants have removal capabilities of 90% (BOD removal rate $3.7\text{ g}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$) of organic substances including BOD and COD; similarly, the removal capabilities of nutrients including nitrogen and phosphorus were 90% (Nitrogen removal rate $0.9\text{ g}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$, phosphorus removal rate $0.09\text{ g}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$) in both *Phragmites australis* and *Zizania latifolia* units with a low level of pollution loads; the removal capabilities in both *P. australis* and *Z. latifolia* units with a high level of pollution load dropped to 50%, *P. australis* units showed particularly low results in the winter; and with regard to greenhouse gases, *P. australis* units showed low CH_4 generation while *Z. latifolia* showed a high value. These results revealed the characteristics of one method of ecoengineering. The overview results of this study can be summarized as follows: 1) Although both *P. australis* and *Z. latifolia* showed BOD removal rates of 90% or more, the load of BOD $200\text{ mg}\cdot\text{l}^{-1}$ was too high for *P. australis* in the beginning of vegetation. 2) Both *P. australis* and *Z. latifolia* showed relatively stable nitrogen removal capability from summer to autumn, but its performances slightly decreased in winter due to the low temperature. 3) The generation rate of CH_4 in *Z. latifolia* units was higher in all the loading levels of BOD 50, 100, and $200\text{ mg}\cdot\text{l}^{-1}$, than in those in *P. australis* units. 4) Soil treatment systems using aquatic plants keep high purifying capabilities in low pollution loads such as BOD $50\text{ mg}\cdot\text{l}^{-1}$ when water temperature is low.

Key words: Aquatic plant, Soil purification system, Nutrient removal, Green house gas, Constructed wetland

INTRODUCTION

Recently, two topics have attracted attention as important environmental issues in Japan and other countries: eutrophication, such as red tides in inland seas and inner bays, and water blooms in lakes; and global warming caused by CO_2 , CH_4 (methane) and

N_2O (nitrous oxide), which were added to the list of green house gases at COP3 (the Third Session of the Conference of the Parties), when the Kyoto Protocol was adopted¹⁾. In order to prevent these problems, it is of great importance to take measures in various areas, particularly, actions to reduce the environmental loads caused by household

effluents are essential^{2, 3)}. These actions can be roughly divided into two categories: bio-engineering and ecoengineering as approaches to water treatment engineering⁴⁾. Of these two approaches, the utilization of ecoengineering is crucial.

Ecoengineering is a method to introduce engineering technology into natural ecosystems to improve the efficiency of purifying actions to remove pollutants for environmental remediation. This technology is starting to be utilized to make biotopes in which wildlife can live, and to purify water in water areas such as rivers, lakes, and tidal flats. In other words, ecoengineering is a technology to control the organic interactions of variety of wildlife and their living environments from an engineering perspective. The wildlife here includes low-level algae and bacteria, their predators such as protozoa and micro metazoa, and fish and birds, comprising food chains and food webs, which are the bases of ecosystems⁵⁾. The living environments include water areas, continental areas, and wetlands. Through the use of this technology, it is expected that the functions of these objects of control, such as those for industry, degradation, absorption, and purification, can be made more efficient, and environmental conservation and remediation can be achieved. Ecoengineering methods have the following characteristics:

- 1) Not only organic materials, but also nitrogen and phosphorus can be cleaned up^{6, 7)}.
- 2) Since the building cost is low, it is possible to construct large scale facilities.
- 3) The maintenance is easy and inexpensive.
- 4) Efficient use of aquatic plants, vegetables, and flowers makes it possible to recycle resources.
- 5) Using accumulated mud and plants as compost and feed enables resources recycling.
- 6) Not only biotopes can be created, but also the landscape can be enhanced for use as recreation areas such as water parks.
- 7) People can participate voluntarily to help improve the environment.
- 8) It can provide sites for environmental education, and enlighten people about improvement of the environment.

Thus, the application of ecoengineering methods is important in creating resource-recycling type local ecosystems and establishing effective purifying systems. A purifying system that utilizes sediment with vegetation is the focus of this experiment. This system has functions such as removal of nitrogen and phosphorus by absorption of plants, degradation and removal of organic substances and nutrient due to the filtration by biofilms attached to the rootstalks of plants, filtration of SS by aquatic plants, purifying actions by nitrifiers and denitrifiers in sediment that accumulate during purification, and purifying actions by food chains in rootstalks and plant bodies in water⁸⁾. In addition, filtration by emergent plants and hydroponic plants has revealed the absorption of oxygen from stems and leaves in aerial parts, and promoting action for degradation of organic substances, and nitrification of ammonia-nitrogen.

In the bottom sediment, free oxygen (O_2) absorbed from leaves transfers to the rhizosphere via rootstalks. Soil around the rhizosphere turns aerobic, and ammonia is nitrified by nitrifiers. Soil farther away from the rhizosphere turns to a facultative anaerobic environment where nitrogen is removed by producing N_2 gas due to denitrification by denitrifiers. These reactions, nitrification and denitrification, lead to efficient water purification. These processes may generate nitrous oxide (N_2O), which is a greenhouse gas, under certain conditions^{9, 10)}. In the denitrification process, denitrifiers require BOD (C) as an energy source, NO_2-N and NO_3-N as bound oxygen for a source of respiration, and when C/N balance is decreased to 3 or less, N_2O is generated. Accordingly, adjusting to the optimum operation conditions is very important. In addition, since when the condition turns anaerobic, the number of methanogenic bacteria increases and methane gas is generated, the transformation of CH_4 into CO_2 is also important^{8, 11-16)}.

Based on conditions described, the purposes of this study are as follows:

- 1) To utilize plants in order to reduce the cost and simplify the maintenance as a low-cost treatment system;

- 2) In order to optimize the removal method for greenhouse gases and nutrients, it is expected that a quantitative evaluation of the correlation between purifying functions and volumes of emitted greenhouse gases will be obtained;
- 3) A method to remove nutrients and to suppress CH_4 and N_2O generation at the same time with ecoengineering should be developed;
- 4) Purifying functions and characteristics of greenhouse gas emission should be clarified for the nutrient removal system, which is a hybrid process combining soil treatment and purification by aquatic plants, as an ecoengineering method.

MATERIALS AND METHODS

The main purpose of this study is to find a method to remove nitrogen and phosphorous as limiting factors of eutrophication, and to suppress the generation of CH_4 and N_2O as greenhouse gases in the units in which *Phragmites australis* and *Zizania latifolia* are planted as a soil treatment system with aquatic plants. The result was analyzed to connect the reactions of plants and the rhizosphere shown in Figure 1 to actions for eutrophication and greenhouse gases.

Equipments for experiment Vegetation pots used for this study were placed in outdoor location. Since environmental factors such as water temperature and radiation vary with the seasons under natural environments in outdoor locations, the purifying function, bacterial activity and characteristics of plant growth were analyzed accordingly.

The purifying system, which utilized sediment with aquatic plants, used polypropylene cylindrical containers (pots) with a diameter of 50 cm and a height of 100 cm, and which contain river sand with a depth of 60 cm (Figure 2). In each pot, *Phragmites australis* or *Zizania latifolia* were planted, and the water level was adjusted to a depth of 30 cm over the sand surface. Water flows into the top of the pots, runs through the pots and the sand layer, and flows out. The generated gases were collected as needed. For collecting gases, the top of the pot was covered by a cylindrical gas compartment⁸⁾ (capacity of 480 l), and the gases in the compartment were collected into a gaspack using a pump. The flowchart of the purifying system utilizing sediment with vegetation employed in this study is shown in Figure 3.

Fig. 1 Flow chart of reactions in plants and rhizosphere

Fig. 2 Profile of the experimental pot used before vegetation

Fig. 3 Experimental unit for water purification utilizing aquatic plants

Sample plants The plants utilized in this study were *Phragmites australis* and *Zizania latifolia*, which are distributed in Japan and other Asian areas. *P. australis* and *Z. latifolia* have very different characteristics in their rootstalks: the root of *P. australis* has many thin roots whereas the root of *Z. latifolia* has many thicker roots⁹⁾. The plants for this study were collected from the lakeside at Lake Kasumigaura in Ibaraki Prefecture, 60km Northeast of Tokyo, Japan.

Wastewater used in this study The filled

sand was obtained in rivers flowing into Lake Kasumigaura in order to make analysis quantitatively. Artificial wastewater containing meat extract and dextrin etc. was used to understand the reaction mechanism adequately. Table 1 shows the composition of the artificial wastewater.

Experiment conditions Since actual household effluents are diluted in a natural water area, and discharged directly to the public water bodies in the developing countries, the purifying capability in different

concentrations of wastewater was evaluated in this experiment. The influent loads were adjusted into three conditions based on standard loads of household wastewater: water volume of $200\text{ l} \cdot \text{person}^{-1} \cdot \text{day}^{-1}$, BOD $40\text{ mg} \cdot \text{l}^{-1}$, COD $20\text{ mg} \cdot \text{l}^{-1}$, T-N $10\text{ mg} \cdot \text{l}^{-1}$, and T-P $1\text{ mg} \cdot \text{l}^{-1}$. The three conditions are BOD $200\text{ mg} \cdot \text{l}^{-1}$ (COD $100\text{ mg} \cdot \text{l}^{-1}$, T-N $50\text{ mg} \cdot \text{l}^{-1}$, and T-P $5\text{ mg} \cdot \text{l}^{-1}$), $100\text{ mg} \cdot \text{l}^{-1}$ (COD $50\text{ mg} \cdot \text{l}^{-1}$, T-N $25\text{ mg} \cdot \text{l}^{-1}$, and T-P $2.5\text{ mg} \cdot \text{l}^{-1}$), and $50\text{ mg} \cdot \text{l}^{-1}$ (COD $25\text{ mg} \cdot \text{l}^{-1}$, T-N $12.5\text{ mg} \cdot \text{l}^{-1}$, and T-P $1.25\text{ mg} \cdot \text{l}^{-1}$). The hydraulic residence time was adjusted to a period of seven days¹⁷. The experiment conditions are shown in Table 2.

Analysis items and methods The effluents after infiltration through the pots were utilized as samples for analysis of nitrogen, phosphorus, and organic substances. As organic substances, TOC and DOC were measured¹⁸. In order to measure DOC, the sample was filtrated with a glass filter (Whatman GC/F). When TOC and DOC were measured, one to two drops of concentrated hydrochloric acid was added into the sample, and the sample was analyzed with TOC-5000A (Shimadzu Corporation).

Table 1 Composition of artificial wastewater (BOD $200\text{ mg} \cdot \text{l}^{-1}$)

Dextrin	30.6 mg
Bacto peptone	65.4 mg
Yeast extract	65.4 mg
Meat extract	74.6 mg
Urea(NH_2) $_2$ ·CO	48.9mg
NaCl	6.6 mg
MgSO $_4$ ·7H $_2$ O	4.0 mg
KH $_2$ PO $_4$	18.6 mg
KCl	13.4 mg
Water	1,000 ml

Table 2 Outline of experimental conditions

Run No	Influent BOD ($\text{mg} \cdot \text{l}^{-1}$)	Influent T-N ($\text{mg} \cdot \text{l}^{-1}$)	Influent T-P ($\text{mg} \cdot \text{l}^{-1}$)	HRT (Days)
1	50	12.5	1.25	7
2	100	25	2.5	7
3	200	50	5	7

Note: Air temperature change from 0 to 37°C and water temperature change from 0 to 32°C in the experimental period.

BOD was analyzed in accordance with the Sewage Water Testing Methods: a diluted sample was put into an incubation bottle, oxygen consumption immediately before the experiment and on the fifth day of the experiment were analyzed by the electrode method for dissolved oxygen¹⁸. Nitrogen and phosphorus were analyzed with the TRRACS2000 (Shimadzu Corporation)¹⁸. The analysis items were total nitrogen (T-N), total phosphorus (T-P), ammonia nitrogen (NH_4 -N), nitrate nitrogen (NO_3 -N), nitrite nitrogen (NO_2 -N), and phosphate-phosphorus (PO_4 -P). The samples for T-N, T-P, NH_4 -N, NO_3 -N, NO_2 -N, and PO_4 -P were treated with the following process before the measurement: the sample, filtrated with a glass filter (Whatman GC/F), and a solution used as an agent for degradation in which 4 g of potassium peroxydisulfate and 0.9 g of sodium hydroxide were dissolved into 100 ml of water, were mixed at the ratio of 2 to 1; and the mixture was heated in an autoclave at 121 °C for 70 minutes in the case of T-N, T-P.

CH_4 and N_2O as greenhouse gases were analyzed by gas chromatography after collection through the cylindrical gas compartment on the pot to a Tedlar bag by pump⁹. In order to improve the accuracy of measurement, the greenhouse gas expected to exceed the suitable range for analysis was diluted by argon gas before the measurement. The samples were obtained over time, with a total of four samples taken at intervals of one hour. It took about 8 minutes to analyze methane and 7 minutes to analyze nitrous oxide. The generated amount of green house gas was analyzed and evaluated based on the peak obtained. The method of gas sampling is shown in Figure 4.

RESULTS AND DISCUSSION

Growth characteristics of the aquatic plants This experiment on the growth characteristics of *Phragmites australis* and *Zizania latifolia* started in the summer. Although the *P. australis* and *Z. latifolia* planted in the summer grew until late October, the growth of *P. australis*- BOD 200 $\text{mg} \cdot \text{l}^{-1}$ units was the slowest. It is suspected that the high level of pollution loads in the

Fig. 4 Schematic diagram of sampling method for greenhouse gases

units from the beginning of vegetation decayed the rootstalks and suppressed the growth significantly. Since all the *Z. latifolia* units showed high rates of growth, *Z. latifolia* was considered to be tolerant of high levels of pollution loads. The leaves and stems started dying rapidly from late October in all the units. This is because the temperature and radiation dropped at the onset of winter. However, the rootstalks of *P. australis* and *Z. latifolia* survived in the sand layer. Particularly, the rootstalks of *Z. latifolia* had even some shoots. Hence, it is suggested that the rhizosphere is important with regards to the characteristics of *P. australis* and *Z. latifolia*, and has purifying functions during the winter.

Organic substance removal capabilities The organic substance removal capabilities of the purifying systems utilizing sediment with vegetation are shown in Figures 5 and 6. With regard to these capabilities, the BOD removal rate was 90% or more in *Phragmites australis* units in all the pollution loads. BOD removal rate in the treated water was stable from summer through to even winter, when both leaves and stems died back. *Zizania latifolia* also showed a BOD removal rate of 90% or more

during the experiment. However, the absolute level of BOD concentration in treated water was around $5 \text{ mg} \cdot \text{l}^{-1}$ in *P. australis*-BOD 200 $\text{mg} \cdot \text{l}^{-1}$ units from summer to autumn, while it increased to about $15 \text{ mg} \cdot \text{l}^{-1}$ in winter. Similarly, in *Z. latifolia*-BOD 200 $\text{mg} \cdot \text{l}^{-1}$ units, the removal capabilities decreased to about $15 \text{ mg} \cdot \text{l}^{-1}$ in winter. Nevertheless, the removal capabilities were around $2 \text{ mg} \cdot \text{l}^{-1}$ in most of the other units. Thus, although the load at BOD 200 $\text{mg} \cdot \text{l}^{-1}$ was considered to be too high for *P. australis* with respect to BOD removal, sufficient purification can be expected in other conditions.

It is considered that not only absorption by plants, but also bacteria and microorganisms in water or on rootstalks, and soil microorganisms in rhizosphere contribute significantly to removal of organic substances. In soil treatment using aquatic plant systems, the biomass in water plays an important role. In order to increase the removal capabilities in the winter, reducing the pollution load is a realistic solution because it is difficult to control the temperature. Therefore, it is necessary to prolong hydraulic residence time to stabilize the treatment capabilities.

Since COD includes persistent substances,

a method with high COD removal capabilities is effective and efficient for water treatment; therefore COD removal capabilities were evaluated. In this experiment, COD removal capability in *Z. latifolia*- BOD 50 $\text{mg}\cdot\text{L}^{-1}$ units was 70% in summer and autumn, and 80% in winter even though the concentration of influents was higher. In *Z. latifolia*- BOD 100 $\text{mg}\cdot\text{L}^{-1}$ units, it was 75% in summer and autumn, and 80% or more in winter. In *Z. latifolia*- BOD 200 $\text{mg}\cdot\text{L}^{-1}$ units, it was 70% in summer and autumn, and 85% or more in winter. Accordingly, *Z. latifolia* had a high COD removal rate throughout the period of summer, autumn, and winter, even after the plants died. Since *P. australis* units showed similar values, removal of COD using plants

is very effective.

Ability to remove nutrients With regard to the purifying systems utilizing sediment with vegetation, the forms of nitrogen and their removal capabilities are shown in Figures 7 and 8. The forms of phosphorous substances and their removal capabilities are shown in Figures 9 and 10. Abilities of *P. australis* and *Z. latifolia* to remove nutrients were high in the summer, and decreased from late October because the plants died due to the decreasing temperature. That is, with respect to nitrogen removal, influents include only about 10% of ammonia, and effluent ammonia of *P. australis*-BOD 200 $\text{mg}\cdot\text{L}^{-1}$ exceed the level in influents in some

Fig. 5 Change in BOD of treated water with time

Fig. 6 Change in percentage of BOD removal with time

units. This indicates that deamination occurs while nitrification does not work in this condition. When the temperature is low, the units with high pollution loads showed low purifying capabilities, while there were not significant differences in the units with low pollution loads. These facts are shown in the correlation of influent loads and water temperature in Figures 11 and 12. Needless to say, the fact that plants die due to low temperature and purifying capabilities gradually decrease in units with high pollution loads means that the activities of plants and bacteria decrease. Consequently, residence time should be prolonged in cold periods, when some units are frozen. Although all the units showed stable

phosphorus removal capabilities in the beginning, the concentration of phosphorus in treated water increased in some units after certain period as shown in the figure. This means that the absorption of phosphorus by plants and adsorption to soil were saturated. *Z. latifolia* units maintained high removal capabilities of nitrogen and phosphorus compared to *P. australis*; a difference that may be due to the growth of roots. This implies that purifying capabilities vary depending on strains of aquatic plants.

The results of this experiment showed that in the growing period, sustainable levels of nitrogen and phosphorus were 0.5 and 0.08 $\text{mg} \cdot \text{l}^{-1}$ in *P. australis*- BOD 50 $\text{mg} \cdot \text{l}^{-1}$ units, 0.5 and 0.13 $\text{mg} \cdot \text{l}^{-1}$ in *P. australis*- BOD 100

Fig. 7 Change in T-N of treated water with time

Fig. 8 Change in percentage of T-N removal with time

$\text{mg} \cdot \text{l}^{-1}$ units, and 8.0 and $2.0 \text{ mg} \cdot \text{l}^{-1}$ in *P. australis*-BOD 200 $\text{mg} \cdot \text{l}^{-1}$ units, respectively. They were 0.2 and $0.08 \text{ mg} \cdot \text{l}^{-1}$ in *Z. latifolia*-BOD 50 $\text{mg} \cdot \text{l}^{-1}$ units, 0.5 and $0.09 \text{ mg} \cdot \text{l}^{-1}$ in *Z. latifolia*-BOD 100 $\text{mg} \cdot \text{l}^{-1}$ units, and 1 and $0.1 \text{ mg} \cdot \text{l}^{-1}$ in *Z. latifolia*-BOD 200 $\text{mg} \cdot \text{l}^{-1}$ units, respectively, in the low loading, particularly, aquatic plant. Soil purification system have high performance of nitrogen and phosphorus removal, therefore, reductions of algal growth potential can be expected¹⁹. Further evaluation is needed from the long term perspective. In addition, the removal capabilities significantly decreased in the winter.

The characteristics of greenhouse gas

Fig. 9 Change in T-P of treated water with time

emission Gas generation when *Phragmites australis* and *Zizania latifolia* fully grew was analyzed. All the units in which *P. australis* and *Z. latifolia* were planted showed little N_2O generation. Dass reported the similar results¹³. On the other hand, CH_4 generation varied depending on the loading conditions, and the amount of the gas emitted significantly increased under high pollution loads. Generation rates of CH_4 per unit area were calculated based on the change of CH_4 concentration during the summer time (average in August, September) in the gas compartment. They were 62.8, 82.3, and $224.0 \text{ mg} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$ in *Z. latifolia*-BOD 50, 100, and 200 $\text{mg} \cdot \text{l}^{-1}$ units, respectively; and 11.2, 16.5, and $126.8 \text{ mg} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$ in *P. australis*-

Fig. 10 Change in percentage of T-P removal with time

BOD 50, 100, and 200 $\text{mg}\cdot\text{l}^{-1}$ units; respectively. As shown in Figures 13 and 14, the generation rate of CH_4 is much higher in *Z. latifolia* units than in *P. australis* units. It is suspected that the differences between the plants were caused by the structures of the roots zone areas. Compared to *Z. latifolia*, *P. australis* has thinner roots that grow compactly. It is suggested that when free oxygen absorbed from leaves is provided to the roots, the whole rhizosphere turns aerobic and the activity of methanogens decreases while the activity of methanotrophs increases. These phenomena were observed in the Landfill site and rice field^{11, 14}. Therefore, transport of oxygen to soil from atmosphere means important factor for making high activity of methanotrophs. And

then, in the aquatic plant soil purification systems, another possibility is that compared to *P. australis* units, *Z. latifolia* units had lower biomass of methanotrophs, which convert CH_4 to CO_2 . As it was observed many thin roots exist in *P. australis* unit and many thick roots exist in *Z. latifolia*, these root zone structure may affect the different oxygen transport potential and biomass CH_4 oxidizing bacteria²⁰. Furthermore, under the conditions of SF (Submerged water flow) and FWS (Free water surface flow) systems, which shows different water level, SF system has less CH_4 emission potential and water purification than FWS system²¹. However, further analysis is needed to clarify this possibility.

Fig. 11 Correlation between percentage of T-N removal and water temperature

Fig. 12 Correlation between percentage of T-P removal and water temperature

Fig. 13 Change in amount of CH_4 generated with time

Fig. 14 Correlation between rate of CH_4 generation and influent BOD

CONCLUSIONS

Characteristic analysis of the organic substance and nutrient removal and the green house gas emission in the soil treatment systems with aquatic plants was evaluated in this study. The main results obtained can be summarized as follows:

- 1) Although both *P. australis* and *Z. latifolia* showed BOD removal rates of 90% or more under the conditions of HRT 7 days and influent BOD 50~200 $\text{mg}\cdot\text{L}^{-1}$, the load of BOD 200 $\text{mg}\cdot\text{L}^{-1}$ was too high for *P. australis* in the beginning of vegetation.
- 2) Both *P. australis* and *Z. latifolia* showed relatively stable nitrogen removal capability from summer to autumn, but its performance slightly decreased about 30% in winter due to the low temperature such as 7°C.
- 3) The generation rate of CH_4 during the summer time in *Z. latifolia* units was higher in all the loading levels of BOD 50, 100, and 200 $\text{mg}\cdot\text{L}^{-1}$ (62.8, 82.3 and 224.0 $\text{mgCH}_4\cdot\text{m}^{-2}\cdot\text{h}^{-1}$ respectively), than in those in *P. australis* units (11.2, 16.5 and 126.8 $\text{mgCH}_4\cdot\text{m}^{-2}\cdot\text{h}^{-1}$). The reason on the

observation of higher CH_4 emission in *Z. latifolia* is suggested that biomass of methanotrophs is large under *P. australis* due to oxygen transport potential is higher in the *P. australis* than in the *Z. latifolia*.

- 4) Soil treatment systems using aquatic plants keep high purifying and CH_4 emission control capabilities in low pollution loads such as BOD 50 $\text{mg}\cdot\text{L}^{-1}$ when water temperature is low.

Thus, aquatic plants have capabilities to suppress the generation of nutrients, organic substances, and greenhouse gases. Hence, further research on low cost and highly effective ecoengineering systems utilizing plants is expected. In order to apply ecoengineering methods based on this research result, it is required to solve the following problems.

The water purifying method with plants utilizing ecoengineering can be applied in various pollution loading conditions or characteristics of water areas by combining several systems regardless low facility building and maintenance costs. Not only nitrogen and phosphorus, but also dissolved organic substances and suspended solids can be removed. Further development of the technology to find optimum conditions to improve treatment capabilities is expected. In developing countries, water pollution worsens because of untreated drainage of household and industrial effluents, and assuring safe water sources is very difficult. Particularly, in Asian countries, immediate measures are crucial from the public health perspective. Since ecoengineering systems are inexpensive and effective, rapid development of the technologies and its proper distribution are required in developing countries.

This research leads to the result that the treatment capability of aquatic plants itself has great potential. As the next step, the purifying capabilities and optimum conditions of the attachment of microorganisms and bacteria to rootstalks should be researched.

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